"In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institution shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or, in his absence, by the dean of the Graduate Division when such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.

________________________________"

THE EFFICIENCY OF MASS TRANSIT OPERATIONS IN THE TRANSPORTATION OF PEOPLE AND IN THE UTILIZATION OF CITY STREETS

A THESIS

Presented to

the Faculty of the Graduate Division

by

Emory Conrad Parrish

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Civil Engineering

Georgia Institute of Technology

June, 1960

6L
12R

THE EFFICIENCY OF MASS TRANSIT OPERATIONS IN THE

TRANSPORTATION OF PEOPLE AND IN

THE UTILIZATION OF CITY STREETS

Approved: [illegible]

[illegible]

[illegible]

Date Approved by Chairman: May 26, 1960

ACKNOWLEDGMENTS

The author would like to express his appreciation to the Georgia Highway Department, the U. S. Bureau of Public Roads, the Atlanta Transit System and the Traffic Engineering Department of the City of Atlanta for assistance in the operation of the field studies for obtaining the data included in this thesis.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS ii

LIST OF TABLES iv

LIST OF ILLUSTRATIONS vi

SUMMARY vii

Chapter

I. INTRODUCTION 1

II. PROCEDURE 12

General
Motor Bus and Electric Trackless Trolley Bus Operation
Space occupied by transit vehicle in traffic stream
Transit vehicle operating speed and average passenger load
Automobile Operation Study
Space occupied by the automobile in the traffic stream
Average automobile passenger load
Average automobile operating speed
Relative Efficiencies

III. DISCUSSION OF RESULTS 39

General
Space occupied by a transit vehicle in the traffic stream
Average operating speed of transit vehicles and the automobile
Average passenger load
Relative efficiencies

IV. SUMMARY OF RESULTS AND CONCLUSIONS 54

V. RECOMMENDATIONS 56

APPENDIX 57

BIBLIOGRAPHY 65

LIST OF TABLES

Table Page

1. Summary of Intersection Data and Space Occupied by a Transit Vehicle in the Traffic Stream. 19

2. Space in the Traffic Stream Occupied by a Transit Vehicle Weighted According to Study Time 24

3. Average Number of Passengers Carried by Electric Trackless Trolley Buses Classified as to Type of Service, Time of Day and Proximity to the Downtown Business District. 29

4. Average Number of Passengers Carried by Diesel Motor Buses Classified as to Type of Service, Time of Day and Proximity to the Dwontown Business District. 30

5. Average Travel Time for Electric Trackless Trolley Buses Classified According to Type of Service, Time of Day and Proximity to the Downtown Business District. 32

6. Average Travel Time for Diesel Motor Buses Classified According to Type of Service, Time of Day and Proximity to Downtown Business District. 33

7. Cordon Count Data for Computing Average Automobile Occupancy. 35

8. Average Travel Time for Automobiles Classified According to the Time of Day, Direction of Travel and Proximity to the Downtown Business District 37

9. Summary of Data Used in Computation of Relative Efficiencies 38

10. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to Time of Day. 41

11. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to Approach Street Width at Study Location 42

12. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to Parking Conditions 44

LIST OF TABLES
CONTINUED

Table | Page

13. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to the Gradient of the Approach Street 45

14. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to the Turning Movements. 46

15. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to the Per Cent of Trucks 48

16. Average Operating Speed of Diesel Motor Buses, Electric Trackless Trolley Buses and Automobiles in Minutes per Mile 49

17. Average Passenger Load Carried by the Automobile, Diesel Motor Bus and Electric Trackless Trolley Bus 51

18. Relative Efficiencies of Automobiles, Diesel Motor Buses and Electric Trackless Trolley Buses in the Utilization of Street Space and Movement of People During Peak Hours of Traffic Movement on Surface Streets. 52

LIST OF ILLUSTRATIONS

Figure Page

1. Atlanta Metropolitan Area Population Trends. 3
2. Total Vehicle Registration in Atlanta Metropolitan Area. . . 4
3. Average Automobile Passenger Load in Atlanta Cordon Area . . 5
4. Total Revenue Passengers Transported by Atlanta Transit System 7
5. Study Area Classification. 14
6. Downtown Area. 15
7. Intersection Study Locations 16
8. Intersection Study Locations in the Downtown Area. 17
9. Field Form for Intersection Conditions Study 58
10. Transit Vehicle Interference Study 61
11. Field Sheet for Bus Operation Study. 63
12. IBM Layout Card for Bus Operation Study. 64

SUMMARY

The purpose of this study is to determine the efficiency of mass transit operations relative to the automobile in the transportation of people and in the utilization of city streets. Previous claims as to the efficiency of transit operations have been based only on the number of passengers transported and the physical dimensions of the vehicles. These facts are inconclusive for the comparison of the efficiency of transit vehicles with that of the automobile. To make a satisfactory comparison of various modes of transportation, it is necessary to consider the space in the traffic stream occupied by each person or passenger and the length of time this space is occupied. Considering these factors, a formula for the computation of a measure of the efficient use of city streets and the movement of people could be expressed as:

$$M = \frac{P}{Sv} \qquad (1)$$

where: M = measure of the efficient use of city streets and the movement of people

P = number of passengers transported

v = speed of operation

S = relative space occupied by a vehicle in the traffic stream.

Considering the factors included in Formula 1, a formula for the computation of the relative efficiency of various modes of transportation in the utilization of streets and the transportation of people could be expressed as:

$$E_r = \frac{M_1}{M_2} = \frac{\frac{P_1}{S_1 v_1}}{\frac{P_2}{S_2 v_2}} \qquad (2)$$

where: E_r = efficiency of one mode of transportation relative to the efficiency of another mode of transportation in utilizing city streets and transporting people

M_1, P_1, S_1, v_1 = quantities defined in Formula 1 for a type of transit vehicle

M_2, P_2, S_2, v_2 = quantities defined in Formula 1 for the automobile.

In order to obtain the values of P, v and S for each mode of transportation studied, i.e., the automobile, the diesel motor bus and the electric trackless trolley bus, the study was divided into an automobile operation study and a transit vehicle study.

The value of P or the number of passengers transported by the automobile in Atlanta was obtained from cordon count data maintained by the Traffic Engineering Department of the City of Atlanta. The value of v or the average operating speed of the automobile was determined by driving a test car in the traffic stream according to standard traffic engineering practices. The value of S or the space occupied by the traffic stream for the automobile was assumed as 1.0.

The transit vehicle study consisted of a detailed analysis of the operating characteristics of transit vehicles on seven operating lines of the Atlanta Transit System. Six of the lines studied were electric trackless trolley bus routes and one was a diesel motor bus route. The values of P and v in the above formula for the two types of transit vehicles were determined by posting observers on a combined total of 395 transit vehicles and recording the number of passengers transported by each vehicle and the time required for the vehicle to travel a given distance. The value of S or the space in the traffic stream occupied by a transit vehicle was determined by adjusting the traffic signal timing at eleven selected intersections so that the intersection would be operating above its possible capacity and then, by comparing volumes of automobiles traversing the intersection with and without transit vehicle interference, the number of automobiles in a moving stream of traffic displaced by a transit vehicle was determined.

The efficiency of the diesel motor bus and electric trackless trolley bus was computed relative to the automobile by substituting in Formula 2 the values of P, v and S as determined for each type of vehicle studied.

Conclusions drawn from this study indicate:

1. The space in a moving stream of traffic occupied by a transit vehicle considering only the effect on street capacity was 3.5 automobiles per bus on arterial streets and 3.8 automobiles per bus on secondary streets with no distinction being made between a diesel motor bus and an electric trackless trolley bus.

2. Transit loading and unloading of passengers on streets with no parking restrictions had less effect on moving streams of traffic than on streets with parking restrictions because of passenger loading zones in parking lanes.
3. In the congested downtown area in Atlanta, the electric trackless trolley bus and diesel motor bus are 5.9 and 5.2 times, respectively, as efficient as the automobile in transporting people and utilizing city streets.
4. In the primarily residential areas in Atlanta, the electric trackless trolley bus and diesel motor bus are 6.5 and 3.7 times, respectively, as efficient as the automobile in transporting people and utilizing city streets.
5. In the areas between the downtown area and the primarily residential areas in Atlanta, the electric trackless trolley bus and diesel motor bus are 8.5 and 5.8 times, respectively, as efficient as the automobile in transporting people and utilizing city streets.

CHAPTER I

INTRODUCTION

The mass transportation of people in urban areas is an important component of the overall transportation scheme for that area. This can readily be emphasized by observing the paralysis of cities due to strikes by transit workers and was true during the transit worker strikes in the Atlanta area in 1946, 1949 and 1950. Even though mass transit systems are important to the transportation schemes in cities, they have experienced a marked decrease in patronage while more and more persons are transported in privately owned automobiles[1]. This increased usage of private automobiles results in overcrowding of city streets and an increased demand for off-street parking. This is not a problem peculiar to the City of Atlanta but is found in cities throughout the United States. The increased usage of automobiles spells trouble for traffic engineers and economic ruin for the transit companies unless the trend can be arrested. Subsidization of the transit companies has been proposed as a means of maintaining mass transit service[2]. Free parking facilities have been established on the fringe of the transit service areas in several cities in an attempt to encourage the use of the transit system. The Atlanta Transit System has established "park and ride" service on several lines and is hopeful that this will be a solution to serving suburban areas and preventing further congestion of the downtown area.

The problems faced by the Atlanta Transit System are examples of these confronting other transit companies throughout the nation. The Atlanta Transit System provides mass transit service to the two county metropolitan area of Fulton and DeKalb Counties. To illustrate this problem, a study of the two county area is necessary and will be discussed in the following paragraphs.

As the first portion of this study, the population trends of the two county area were studied. Figure 1 is a graph of these population trends. The solid line is based on historical data and the dashed line is based on estimates of the Atlanta Metropolitan Planning Commission. The population of the two county area in 1930 was approximately 401,000 and in 1955 the estimated population was 703,000 or approximately double the 1930 figure.

Figure 2 is a graphic representation of the total motor vehicle registration for Fulton and DeKalb Counties. The vehicle registration in 1955 was approximately two and three quarters times the registration in both 1938 and 1944.

Figure 3 is a graph of the average occupancy per automobile in the city of Atlanta based on cordon counts at the fringes of the downtown area. As is indicated in the graph, the vehicle occupancy increased during the early years of World War II to a peak in 1943 and has decreased since that time to a fairly uniform value. The occupancy has been practically uniform since 1948.

Figures 1, 2 and 3 show that there has been an increase in the number of automobiles in the Atlanta area and that the vehicle occupancy is practically the same as in previous years.

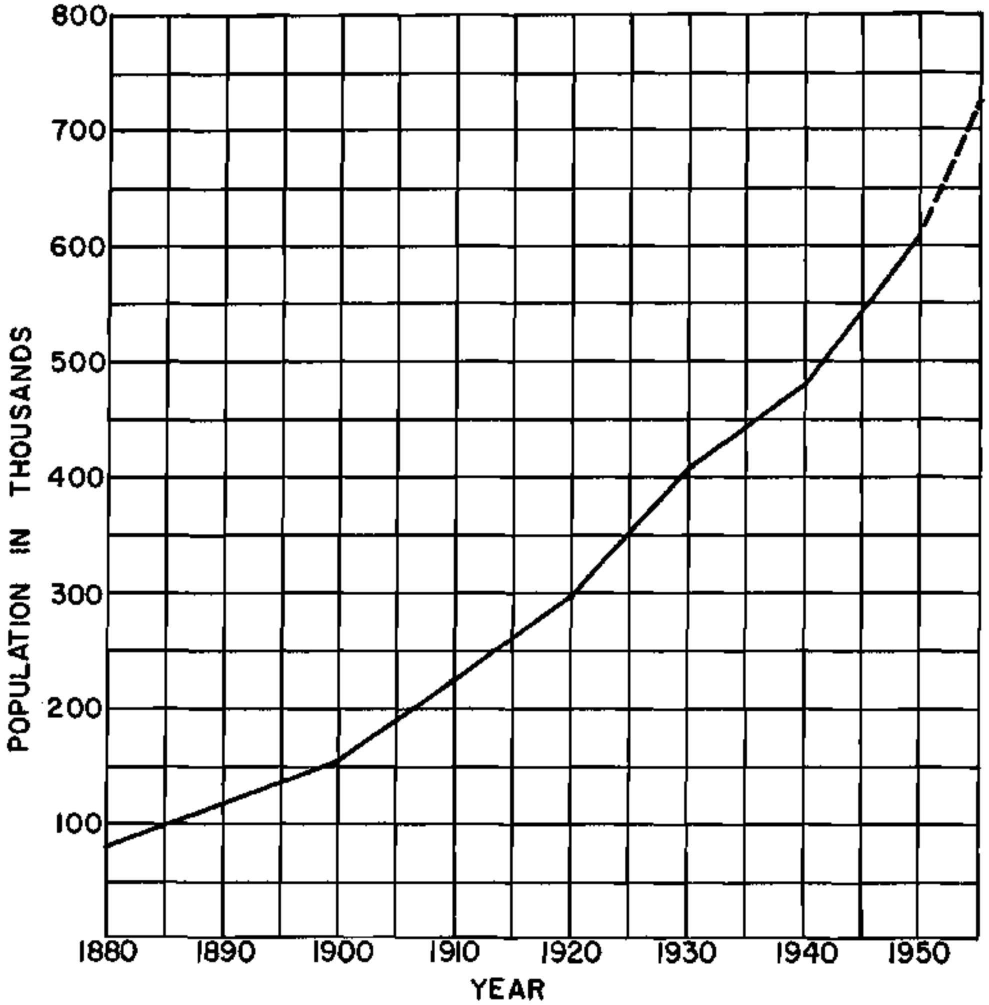

FIGURE 1.

ATLANTA METROPOLITAN AREA POPULATION TRENDS (TWO COUNTY AREA)

SOURCE: U.S. BUREAU OF CENSUS AND ATLANTA METROPOLITAN PLANNING COMMISSION

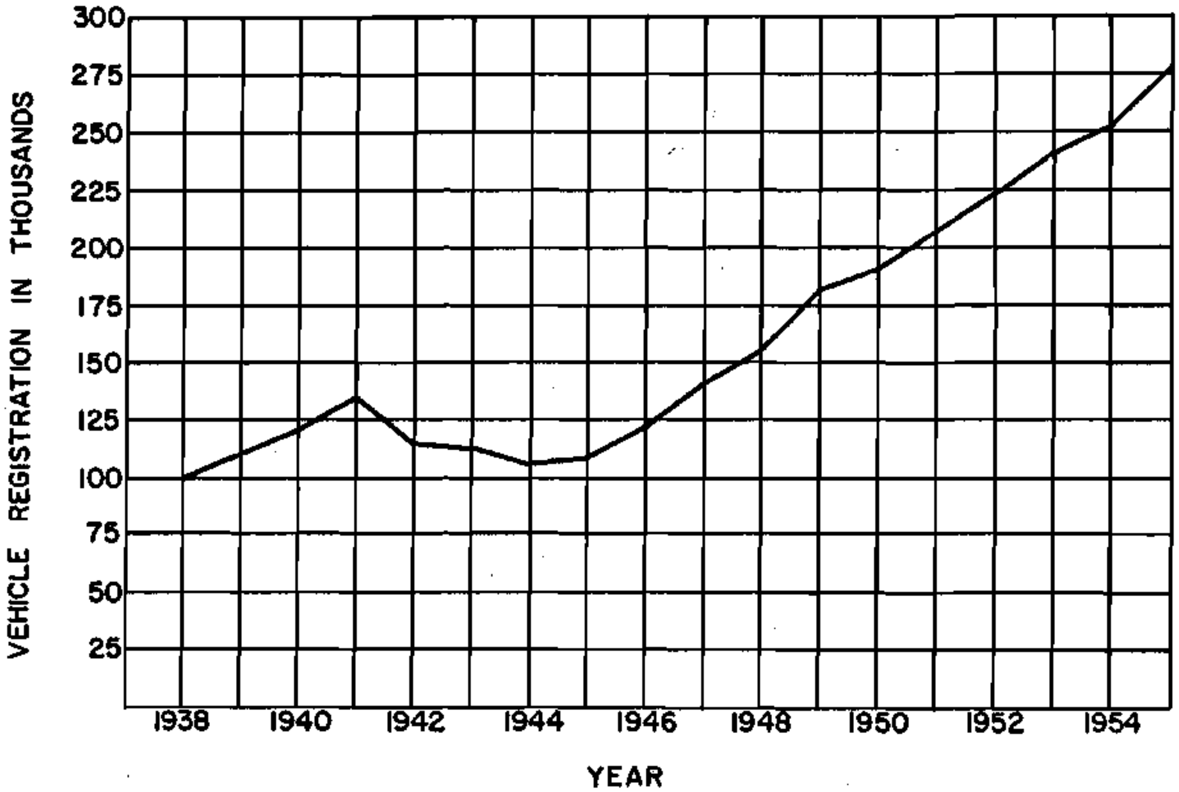

FIGURE 2.

TOTAL VEHICLE REGISTRATION IN ATLANTA METROPOLITAN AREA (TWO COUNTY AREA)

SOURCE: ATLANTA METROPOLITAN PLANNING COMMISSION AND GEORGIA STATE LICENSE TAG BUREAU.

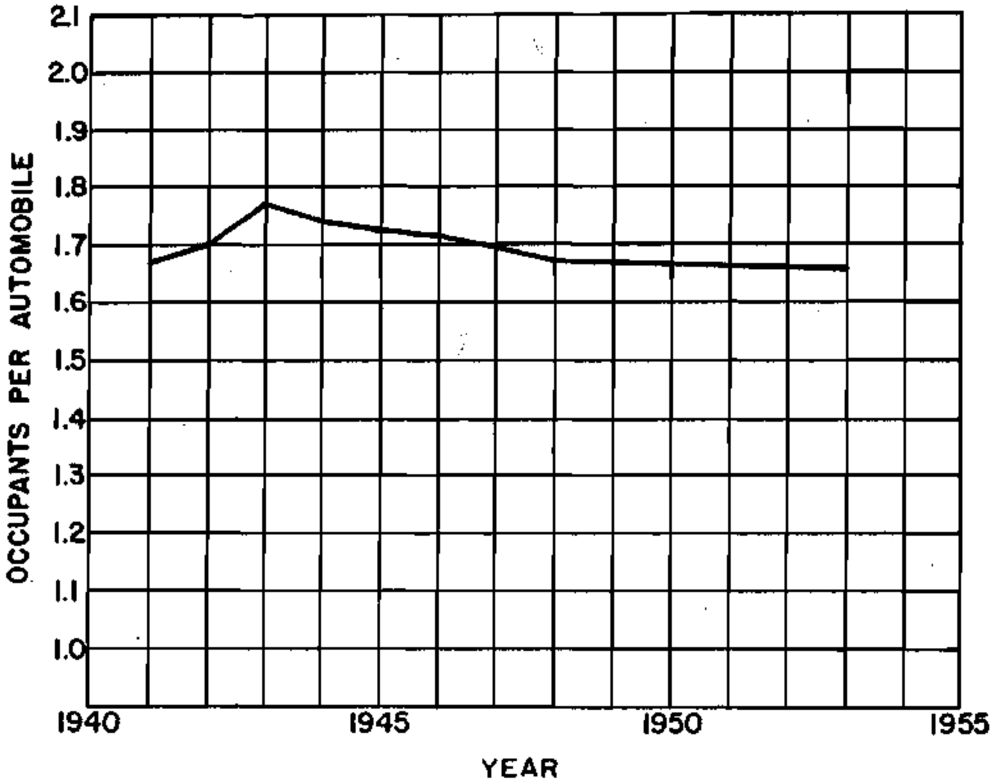

FIGURE 3.

AVERAGE AUTOMOBILE PASSENGER LOAD IN ATLANTA CORDON AREA

SOURCE: ATLANTA TRAFFIC ENGINEERING DEPARTMENT

How then have these increases in population and vehicles affected the Atlanta Transit System? Figure 4 is a graph of the total revenue passengers transported each year by the Atlanta Transit System and the Metropolitan Transit System, a branch of the Atlanta Transit System from 1936 through 1955. As can be seen, the number of passengers increased from 1936 to a peak in 1946 and has steadily decreased since that date. The total number of passengers transported by the two companies in 1955 was only slightly more than was transported in 1941.

Using 1941 and 1955 as years for comparison, the two-county Atlanta Metropolitan Area in 1955 had about one and a half times as many people and twice as many registered vehicles as in 1941, while in 1955 the transit system was transporting the same number of people as in 1941.

A study of data contained in the preceding paragraphs reveals that transit companies are facing a problem. What is the cause of this problem and what are the solutions for it? There are many factors involved in this problem. A thorough investigation of the economics of mass transit versus private automobile usage of city streets would include convenience and comfort factors, all phases of user costs, and efficiency of operation. As one phase of the investigation, this study has for its purpose a comparison of the relative efficiency of mass transit vehicles and private automobiles in the transportation of people and the utilization of city streets.

It may be said that the controversy as to the efficiency of mass transit operations in the movement of people began with the advent of the horse-drawn trolley. From that day forward it was the general belief

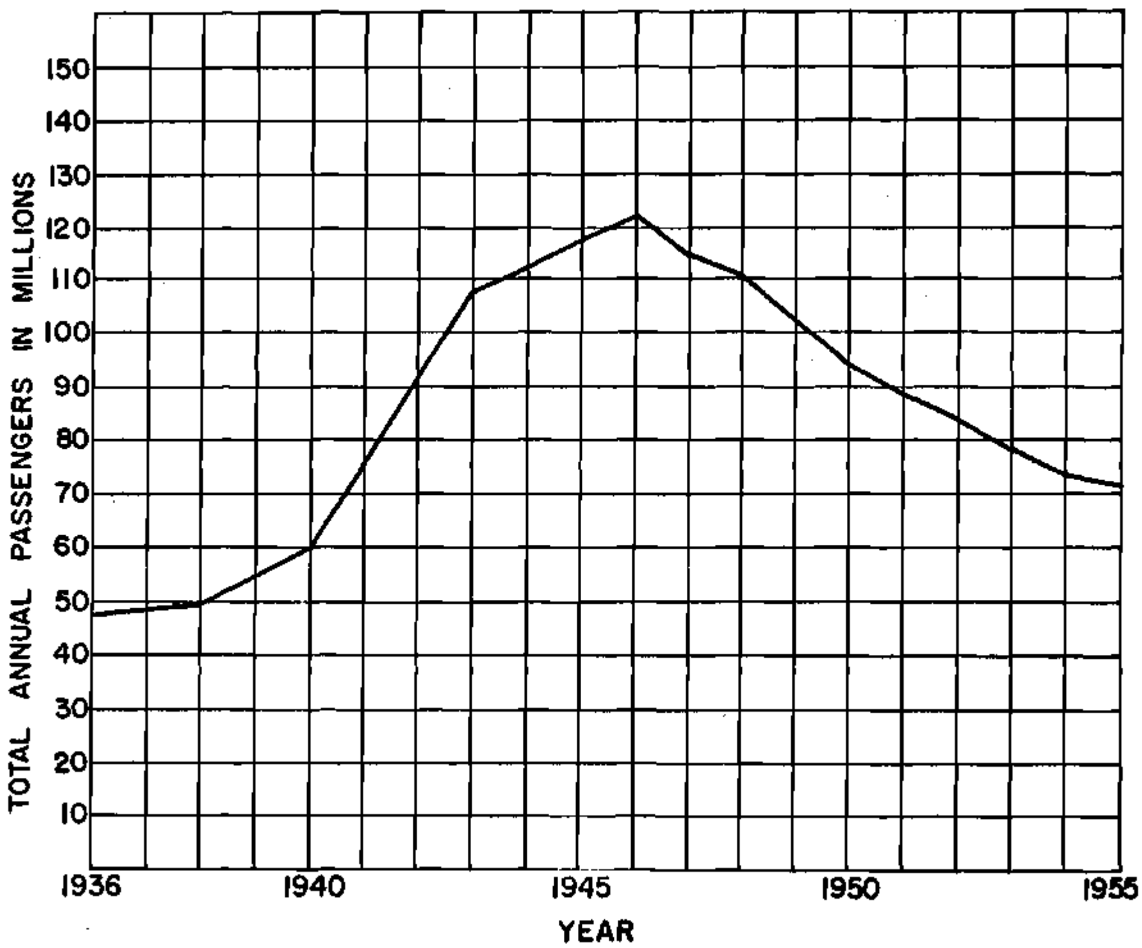

FIGURE 4.

TOTAL REVENUE PASSENGERS TRANSPORTED BY ATLANTA TRANSIT SYSTEM

SOURCE: ATLANTA TRANSIT SYSTEM, METROPOLITAN TRANSIT SYSTEM that transit vehicles performed the job of moving people and utilizing city streets much more efficiently than the horse-dwawn carriage or the "horseless carriage." This belief has been accepted to the extent that few have ever chosen to contest the claims that have been made as to the greater efficiency of mass transit operations over other methods of transportation for movement of people. Up to the time of this study, facts to substantiate these claims have included only vehicle capacity and standing dimensions of the vehicles[3]. As an example of the type of comparison that has been made, the electric trackless trolley buses in the downtown area of Atlanta, during the morning peak hour, transport an average passenger load of 52.9 persons. The average overall dimensions of this vehicle are 8.5 feet by 35.0 feet and it occupies a standing street space of 297.5 square feet. The average street space occupied by a person in an electric trackless trolley bus would then be 5.6 square feet. The automobile in Atlanta transports an average of 1.7 persons per automobile. The average overall dimensions of the automobile are 6.4 feet by 17.2 feet and it occupies a standing street space of 110.1 square feet. The average street space occupied by a person in an automobile would then be 64.8 square feet per person. Considering only the standing dimensions of the vehicle and the passenger load transported, the electric trackless trolley bus is 11.8 times more efficient than the automobile in transporting people and utilizing city street. These facts are inconclusive for the comparison of transit vehicles with the automobile as no consideration has been given to the medium in which the vehicles operate -- "a moving stream of traffic." To make a satisfactory comparison of various types of vehicles, it is necessary to consider the space in a moving traffic stream occupied by each person in the type vehicle studied and the length of time the space is occupied in traveling a given distance. The space occupied per person in the traffic stream is a measure of the efficient use of street space and can be defined as the space occupied by the vehicle in a moving stream of traffic divided by the number of persons in the vehicle. The space occupied by the vehicle in a moving stream of traffic, as determined in this study, is not an area in square feet or square yards, but it is the relative space in the traffic stream occupied by a vehicle of one type based on the number of vehicles of another type that are displaced from the traffic stream by the operation of the first type vehicle. In this study, the space in the traffic stream occupied by a transit vehicle is determined relative to the number of automobiles displaced from the traffic stream by the operation of the transit vehicle and has, as dimensions, the number of automobiles displaced per bus. For example, the space in the traffic stream occupied by a bus relative to the automobile is 3.5 automobiles per bus. The length of time the space is occupied in traveling a given distance or the speed of operation is a measure of the efficient movement of people and can be defined as the distance traveled divided by the speed of the vehicle. Considering the space occupied per person in a moving stream of traffic and the length of time the space is occupied in traveling a given distance, a formula for the computation of a measure of the efficient use of streets by a vehicle and the movement of people in a traffic stream could be defined as:

$$M = \frac{P}{Sv} \tag{1}$$

where: M = measure of the efficient use of city streets by a vehicle and the movement of people in a traffic stream

P = number of passengers transported

v = speed of the operation in miles per minute

S = relative space occupied by a vehicle in the traffic stream.

By substituting the dimensions of P, v and S, Formula (1) becomes

$$M = \frac{\text{Passengers}}{\text{Relative Vehicle Space}} \times \frac{1}{\text{Velocity}} .$$

The quantity, passengers divided by the relative vehicle space, is the number of passengers transported per unit of relative vehicle space. Since Formula (1) is used in comparing two modes of transportation, the distance factor was eliminated from the formula as it is equal for both modes of transportation. If the distance factor is included in Formula (1), the quantity of one divided by the velocity becomes distance divided by velocity and is equal to time. From a study of the dimensions, Formula (1) can be defined as the passengers transported per unit of relative vehicle space multiplied by the time.

Considering Formula (1), a formula for the computation of the relative efficiency of various modes of transportation in the utilization of streets and the transportation of people could be expressed as:

$$E_r = \frac{M_1}{M_2} = \frac{\frac{P_1}{S_1 v_1}}{\frac{P_2}{S_2 v_2}} = \frac{P_1 S_2 v_2}{P_2 S_1 v_1} \qquad (2)$$

where: E_r = efficiency of one mode of transportation relative to the efficiency of another mode of transportation in utilizing city streets and transporting people. In this case, the efficiency of a type of transit vehicle relative to the automobile.

M_1, P_1, S_1, v_1 = quantities as defined in Formula (1) for a type of transit vehicle

M_2, P_2, S_2, v_2 = quantities as defined in Formula (1) for the automobile.

The values of P, v and S were obtained as accurately as practicable for the types of vehicles studied, i.e., automobile, to include the motor truck, and diesel motor bus and electric trackless trolley bus.

CHAPTER II

PROCEDURE

The field work for this thesis was divided into two studies. The first study was the "Motor Bus and Electric Trackless Trolley Bus Operation Study" and consisted of a study of loading practices and travel speeds for motor buses and electric trackless trolley buses in normal operation during various periods of the day, and of the effect these vehicles have on street capacity. The second study was the "Automobile Operation Study" and consisted of the determination of the average passenger load and the average travel time for the automobile.

Motor Bus and Electric Trackless Trolley Bus Operation

This study was divided into two sections. The first section consisted of the determination of the space occupied by the transit vehicle in the traffic stream and the second section consisted of the determination of the average operating speed and the average passenger load of the transit vehicle.

<u>Space occupied by transit vehicle in traffic stream.</u>--The effect that buses have on street capacity or the space in a traffic stream occupied by a transit vehicle varies with the street width, traffic density, the number of passengers loading and unloading, whether or not bus traffic is straight through the intersection, street gradient, whether or not

on-street parking is permitted, location of bus stops, rate of acceleration and a number of lesser important factors[4].

Planning for the field collection of data consisted of preparation of field forms, classification of study areas and the selection of intersections to be studied. For this portion of the study the Metropolitan Area of Atlanta was classified into three areas, i.e., downtown, intermediate and outlying areas. The downtown area was comprised of the central business district of Atlanta. The intermediate area was the area between the central business district and the primarily residential districts. The outlying area was composed of the suburban areas. The area included in each classification is shown on Figures 5 and 6. Mass transit service was available in each of the three areas.

The selection of street intersections for study was based on the criteria of the geographic location of the intersection, the width of the approach streets to the intersection and that comparatively large volumes of automobiles and transit vehicles must traverse the selected intersection. A total of thirteen intersections on nine arterial streets and two secondary streets were selected for study. It was possible to select these critical intersections so that a sample could be obtained in each of the study areas. Locations of studied intersections are shown on Figures 7 and 8.

The field work for this portion of the study was performed in February and March, 1955, during the morning and afternoon peak hours of traffic flow for week-day traffic. The field data were obtained by personnel of the City of Atlanta Traffic Engineering Department. Traf-

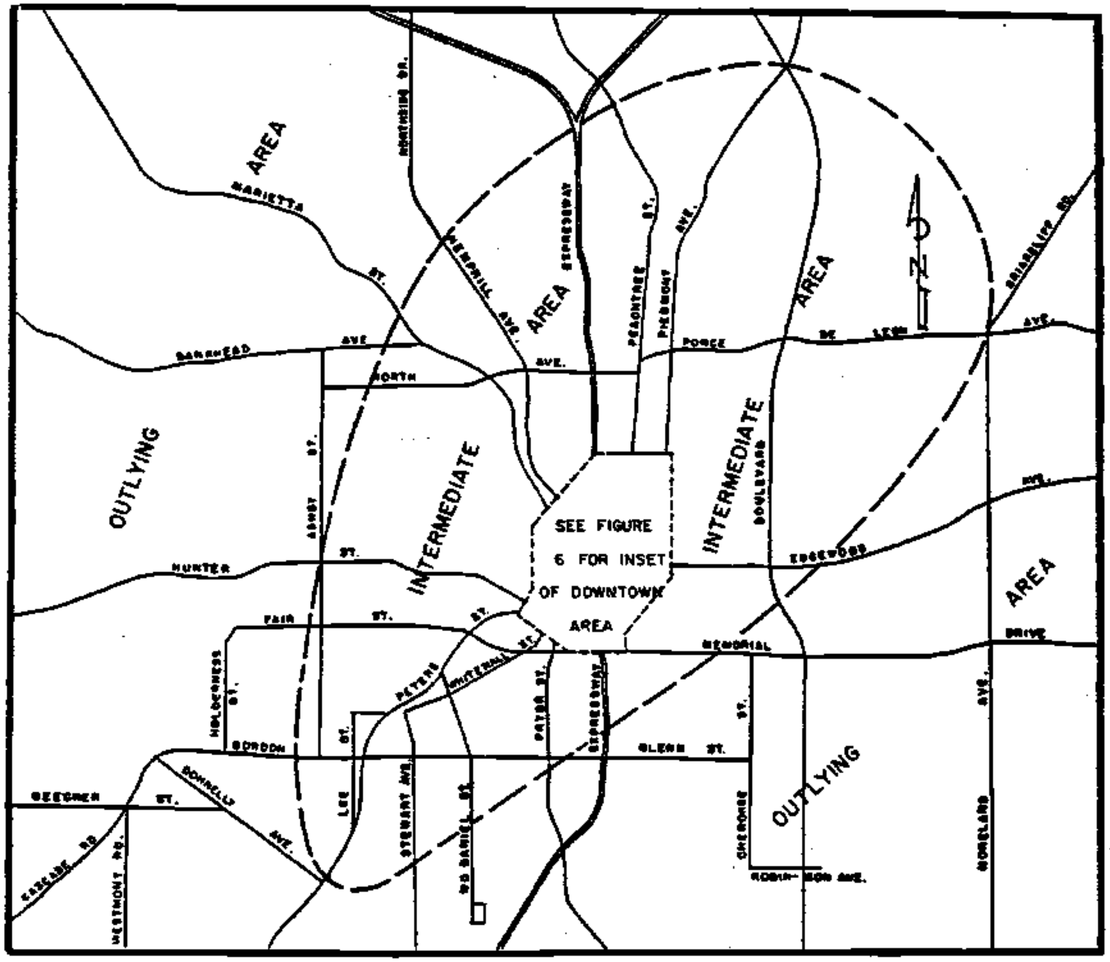

FIGURE 5.
STUDY AREA CLASSIFICATION
BUS AND TROLLEY OPERATION STUDY

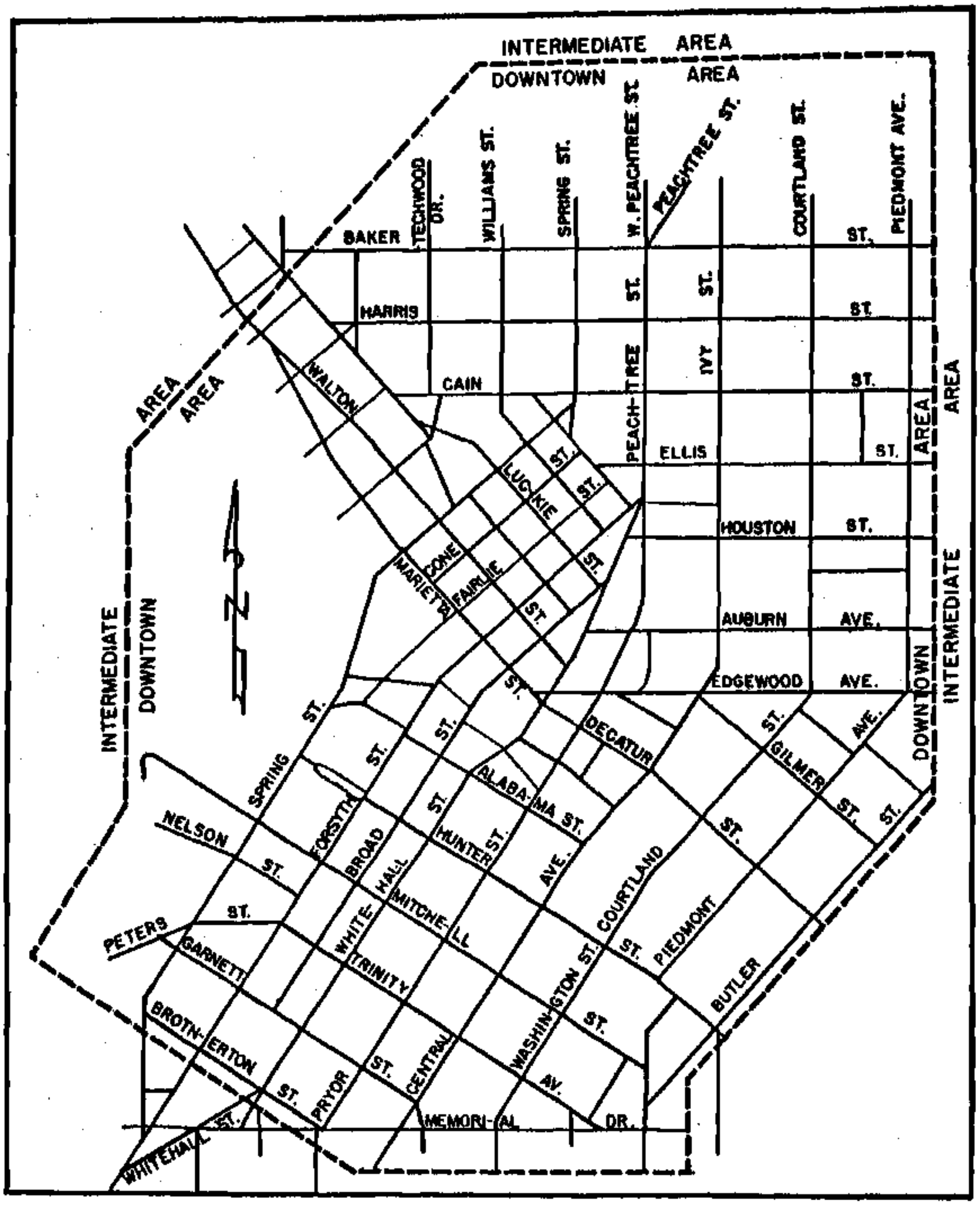

FIGURE 6.
DOWNTOWN AREA
STUDY AREA CLASSIFICATION
BUS AND TROLLEY OPERATION STUDY

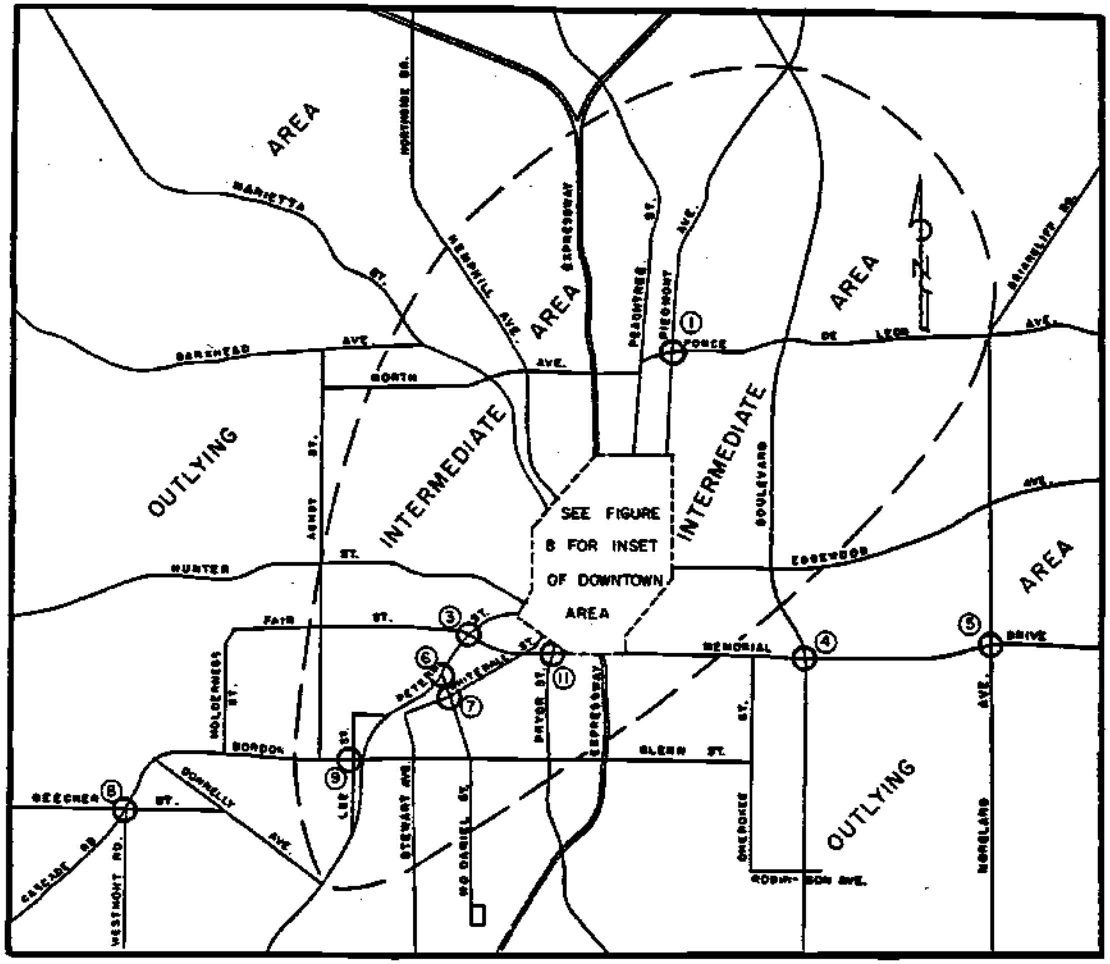

FIGURE 7.
INTERSECTION STUDY LOCATIONS
BUS AND TROLLEY OPERATIONS STUDY

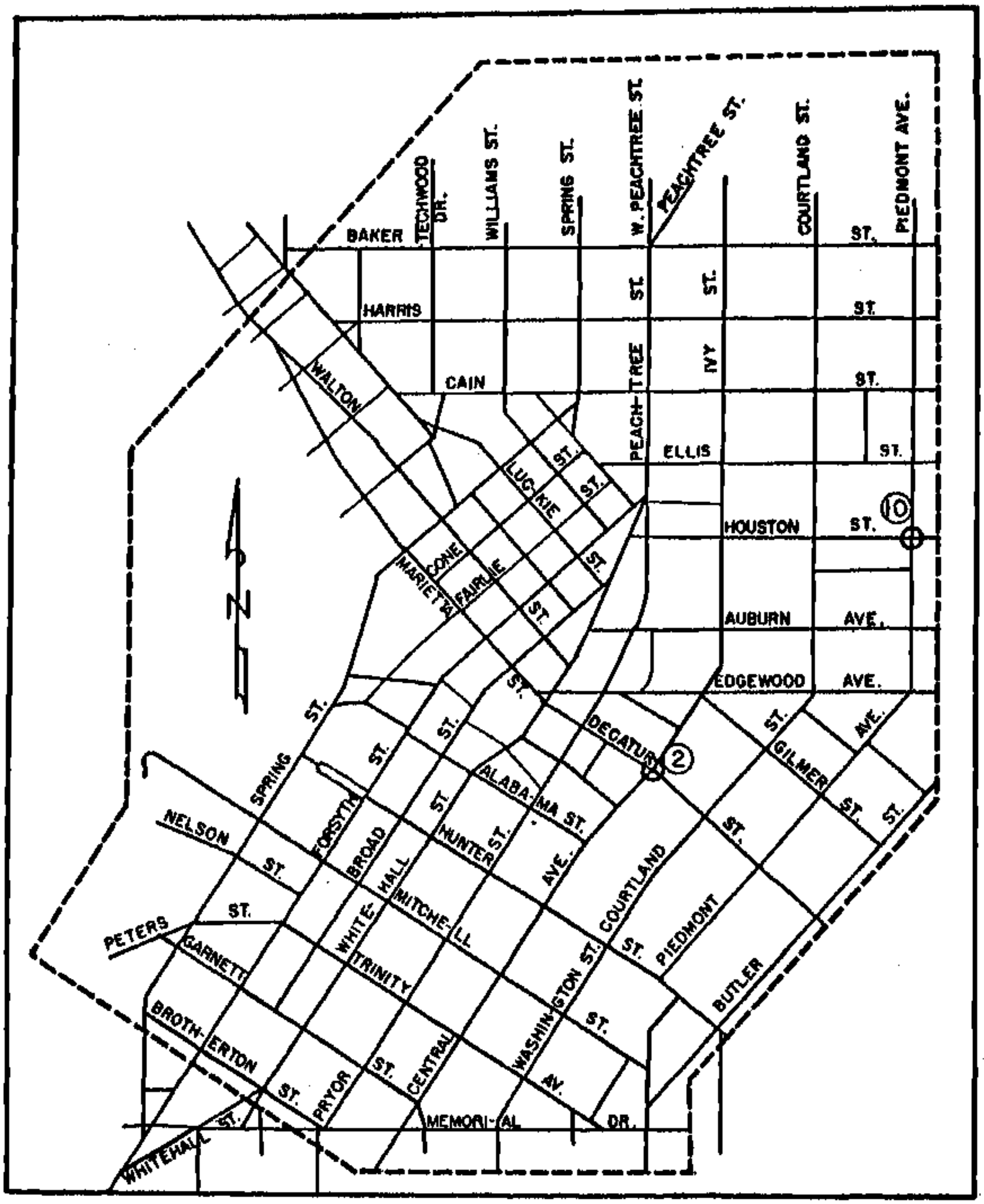

FIGURE 8.
INTERSECTION STUDY LOCATIONS
IN THE DOWNTOWN AREA
BUS AND TROLLEY OPERATION STUDY

fic recorders and observers were stationed at the selected intersections to inventory physical intersection characteristics and to record data pertaining to traffic flow through the intersection.

The inventory of physical intersection characteristics was conducted so as to reflect the intersection conditions that existed at the time of each of the traffic flow studies conducted at the intersection. The inventory included such items as classification and width of streets, existence of turning lanes, signal timing, type of traffic, vehicle and pedestrian control, location of bus stops, etc. These data were recorded on an intersection conditions form. A copy of the completed form for the Boulevard and Memorial Drive intersection for one such study is included in the Appendix as Figure 9. The number of such intersection conditions studies conducted and the quantity of data obtained precludes the inclusion of all field data in this thesis. All data obtained at each intersection were summarized in Table 1. The intersection site numbers shown on Table 1 correspond to the intersection numbers shown on Figures 7 and 8. The field data for all intersection studies are on file at the Division of Highway Planning, State Highway Department of Georgia, Atlanta, Georgia.

In the intersection traffic flow or bus interference study, traffic recorders were stationed on the approach legs of the intersection to count and record volumes and types of vehicular traffic using the intersection when the traffic demand was equal to or greater than the possible capacity of the approach streets to the intersection. The possible capacity of a roadway is defined on page 6 of the Highway Capacity Manual published by the U. S. Bureau of Public Roads in 1950

Table 1. Summary of Intersection Data and Space Occupied by a Transit Vehicle in the Traffic Stream

Site No.	Location: Street	Location: At	Direction of Travel	Time of Day	Street Width	Parking Permitted	Street Gradient	Location Bus Stop	Signal Time in Min. Total	Signal Time in Min. Green
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
					Arterial Streets					
1	Piedmont Ave.	North Ave.	SB	AM	39.0	No	-2.0%	Near	0.83	0.37
	Note: No opposing traffic on green. Street one way southbound on south leg.									
2	Decatur St.	Ivy St.	EB	PM	42.0	No	Level	Near	1.00	0.40
3	Peters St.	Fair St.	SB	PM	50.0	Yes	-0.5%	Near	1.33	0.81
4	Memorial Dr.	Boulevard	WB	AM	48.0	No	Level	Near	1.33	0.71
5	Memorial Dr.	Moreland Ave.	WB	AM	30.0	No	+3.5%	Near	1.00	0.49
5	Memorial Dr.	Moreland Ave.	EB	PM	30.0	No	-2.5%	Near	1.00	0.49
6	Peters St.	McDaniel St.	NB	AM	56.0	No	Level	Near	1.00	0.58
7	Whitehall St.	McDaniel St.	NB	AM	41.0	No	Level	Near	1.33	0.78
8	Cascade Ave.	Beecher St.	EB	AM	40.0	Yes	Level	Near	1.33	0.58
8	Cascade Ave.	Beecher St.	WB	PM	46.0	Yes	Level	Near	1.33	0.58
9	Lee St.	Gordon St.	SB	PM	40.0	Yes	Level	Near	1.00	0.50
					Secondary Streets					
10	Houston St.	Piedmont Ave.	EB	PM	40.0	No	-2.0%	Near	1.00	0.35
11	Pryor St.	Memorial Dr.	NB	AM	36.0	Yes	+3.5%	Near	0.91	0.41

Table 1. Cont'd. Summary of Intersection Data and Space Occupied by a Transit Vehicle in the Traffic Stream

Site No	Police at Intersection	Tran. Veh. in Cycle	Rate of Flow Per Minute of Green: Autos	Trucks	Total	Transit Vehicles	Turning Movement In Per Cent: Left	Right	Per Cent Trucks	Number Of Operations	Total Study Time In Minutes	Unweighted Bus Equiv. Autos/Bus
(1)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
						Arterial Streets						
1	No	No	40.0	1.0	41.0	0.00	1.3	3.9	2.6	1	45.7	
		Yes	36.4	1.3	37.7	1.35	1.4	6.5	3.6			2.44
2	No	No	29.8	1.6	31.4	0.00	0.0	0.0	4.2	1	34.0	
		Yes	25.9	2.6	28.5	1.40	0.0	0.0	7.9			2.07
3	No	No	30.6	0.4	31.0	0.00	0.6	5.8	1.2	3	122.4	
		Yes	27.8	0.7	28.5	1.29	0.3	6.3	2.4			1.93
4	No	No	51.5	0.7	52.2	0.00	0.0	7.8	1.3	3	101.1	
		Yes	42.2	1.0	43.2	1.22	0.0	9.4	2.2			7.37
5	No	No	37.7	0.4	38.1	0.00	3.7	2.1	1.0	1	30.0	
		Yes	33.2	0.8	34.0	1.36	2.9	3.5	2.9			3.01
5	No	No	37.7	1.4	39.1	0.00	3.6	2.6	3.6	2	57.0	
		Yes	30.8	0.6	31.4	1.24	6.4	3.2	1.9			6.20
6	No	No	42.5	0.3	42.8	0.00	0.4	2.0	0.8	1	30.0	
		Yes	36.2	0.1	36.3	1.34	0.4	1.8	0.4			4.85
7	No	No	33.9	1.0	34.9	0.00	0.3	0.7	2.9	2	71.8	
		Yes	29.2	0.5	29.7	1.24	0.4	0.0	1.7			4.19
8	No	No	27.0	0.3	27.3	0.00	0.0	8.8	1.2	1	27.9	
		Yes	25.6	0.0	25.6	0.86	0.0	6.7	0.0			1.97
8	No	No	31.0	0.0	31.0	0.00	12.7	6.1	0.0	1	39.9	
		Yes	27.2	0.6	27.8	2.06	9.8	4.9	2.4			1.55
9	No	No	18.2	0.6	18.8	0.00	10.6	13.8	3.1	4	112.0	
		Yes	16.6	0.4	17.0	1.30	10.5	21.1	2.3			1.38
										Total	671.8	
						Secondary Streets						
10	No	No	32.8	0.2	33.0	0.00	0.0	25.8	0.8	1	22.0	
		Yes	26.6	2.8	29.4	0.95	0.0	29.0	9.6			3.78
11	No	No	22.4	0.7	23.1	0.00	6.3	5.2	3.1	6	232.1	
		Yes	17.3	0.7	18.0	1.34	5.4	5.4	4.0			3.80
										Total	254.1	

as "the maximum number of vehicles that can pass a given point on a lane or roadway during one hour, under the prevailing roadway and traffic conditions." For a signalized intersection, the possible capacity of an approach street would be exceeded when the number of vehicles desiring to utilize the approach street was greater than the volume that could pass through during the green signal cycle so that a line of vehicles would be waiting at the completion of the green cycle. In order for these "loaded" conditions to exist at all studied intersections, it was necessary to decrease the green signal time in several instances. Traffic volumes on each of the approach legs to the intersection for each traffic signal cycle were classified by vehicle type and turning movements, and were recorded on an intersection count field sheet. It was not possible to insure that the approach street was "loaded" during all signal cycles so it was necessary to record observations as to whether or not each cycle was loaded. A copy of the completed field sheets for westbound traffic on Memorial Drive at Boulevard is included in the Appendix as Figure 10. Volumes of local buses shown on Figure 10 do not mean that the bus passed through the intersection during that signal cycle. Since the purpose of this portion of the study was to determine the interference of transit vehicles to the flow of traffic, each signal cycle was classified as to the extent of interference by transit vehicles. This interference might include loading or unloading of passengers, the trolley jumping the overhead wire or other unusual occurrences that would interfere with the flow of traffic. A transit vehicle was classified as interfering with the flow of traffic as long as it was at the intersection regardless of the number of cycles in which this interference occurred.

The field data for all intersections were summarized and recorded on Table 1. In summarizing traffic volumes for inclusion in Table 1, average volumes were computed on the basis of the rate of flow per minute of green. That is, the total volume of each type of vehicle utilizing the approach leg of the intersection during the "loaded" cycles was divided by the total green signal time in minutes for the "loaded" cycles.

The formula for the computation of the space in the traffic stream occupied by a transit vehicle in terms of automobiles per bus can be defined as:

$$S = \frac{V_1 - V_2}{V_t} \tag{3}$$

where: S = space occupied in automobiles per bus

V_1 = volume of automobiles with no bus interference

V_2 = volume of automobiles with bus interference

V_t = volume of interfering transit vehicles.

As is stated above, volumes were computed on the basis of flow per minute of green signal time and included in Table 1. The space in the traffic stream occupied by a transit vehicle at each of the studied intersections was computed by substituting in Formula (3) the data for each intersection shown in Columns 13, 16 and 17 of Table 1. The number of automobiles displaced by one transit vehicle in the traffic stream at each of the studied intersections is shown in Column 23 of Table 1.

Since the total study time at each of the selected intersections varied from 22.0 minutes to 3 hours and 52.0 minutes, it was apparent that these bus equivalents should be weighted according to the study time spent at each intersection. For purposes of comparison, the A.M. and P.M. bus equivalents were first weighted separately and then as a combined total. The formula for this computation can be stated as:

$$S_w = \frac{S_{u1}\ T_1}{T} + \frac{S_{u2}\ T_2}{T} \quad . \; . \; . \quad \frac{S_{un}\ T_n}{T} \tag{4}$$

where: S_w = the weighted bus equivalent

S_{u1} = the unweighted bus equivalent for intersection number one

T_1 = study time in minutes at intersection number one

S_{u2} = the unweighted bus equivalent for intersection number two

T_2 = study time in minutes at intersection number two

T = total study time in minutes at all intersections. If bus equivalent is computed for A.M. then only total A.M. study time is summated.

The weighted bus equivalent in automobiles per bus for A.M., P.M. and combined studies is shown in Table 2. The weighted bus equivalent for combined A.M. and P.M. studies is used in subsequent calculations in this thesis.

The weighted bus equivalent or the space occupied by a transit vehicle in the traffic stream was not computed for diesel motor buses separate from the computation for electric trackless trolleys. It was

Table 2. Space in the Traffic Stream Occupied by a Transit Vehicle Weighted According to Study Time.

Time of Day	Space Occupied in the Traffic Stream in Automobiles per Bus	
	Arterial Street	Secondary Street
A.M. Peak	4.7	3.8
P.M. Peak	2.4	3.8
Combined A.M. and P.M.	3.5	3.8

not possible to locate heavily traveled intersections in Atlanta that had relatively large volumes of only diesel motor buses or electric trackless trolley buses utilizing the intersection. Therefore, the space equivalent computed in this study is for combined diesel motor and electric trackless trolley buses.

Transit vehicle operating speed and average passenger load.--Planning for this portion of the study consisted of the selection of transit vehicle routes to be studied and the preparation of field data forms. Route selection was made in cooperation with the Atlanta Transit System. Seven operating transit lines were selected and data pertaining to the number of bus stops and distance between each bus stop were obtained from the Transit Company. These data were used in preparation of the field work sheet. Figure 11, included in the Appendix, is an example of the type of field sheet used. A field sheet was prepared for each studied transit route. The data that were included on the field form are typewritten on Figure 11. The data shown by Leroy lettering were entered by the observer in the field (columns 2-5) or by the study analyst in the office (columns 6-7).

Operation of the field portions of this study was by personnel of the Division of Highway Planning of the State Highway Department of Georgia and was conducted during January 1955. The study extended over a period of five days, Monday through Friday, and information was obtained on 359 one-way bus trips divided about equally between the morning peak, afternoon peak and offpeak periods of traffic flow. Observers were posted on buses on each of the seven operating lines studied. Six of the lines studied were electric trackless trolley bus lines (Routes 2, 3, 10, 17, 20 and 23) and one was a diesel motor bus line (Route 21). For each transit vehicle trip during the operating hours of the study on each of the selected lines, the observers compiled complete records showing the travel time between stops, the number of passengers loading or unloading at each stop and the number of passengers on board between stops. These records were maintained on the field work sheet, Figure 11, provided for this purpose. In order to obtain more extensive data for the downtown and intermediate areas, the observers were instructed to terminate their run at some designated point within the outlying area rather than continuing to the end of the line. By thus shortening the trip lengths under observation, the resulting time saved allowed more data to be collected in the downtown and intermediate areas. Therefore, the data for the outlying area are considered to be less reliable than those for other areas.

Due to the large volume of field data obtained in this study (395 trips), electronic IBM equipment was used in summarizing the field data. Only tabulating equipment was available, so many of the calculations were performed on an electric calculator. Certain of these calculations were necessary before the data could be processed (columns 6-7, Figure 11). The passenger miles shown in column 6, Figure 11 are the product of the total number of passengers aboard between stops and the mileage between stops. The passenger minutes shown in column 7, Figure 11 are the product of the total number of passengers aboard between stops and the time in minutes between stops. After these calculations were completed for all the trips on all the studied routes, the information as to route number, direction of travel, trip number and the data contained in columns 1, 2, 5-7, were punched into standard IBM cards. Figure 12, as included in the Appendix, is a copy of the "lay-out card" which shows columnar designation for keypunched data. One card was prepared for each stop made by the transit vehicle for each transit vehicle trip studied, i.e., stop 1, 4, 5, 6, etc. on Figure 11. The location of each probable stop had been previously classified as to the study area, i.e., downtown, intermediate or outlying. This information was punched into column 6 of the IBM card (Figure 12). The cards for each route were "sorted" by IBM procedures into groups by A.M. Peak, P.M. Peak and Offpeak hours, direction of travel and study area classification. The groups included: (1) A.M. peak, outbound, downtown; (2) A. M. Peak, inbound, downtown; (3) A.M. peak, outbound, intermediate; etc. The card groups for the six electric trackless trolley routes were combined by group classification. IBM tabulating procedures were used and totals were obtained by card group for the miles traveled, passenger miles, minutes consumed and passenger minutes. Totals for these quantities were also obtained for the one diesel motor bus route studied. The average number of passengers carried and the average travel time for transit vehicles were then computed.

The average passenger load determined in this study is the average number of persons carried weighted according to the passenger miles traveled. The weighted average carried load is the summation of the products of the number of passengers aboard between stops and the distance in miles between stops divided by the total distance in miles. This can be stated as:

$$P = \frac{P_1D_1 + P_2D_2 + P_nD_n}{D} \qquad (5)$$

where: P = average passenger load

P_1 = number of passengers carried between stops 1 and 2

D_1 = distance in miles between stops 1 and 2

P_2 = number of passengers carried between stops 2 and 3

D_2 = distance in miles between stops 2 and 3

D = total distance in miles.

Table 3 is a summary of the average passenger load carried by electric trackless trolley buses classified as to type of service, direction of travel, time of day and proximity to the downtown business district. Table 4 is a summary of the same information for diesel motor buses.

The operating speed determined in this study is the average speed weighted according to passenger miles traveled and passenger minutes consumed. The weighted average operating speed is then the summation of the products of the number of passengers aboard and the distance between stops divided by the summation of the products of the number of passengers aboard between stops and the elapsed time between stops in minutes. This can be stated as:

$$V = \frac{P_1D_1 + P_2D_2 + P_nD_n}{P_1T_1 + P_2T_2 + P_nT_n} \qquad (6)$$

Table 3. Average Number of Passengers Carried by Electric Trackless Trolley Buses Classified as to Type of Service, Time of Day and Proximity to the Downtown Business District.

Type of Service	Time of Day	Direction of Travel	Average Load (Number of Persons)		
			Downtown	Intermediate	Outlying
Local	A.M. Peak	Inbound	52.9	54.3	42.7
		Outbound	46.3	43.1	29.0
	P.M. Peak	Inbound	44.9	39.4	28.7
		Outbound	46.6	53.9	41.1
	Off Peak	Inbound	30.5	29.0	19.9
		Outbound	26.8	28.8	21.0

Table 4. Average Number of Passengers Carried by Diesel Motor Buses Classified as to Type of Service, Time of Day and Proximity to the Downtown Business District.

Type of Service	Time of Day	Direction of Travel	Average Load (Number of Persons)		
			Downtown	Intermediate	Outlying
	A.M. Peak	Inbound	42.5	35.4	21.0
		Outbound	46.0	32.1	17.9
Local	P.M. Peak	Inbound	37.5	23.5	15.8
		Outbound	49.5	41.8	35.0
	Off Peak	Inbound	28.4	23.4	12.8
		Outbound	27.8	25.0	14.5

where: V = average operating speed in miles per minute

P_1 = number of passengers aboard between stops 1 and 2

D_1 = distance in miles between stops 1 and 2

P_2 = number of passengers aboard between stops 2 and 3

D_2 = distance in miles between stops 2 and 3

T_1 = elapsed time in minutes between stops 1 and 2

T_2 = elapsed time in minutes between stops 2 and 3.

Table 5 is a summary of the average operating speed of the electric trackless trolley buses classified as to type of service, direction of travel, time of day and proximity to the downtown business district. Table 6 is a summary of the same information for diesel motor buses. The average operating speed was computed in minutes per miles instead of miles per minute to simplify succeeding calculations. These values are the reciprocal of values in miles per minute.

Automobile Operation Study

In order to compare the relative efficiencies of transit vehicles and automobiles, it was necessary to determine the same characteristics of the automobile in the Atlanta area as those determined for the transit vehicles. These characteristics included the space occupied by the automobile in the traffic stream, average automobile passenger load and average automobile operating speed.

Space occupied by the automobile in the traffic stream.--Since the automobile, to include the motor truck, was used as the basis for comparison, the space occupied per vehicle in the traffic stream for the automobile was assumed as unity.

Table 5. Average Travel Time for Electric Trackless Trolley Buses Classified According to Type of Service, Time of Day and Proximity to the Downtown Business District.

Type of Service	Time of Day	Direction of Travel	Travel Time (Minutes per Mile)		
			Downtown	Intermediate	Outlying
	A.M.Peak	Inbound	10.35	5.45	4.08
		Outbound	10.47	5.25	3.77
Local	P.M.Peak	Inbound	10.65	5.37	3.95
		Outbound	12.19	6.39	4.12
	Off Peak	Inbound	10.04	5.45	3.54
		Outbound	9.32	4.94	3.51

Table 6. Average Travel Time for Diesel Motor Buses Classified According to Type of Service, Time of Day and Proximity to Downtown Business District.

Type of Service	Time of Day	Direction of Travel	Travel Time (Minutes per mile)		
			Downtown	Intermediate	Outlying
	A.M.Peak	Inbound	11.63	6.20	4.87
		Outbound	9.07	5.40	4.19
Local	P.M.Peak	Inbound	13.40	5.93	4.59
		Outbound	12.17	6.27	5.28
	Off Peak	Inbound	10.12	5.27	4.74
		Outbound	10.33	5.07	4.49

Average automobile passenger load[5].--Data pertaining to the average automobile passenger load in the Atlanta area were obtained from the Traffic Engineering Department of the City of Atlanta. In previous years, personnel of this department had conducted automobile passenger load studies along a cordon line surrounding the central business district of Atlanta. Studies were conducted during the years 1941, 1945, 1947 - 1948, 1951 and 1953. Table 7 is a summary of the cordon county data obtained from the Traffic Engineering Department of the City of Atlanta. The information shown on Table 7 was used in the preparation of Figure 3. This figure indicates that the automobile passenger load in Atlanta increased during the years of World War II to a peak of 1.78 persons in 1943. The average automobile passenger load has decreased since that date to a fairly uniform value of 1.67 persons per automobile. Due to the fact that time, personnel and funds were not available for obtaining these data for 1955 and since it appears from Figure 3 that the automobile passenger load has attained a uniform value for all practical purposes, the value of 1.67 or 1.7 persons per vehicle was used in this study for the average automobile passenger load.

Average automobile operating speed[6].--The average operating speed of automobiles was determined by driving a test car along the identical routes that were covered in the transit vehicle study. On each of the seven routes studied from nine to fifteen round trips were made with the test car being driven at a speed which the driver thought was representative of the average speed of the traffic. In effect, this means that the test car passed as many vehicles as passed it. No

Table 7. Cordon Count Data for Computing Average Automobile Occupancy

Year Count was Made	Total Number of Automobiles Counted	Total Number of Persons Counted	Average Number of Persons per Automobile
1941	93,970	156,839	1.66
1942	78,918	134,410	1.70
1943	58,508	104,089	1.78
1944	65,908	114,681	1.74
1945	77,632	133,500	1.72
1947	96,503	163,591	1.70
1948	105,928	177,924	1.68
1951	116,278	192,669	1.66
1953	119,434	199,486	1.67

effort was made to bracket the peak periods with a specified number of trips. The peak periods were assumed to be the same as the peak bus passenger periods.

Table 8 is a tabular summary of the results of the automobile operating speed studies classified according to the time of day, direction of travel and proximity to the downtown business district.

Relative Efficiency of Transit Vehicles and Automobiles

The objective of this thesis was to determine the relative efficiencies of various modes of transportation in the transportation of people and the utilization of city streets. The expression for computing the relative efficiency of modes of transportation, as given in Chapter I as Formula 2, recognizes both the space occupied per person in the traffic stream, which is a measure of the efficient use of street space, and the speed of operation, which is a measure of the efficient movement of people.

The data obtained in the field studies are summarized in Table 9. to show the data used in the computation of relative efficiencies. The data contained in Table 9 were substituted into Formula 2 and the efficiency of the diesel motor bus and electric trackless trolley bus was computed relative to the efficiency of the automobile.

Table 8. Average Travel Time for Automobiles Classified According to the Time of Day, Direction of Travel and Proximity to the Downtown Business District.

Area of City	Time of Day	Average Travel Time (Minutes Per Mile) Inbound	Outbound	In and Out
Downtown	A.M. Peak	8.19	6.85	7.52
	P.M. Peak	8.30	8.62	8.46
	A.M. & P.M. Combined	8.24	7.73	7.98
	Off Peak	7.14	6.19	6.66
Intermediate	A.M. Peak	5.29	4.12	4.70
	P.M. Peak	4.65	5.90	5.27
	A.M. & P.M. Combined	4.97	5.01	4.99
	Off Peak	4.32	4.15	4.23
Outlying	A.M. Peak	3.69	3.31	3.50
	P.M. Peak	3.68	4.16	3.92
	A.M. & P.M. Combined	3.68	3.73	3.75
	Off Peak	3.16	3.25	3.20

Table 9. Summary of Data Used in Computation of Relative Efficiencies. Morning and Afternoon Peak Hours Combined for Heavy Direction of Travel.

Type of Vehicle	Travel Time: Minutes per Mile	Carried Load: Persons per Vehicle	Space per Vehicle: Auto Units
A. Downtown Area			
Automobiles	8.0	1.7	1.0
D.M. Buses*	11.9	46.0	3.5
E.T.T. Buses**	11.3	49.8	3.5
B. Intermediate Area			
Automobiles	5.6	1.7	1.0
D.M. Buses	6.3	38.6	3.5
E.T.T. Buses	6.0	54.1	3.5
C. Outlying Area			
Automobiles	3.8	1.7	1.0
D.M. Buses	4.9	28.0	3.5
E.T.T. Buses	4.1	41.9	3.5

* Diesel Motor Buses
** Electric Trackless Trolley Buses

CHAPTER III

DISCUSSION OF RESULTS

While the purpose of this study was to determine the efficiency of two types of mass-transit vehicles relative to the efficiency of the automobile, it is felt that the results of several phases of the study should be discussed in addition to the results of the relative efficiency determination.

Space occupied by a transit vehicle in the traffic stream.--The results of the study to determine the space occupied by a transit vehicle in the stream were very erratic for arterial streets while little variation was observed for secondary streets. The bus equivalent determined at the nine intersections on arterial streets varied from 1.38 to 7.37 automobiles per bus (Table 1). The range of the results was due to variations in site conditions. The site conditions were analyzed to determine the relationship between conditions and results. As can be seen on Table 1, the possible variables in site conditions were time of day, street width, parking conditions, gradient, location of bus stops, police control at the intersection, turning movements and the percentage of trucks. The possible variables of location of bus stops, police control and the portion of the total turning movements made by transit vehicles was eliminated from the analysis of site conditions as these factors were identical for all of the nine studied locations.

The analysis of site conditions related to the time of day revealed that during the morning peak hour studies there was a higher space equivalent than during the afternoon peak hour. This may be explained by the fact that traffic during the morning peak hour travels at a faster rate of speed than it does during the afternoon peak hour (Tables 5, 6 and 8). Any delay to this normally faster flowing stream of traffic, such as transit passenger loading or unloading, would possibly result in a greater number of automobiles being displaced by the delaying transit vehicle than would be displaced during the slower moving traffic stream of the afternoon peak hour. Table 10 is a summary of the space in the traffic stream occupied by a transit vehicle classified according to the time of day each study was conducted.

Table 11 is a summary of the results of the studies of the space in the traffic stream occupied by a transit vehicle, classified according to street widths at the study locations. It should be noted that the values for space equivalents determined at intersections with street widths of 30.0 feet, 46.0 - 50.0 feet, and 56.0 feet were higher than those for street widths of 39.0 - 42.0 feet. This is explained by the fact that a street with a curb-to-curb width of 30.0 feet is a two moving traffic lane facility and does not have adequate width for parking lanes. A transit vehicle stopping to load or unload passengers on this street would block a moving lane of traffic resulting in a higher space equivalent for the transit vehicle. A street with a curb-to-curb width of 46.0 feet to 50.0 feet is normally a four moving traffic lane facility if parking is prohibited. If parking is permitted, the street

Table 10. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to Time of Day.

	Space Equivalents* Determined During A.M. Peak Hour	Space Equivalents* Determined During P.M. Peak Hour
	1.97	1.38
	2.44	1.55
	3.01	1.93
	4.19	2.07
	4.85	6.20
	7.37	
Average	3.97	2.63

* See Table 1, Cols. 2, 3, 5 and 23 for location and time of day for each intersection study.

Table 11. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to Approach Street Width at Study Location

Street Width in Feet	Space Equivalents in Automobile per Bus*
30.0	3.01
	6.20
39.0 - 42.0	1.38
	1.97
	2.07
	2.44
	4.19
46.0 - 50.0	1.55
	1.93
	7.37
56.0	4.85

*See Table 1, Cols. 2, 3, 5 and 23 for location and time of day for each intersection study.

would normally operate as a two or three moving traffic lane facility. The two low space equivalents shown on Table 11 for streets with widths of 46.0 feet to 50.0 feet occurred on streets with parking permitted. The effect that parking conditions have on the transit vehicle space equivalent will be discussed in later paragraphs. The street with a curb-to-curb width of 56.0 feet operated as a four moving traffic lane facility with parking prohibited. The same remark applies to a street of this width as to the 30.0 feet street above.

Table 12 is a summary of the space in the traffic stream occupied by a transit vehicle classified according to parking conditions at the study site. It should be noted that the space equivalent was lower at locations where parking was permitted. This was due to the fact that parking was prohibited near the intersection for a transit loading zone. This removed the transit vehicles from a moving lane of traffic during loading or unloading operations resulting in a fewer number of automobiles displaced by a transit vehicle.

Table 13 is a summary of the space in the traffic stream occupied by a transit vehicle classified according to the gradient of the approach street at the intersection. There was a wide variation in the space equivalent when classified in this manner but the averages by gradient type were close.

Table 14 is a summary of the space in the traffic stream occupied by a transit vehicle classified according to the turning movements at the study locations. Transit vehicle movement was straight through the intersection in all cases. As can be seen from Table 14, there does not

Table 12. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to Parking Conditions.

Space Equivalents on Streets with No Parking*	Space Equivalents on Streets with Parking Permitted*
2.07	1.38
2.44	1.55
3.01	1.93
4.19	1.97
4.85	
6.20	
7.37	

*See Table 1, Cols. 2, 3, 5 and 23 for location and time of day for each intersection study.

Table 13. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to the Gradient of the Approach Street.

Approach Street Gradient	Space Equivalents in Automobiles per Bus*	Average
-0.5% to -2.5%	1.93	
	2.44	
	6.20	
		3.52
Level	1.38	
	1.55	
	1.97	
	2.07	
	4.19	
	4.85	
	7.37	
		3.34
+3.5%	3.01	3.01

*See Table 1, Cols. 2, 3, 5 and 23 for location and time of day for each intersection study.

Table 14. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to the Turning Movements.

Turning Movements in Per Cent		Space Equivalent in
Left Turns	Right Turns	Automobiles per Bus*
0.0	0.0	2.07
0.0	6.7	1.97
0.0	9.4	7.37
0.3	6.3	1.93
0.4	1.7	4.19
0.4	1.8	4.85
1.4	6.5	2.44
2.9	3.5	3.01
6.4	3.2	6.20
9.8	4.9	1.55
10.5	21.1	1.38

*See Table 1, Cols. 2, 3, 5 and 23 for location and time of day for each intersection study.

appear to be a direct relationship between the percentage of left and right turns by automobiles and the space occupied by a transit vehicle in the traffic stream.

Table 15 is a summary of the space in the traffic stream occupied by a transit vehicle classified according to the percentage of trucks. As in the case of the classification according to the percentage of turning movements, there does not appear to be a direct relationship between the percentage of trucks and the space in the traffic stream occupied by a transit vehicle.

As was shown in Table 2, the weighted average of the space in the traffic stream occupied by a transit vehicle was 3.46 or 3.5 automobiles per bus. This means that each transit vehicle displaces 3.5 automobiles in the traffic stream, or conversely, 3.5 automobiles displace 1.0 transit vehicle in the traffic stream. This information will be utilized in the discussion of the results of the relative efficiency determination.

Average operating speed of transit vehicles and the automobile.--Table 16 is a summary of the average operating speed of diesel motor buses, electric trackless trolley buses and the automobile expressed in minutes per mile. The results of this portion of the study were about as expected with the operating speed of the automobile higher than that of the transit vehicles in all but one instance. This exception cannot be explained. In all but three instances the operating speed of the electric trackless trolley bus was higher than that of the diesel motor bus. The speed differential in each of the three exceptions was less than 0.18 miles per hour.

Table 15. Space in the Traffic Stream Occupied by a Transit Vehicle Classified According to the Per Cent of Trucks.

Per Cent Trucks	Space Equivalent in Automobiles per Bus*
0.0	1.97
0.4	4.85
1.7	4.19
1.9	6.20
2.2	7.37
2.3	1.38
2.4	1.55
2.4	1.93
2.9	3.01
3.6	2.44
7.9	2.07

*See Table 1, Cols. 2, 3, 5 and 23 for location and time of day for each intersection study.

Table 16. Average Operating Speed of Diesel Motor Buses, Electric Trackless Trolley Buses and Automobiles in Minutes per Mile

Time of Day	Study Area	Diesel Motor Buses	Electric Trackless Trolley Buses	Automobile
A.M. Peak*	Downtown	11.63	10.35	8.19
	Intermediate	6.20	5.45	5.29
	Outlying	4.87	4.08	3.69
P.M. Peak*	Downtown	12.17	12.19	8.62
	Intermediate	6.27	6.39	5.90
	Outlying	5.28	4.12	4.16
Off Peak**	Downtown	10.23	9.68	6.66
	Intermediate	5.17	5.20	4.23
	Outlying	4.62	3.52	3.20

* Peak direction of travel.
** Combined direction of travel.

The data included in Table 16 show that a passenger in an automobile traveling in the downtown area during the morning peak can travel one mile in 8.19 minutes while a passenger in a diesel motor bus or electric trackless trolley bus would require 11.63 minutes and 10.35 minutes, respectively, to travel the same distance.

Average passenger load.--Table 17 is a summary of the average passenger load carried by the automobile, diesel motor bus and electric trackless trolley bus classified according to the time of day, peak direction of travel and study area. In practically all cases the electric trackless trolley bus carried the heaviest passenger load, as was expected. Electric trackless trolley routes are normally established in areas that will afford large volumes of passenger travel due to the expense of the construction and maintenance of overhead trolley wires.

Relative efficiencies.--Table 18 is a summary of the relative efficiencies of various modes of urban transportation in the transportation of people and the utilization of city streets. In the congested downtown area, the relative efficiencies of the diesel motor bus and the electric trackless trolley bus when compared with the automobile were 5.2 and 5.9, respectively, but in the intermediate area the relative efficiencies were 5.8 and 8.5 respectively. The fact that there was an increase in the difference between the relative efficiencies of the two modes of transportation in the intermediate area is explained by an increase in the passenger load and operating speed of the electric trackless trolley bus and a decrease in the passenger load and a smaller increase in operating speed of the diesel motor bus. While there was a decrease in

Table 17. Average Passenger Load Carried by the Automobile, Diesel Motor Bus and Electric Trackless Trolley Bus.

Time of Day	Study Area	Diesel Motor Bus	Electric Trackless Trolley Bus	Automobile
A.M. Peak*	Downtown	42.5	52.9	1.7
	Intermediate	35.4	54.3	1.7
	Outlying	21.0	42.7	1.7
P.M. Peak*	Downtown	49.5	46.6	1.7
	Intermediate	41.8	53.9	1.7
	Outlying	35.0	41.1	1.7
Off Peak**	Downtown	28.1	28.7	1.7
	Intermediate	24.2	28.9	1.7
	Outlying	13.7	20.5	1.7

* Peak direction of travel.
** Combined direction of travel.

Table 18. Relative Efficiencies of Automobiles, Diesel Motor Buses and Electric Trackless Trolley Buses in the Utilization of Street Space and Movement of People During Peak Hours of Traffic Movement on Surface Streets.

Area	Type of Vehicle	Relative Efficiency
Downtown	Automobiles	1.0
	Diesel Motor Buses	5.2
	Electric Trackless Trolley Buses	5.9
Intermediate	Automobiles	1.0
	Diesel Motor Buses	5.8
	Electric Trackless Trolley Buses	8.5
Outlying	Automobiles	1.0
	Diesel Motor Buses	3.7
	Electric Trackless Trolley Buses	6.5

in the relative efficiency of the two modes of transportation in the outlying area, the difference in the efficiencies remained practically the same.

The determination of relative efficiencies of various modes of transportation in this thesis considered the space occupied by a vehicle in a moving stream of traffic, the length of time this space was occupied or the operating speed and the number of persons transported. Referring to Tables 2, 16 and 17, a transit vehicle replaces 3.5 automobiles in the traffic stream but the electric trackless trolley bus in the downtown area transports 31.1 times as many persons as each automobile. Therefore, each person in an automobile occupies 8.89 times as much space in the traffic stream as does one passenger in the electric trackless trolley bus. Each transit vehicle in the traffic stream could be replaced by 3.5 automobiles without increasing traffic congestion but the 52.9 passengers transported by the electric trackless trolley bus in the downtown area would be replaced by only 6.0 persons in automobiles but the 6.0 persons would cover the same distance in 0.79 of the time.

CHAPTER IV

SUMMARY OF RESULTS AND CONCLUSIONS

Considering the scope of the study and the data available, the following results may be considered.

Summary of Results

1. The space in a moving stream of traffic occupied by a transit vehicle considering only the effect on street capacity was 3.5 automobiles per bus on arterial streets and 3.8 automobiles per bus on secondary streets.

2. Transit loading and unloading of passengers on streets with no parking restrictions had less effect on moving streams of traffic than on streets with parking restrictions because of passenger loading zones in parking lanes.

3. In the congested downtown area of Atlanta, the electric trackless trolley bus is 5.9 times as efficient as the automobile in transporting people and utilizing city streets.

4. In the congested downtown area in Atlanta, the diesel motor bus is 5.2 times as efficient as the automobile in transporting people and utilizing city streets.

5. In the area between the downtown area and the primarily residential areas in Atlanta, the electric trackless trolley bus is 8.5 times as efficient as the automobile in transporting people and utilizing city streets.

6. In the area between the downtown area and the primarily residential areas in Atlanta, the diesel motor bus is 5.8 times as efficient as the automobile in transporting people and utilizing city streets.

7. In the primarily residential areas in Atlanta, the electric trackless trolley bus is 6.5 times as efficient as the automobile in transporting people and utilizing city streets.

8. In the primarily residential areas in Atlanta, the diesel motor bus is 3.7 times as efficient as the automobile in transporting people and utilizing city streets.

Conclusions

Based on the findings revealed by this study, it is concluded that the diesel motor bus and the electric trackless trolley bus are more efficient than the automobile in transporting people and utilizing city streets.

CHAPTER V

RECOMMENDATIONS

Numerous recommendations have been made to improve the efficiency of mass transit operations in urban areas and also to entice more people to ride mass transit vehicles in order to reduce the number of automobiles utilizing city streets.

One of the recommendations for improving operating efficiency in the downtown area is the establishment of curb lanes for the exclusive use of transit vehicles[7]. The City of Atlanta has established one such transit lane along Peachtree Street in the downtown area[8]. It is recommended that future research on mass transit operations include a comparison of the space occupied in a moving stream of traffic by a transit vehicle utilizing an exclusive transit lane and the space occupied under the conditions that existed when the field work for this thesis was performed.

Another suggested method for improving the operating efficiency of mass transit is the establishment of streets designed primarily for transit usage[9]. Traffic signals on these streets would be timed for efficient transit operations and would discourage automobiles from using these streets. Future research on mass transit operations should include a study of such streets.

APPENDIX

[illegible]

City	Atlanta	State	Georgia	Data furnished by City of Atlanta Traffic Engineering Dept.
Date	2/18/55	Time	7:15 A.M. – 8:15 A.M.	Weather: Clear, Dry, Cool

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1. [illegible]	Boulevard		Memorial Dr.	
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	32	40	48	48
[illegible]	None			
[illegible]	16	20	24	24
[illegible]	32	40	48	48
[illegible]	None			
[illegible]	16	20	24	24
3. [illegible]				
[illegible]	None			
[illegible]	None			
[illegible]	None			
[illegible]	None			
4. [illegible]				
[illegible]				
[illegible]	✓	✓	✓	✓
[illegible]				
5. [illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	31	31	43	43
[illegible]				
[illegible]				
[illegible]	3	3	3	3

[illegible] 3 [illegible] 80 [illegible]

[illegible]

NOTE:
No Left From
E.-W. Street

6. [illegible]		
[illegible]		
[illegible]	✓	
[illegible]		
[illegible]		
[illegible]		
[illegible]		
7. [illegible]	[illegible]	[illegible]
[illegible]		
[illegible]		
[illegible]		
[illegible]	✓	✓
[illegible]		
8. [illegible]		
[illegible]		
[illegible]	✓	✓
[illegible]		
[illegible]		
[illegible]		
[illegible]		
9. [illegible]		
[illegible]		
[illegible]	✓	✓
[illegible]		
[illegible]		

FIGURE 9.

FIELD FORM FOR INTERSECTION CONDITIONS STUDY

10. TRAFFIC CONTROL (Check where appropriate)

Stop signs							
X-way streets		Fixed time		Isolated location		Simultaneous	
Both streets		Program type	✓	Coordinated system		Alternate	
Traffic signals	✓	Fully actuated		Not interconnected	✓	Progressive	
Police directed		Semi-actuated		Interconnected		Simple	✓
No control		Police Operated				Flexible	

11. TYPE OF PEDESTRIAN CONTROL & OBSERVANCE (Check)

Same as vehicles	✓	Good	
Push button		Fair	✓
Separate "all red"		Poor	
Separate signals			

"Walk" period N-S ______ sec. E-W ______ sec.

Was officer present? Yes ______ No ✓

12. RELATED DATA FOR COORDINATED SYSTEMS (Check first col.)

Direction of flow	Favored by signal timing	Progressive band: [illegible]	Progressive band: [illegible]
Northbound			
Southbound			
Eastbound			
Westbound			

	Northbound Approach	Northbound Exit	Southbound Approach	Southbound Exit	Eastbound Approach	Eastbound Exit	Westbound Approach	Westbound Exit
13. PARKING (Check where permitted)	✓			✓		✓		
Distance eliminated from crosswalk	100			100		100		
Duration of legal parking period	1 hr			1 hr		1 hr		
Actual parking during study	Full			Full		Full		
Parking turnover during study	None			None		None		
14. BUS STOPS (check locations)					✓		✓	
15. STREETCAR TRACKS (Check locations) None								
16. STREETCAR LOADING PLATFORMS OR ZONES None								
17. NUMBER OF TRAFFIC LANES	2	1	2	2	2	2	2	2

Were crosswalks marked? Yes Were centerlines marked? Yes Were lane lines marked? Yes

FIGURE 9. CONT'D.

FIELD FORM FOR INTERSECTION CONDITIONS STUDY

Form [illegible]

[illegible]

Identification: City Atlanta State Georgia Data furnished by City of Atlanta Traffic Engineering Dept.

Names of streets: N-S Boulevard E-W Memorial Drive

Time of study: Date, 2/18/55 Day, One Hour, from 7:15 A.M. to 8:15 A.M., Daylight (✓) Dark ( )

18- PEAK HOUR TRAFFIC COUNT

	Northbound			Southbound			Eastbound			Westbound		
	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right
Automobiles	577	0	53	443	0	90	500	0	28	1,289	0	110
Truck-sized veh.	26	0	8	21	0	7	43	0	1	44	0	3
Local buses	0	0	0	0	0	0	17	0	0	28	0	0
Subtotal	603	0	61	464	0	97	560	0	29	1,361	0	113
Streetcars												

19- PEAK 20 MINUTE COUNT (15 or 20 minutes preferred)

Automobiles	221	0	19	163	0	32	187	0	11	538	0	46
Truck-sized veh.	9	0	3	8	0	2	16	0	0	13	0	0
Local buses	0	0	0	0	0	0	7	0	0	12	0	0
Subtotal	230	0	22	171	0	34	210	0	11	563	0	46
Streetcars												

20- INDEX OF CONGESTION

	N-bound	S-bound	E-bound	W-bound
Indicate number of minutes that each approach was loaded to its possible capacity	57	17	46	48
Number of loaded cycles (if available from form [illegible])				
During peak hour	43	13	35	36
During short count				

21- PEDESTRIAN COUNT

	During peak hour	During short count
Crossing N-S Street	12	
Crossing E-W Street	34	

Above figures based on: (Check one)

Actual count ✓

Estimated

FIGURE 9. CONT'D.

FIELD FORM FOR INTERSECTION CONDITIONS STUDY

Form [illegible]

[illegible] – [illegible] No. 1 of 2

[illegible] [illegible] Memorial Drive [illegible] Boulevard

[illegible] West [illegible] City Atlanta

[illegible] 7:15-8:15A.M. [illegible] 2-18-55 [illegible] Bearden

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]			[illegible]			[illegible]			[illegible]
[illegible]	[illegible]	[illegible]	Thru	Left	Right	Thru	Left	Right	Thru	Left	Right	[illegible]
1	43	✓	34		1				1			
2		✓	24									
3		✓	21		3							
4		✓	23		4							
5		✓	20		4	3			1			
6		✓	29		4							
7		✓	29		5							
8		✓	27		5							
9		✓	36		2				1			
10			15									
11			22						1			
12			23									
13		✓	34		1	4			1			
14		✓	37		5	1						
15		✓	35		3				1			
16		✓	35		3				2			
17		✓	36		1							
18		✓	27	NO LEFT TURN PERMITTED	6	2	NO LEFT TURN PERMITTED			NO LEFT TURN PERMITTED		
19		✓	34		1	1			1			
20		✓	35		2	1			2			
21		✓	37		3	1						
22			23		4				1			
23		✓	30		2	1			1			
24		✓	31		2	4			1			
25		✓	37		3							
26		✓	35		1				2			
27		✓	36		6	1						
28		✓	32		1				1			
29		✓	38		3	1						
30		✓	36		5							
31		✓	35		4							
32		✓	25		1	1						
33		✓	20						2			
34		✓	20			1		1				

FIGURE 10.

TRANSIT VEHICLE INTERFERENCE STUDY

[illegible]

[illegible] NO. 2 OF 2

[illegible] Memorial Drive [illegible] Boulevard

[illegible] West [illegible] City Atlanta

[illegible] 7:15-8:15 A.M. [illegible] 2-18-55 [illegible] Bearden

[illegible]

Cycle No.	[illegible] Secs.	[illegible] if loaded	[illegible] Thru	Left	Right	[illegible] Thru	Left	Right	[illegible] Thru	Left	Right	[illegible] notes
35	43	✓	34	NO LEFT TURN PERMITTED	2	2	NO LEFT TURN PERMITTED		2	NO LEFT TURN PERMITTED		
36		✓	30		3							
37			24		2			1				
38		✓	27		2				1			
39		✓	28		2	2						
40			20					1				
41			10		2	4			1			
42			24		3	3			2			
43		✓	30		3	5						
44		✓	31		4	2			2			
45			20		2	4			1			

FIGURE 10. CONT'D.

TRANSIT VEHICLE INTERFERENCE STUDY

Route 17
Direction OUTBOUND
Schedule No. 6
Trip No. 1-6:00A.M.

ATLANTA BUS OPERATION STUDY

Sheet 1 of 1
Date JAN. 20, 1955
Day of Week THURS.
Observer THRELKELD

Location of Stop (1)			Time of Arrival (2)	Operating Time (3)		Delay Time (4)				Number of Passengers (5)			Passenger Miles (6)	Passenger Minutes (7)
No.	Street	Miles		Travel	Load	Signal	Other Bus	Other Time	Other Cause	On	Off	Total Aboard		
1	Pryor & Auburn		6-02-16"		0	17"						25	8.90	47.5
		.120		35"										
2	Auburn & Ivy				0	0								
		.110		30"										
3	Auburn & Courtland				0	7"								
		.117		25"										
4	Auburn & Piedmont		6-04-10"		12"	25"				2		27	3.46	29.7
		.125		29"										
5	Auburn & Butler		6-05-16"		3"	0					1	26	3.87	10.4
		.140		21"										
6	Auburn & Fort		6-05-40"		6"	20"		10"	CAR	1		27	2.32	29.7
		.098		30"										
7	Auburn & Hilliard		6-06-46"		7"	0				1		28	1.96	11.2
		.070		17"										
8	Auburn & Yonge		6-07-10"		6"	0				1		29	7.86	46.4
		.089		16"										
9	Auburn & Jackson				0	21"								
		.135		25"										
10	Auburn & Boulevard				0	6"								
		.067		22"										
11	Blvd. & Edgewood		6-08-46"		6"	16"				1		30	4.02	27.0
		.134		32"										
12	Edgewood & Howell		6-09-40"		14"	0				2	2	30	3.84	15.0
		.130		16"										
13	Edgewood & Randolph		6-10-10"		13"	23"				2	1	31	6.08	34.1
		.186		30"										
14	Edgewood & Krog		6-11-16"		3"	0					1	30	5.70	21.0
		.079		19"										
15	Edgewood & Waddell				0	0				1		31	19.13	77.5
		.120		20"										
16	Edgewood & Spruce		6-11-58"		6"	0								
		.095		22"										
17	Edgewood & Delta				0	0								
		.102		21"										
18	Edgewood & Waverly Wy.				0	0								
		.117		22"										
19	Edgewood & Elizabeth				0	0								
		.130		27"										
20	Hurt & DeKalb				0	0								
		.087		25"										
21	DeKalb & Battery				0	0								
		.077		20"										
22	DeKalb & Degress		6-14-28"		7"	0				1	5	27		

FIGURE 11.

FIELD SHEET

BUS OPERATION STUDY

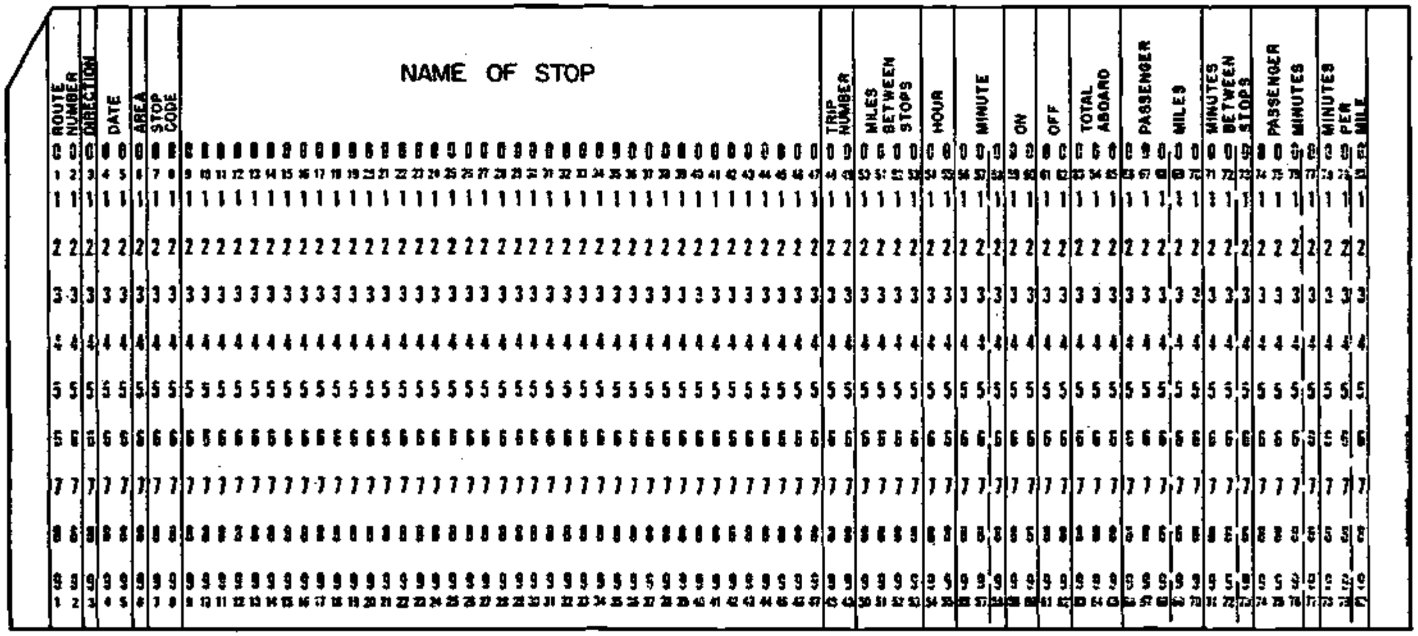

FIGURE 12.
IBM LAYOUT CARD FOR
BUS OPERATION STUDY

BIBLIOGRAPHY

LITERATURE CITED

1. "Statistics Show Ten Year Trends in Passenger Travel," Mass Transportation, Vol. 54, No. 1, January 1958, p. 16.

2. "A Framework for Urban Studies," Highway Research Board Special Report 52, October, 1959.

3. Anderson, George W., "Urban Mass Transportation." The Traffic Quarterly, Vol. X, No. 2, April 1956, p. 194.

4. Highway Capacity Manual, U. S. Government Printing Offices, Washington, D. C., 1950, pp. 66-104.

5. Manual of Traffic Engineering Studies, 2nd ed. New York: Association of Casualty and Surety Co., 1953, Study 7, p. 46.

6. Traffic Engineering Handbook, 2nd ed., Connecticut: Institute of Traffic Engineers, 1950, p. 155.

7. Anderson, op. cit., p. 203.

8. "Atlanta's Successful New Bus Lane," Mass Transportation, Vol 54, No. 4, April 1958, p. 11.

9. Sexton, Burton H., "Transit Traffic Engineering." The Traffic Quarterly, Vol VI, No. 1, January 1952, p. 87.

OTHER REFERENCES

1. "Atlanta Says No to Diversification," Mass Transportation, Vol. 53, No. 7, July 1957, p. 24.

2. Baine, John C., "The Importance of Transit to the Downtown Business Section," Mass Transportation, Vol. 50, No. 4, April 1954, p. 35.

3. Bauer, John and Costello, Peter, Transit Modernization and Street Traffic Control: Chicago: Public Administration Service, 1950.

4. Burnell, John B., "Urban Passenger Transport-Problems, Palliatives, Cures," Journal of the Institute of Transport, Vol. 26, No. 9, March 1956, pp 309-317.

5. "Crisis in City Transit," Architectural Forum, Vol. 106, No. 6, June 1957, pp 108-115.

6. Davis, Harmer E., The Urban Transportation -- What Approach?: Berkeley: University of California, Institute of Transportation and Traffic Engineering, 1952.

7. Davis, Harmer E., Urban Transportation -- Service of Chaos?: Berkeley: University of California, Institute of Transportation and Traffic Engineering, 1953.

8. Davis, Harmer E. and Kennedy, Norman, Urban and Interurban Problems of Mass Transportation: Berkeley: University of California, Institute of Transportation and Traffic Engineering, 1952.

9. Davis, Harmer E. and Kennedy, Norman, Urban Mass Transportation; Some Characteristics and Problems: Berkeley: University of California, Institute of Transportation and Traffic Engineering, 1952.

10. DeLeuw, Charles E., Is Subsidy Necessary for Adequate Mass Transit?, N.Y.: American Society of Civil Engineers, 1955.

11. Ecker, John B., "Major Problems of Transit Operations Related to Traffic Engineering," Traffic Engineering, Vol. 22, No. 9, June 1952, p. 323.

12. Frieling, G. H., "Transit is Tied Up in Traffic," Traffic Engineering, Vol. 24, No. 12, September 1953, p. 467.

13. Gross, Ralph F., Urban Transportation Problems," Traffic Engineering, Vol.24, No. 3, December 1953, p. 87.

14. Hyde, D. C., "Does Urban Transit Have a Future?" Proceedings, Institute of Traffic Engineers, 25th, 1955, pp. 114-123.

15. Kearns, E. E., "Recognizing and Realistically Planning for Large City Transportation Growth," Traffic Engineering, Vol. 27, No. 3, December 1956, pp 122-126, 151.

16. Morris, Harold G., "The Traffic Engineer and Transit," Traffic Engineering, Vol.25, No. 6, March 1955, p. 225.

17. "Nashville Reserves a Separate Lane for Buses," Mass Transportation, Vol. 52, No. 2, February 1956, p. 30.

18. National Committee on Urban Transportation, Measuring Transit Service, Chicago, Public Administration Service, 1958. (Procedure Manual 4A).

19. Rainville, W. S., Jr., "Transit - The Traffic Engineer's Opportunity," Traffic Engineering, Vol.28, No. 9, June 1958, pp 15-19, 39.

20. "Reserved Transit Lanes," Traffic Engineering, Vol.29, No. 10, July 1959, pp. 37-40.

21. Rossell, W. T. and Gaul, David Q., "Rapid Transit's Value to a City," The Traffic Quarterly, Vol. X, No. 1, January 1956, p. 106.

22. Schroeder, Werner W., Metropolitan Transit Research: Chicago: Chicago Transit Board, 1957.

23. "Sick Transit: The City's No. 1 Problem," Architectural Forum, Vol. 110, No. 1, January 1959, pp 118-122.

24. Simpson and Curtin, A Plan for Transit Improvement in the Metropolitan Area of Atlanta, Georgia, Philadelphia, 1953.

25. Smith, R. Gilman, "The Urban Traffic Problem and the Automobile Commuter," Mass Transportation, Vol.51, No. 9, September 1955, p. 48.

26. "The Trend of Transit Riding - 1907 to 1953," Mass Transportation, Vol. 50, No. 1, January 1954, p. 98.