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An analysis of the passenger vehicle interface of street transit systems with applications to design optimization

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AN ANALYSIS OF THE PASSENGER VEHICLE INTERFACE OF STREET TRANSIT SYSTEMS WITH APPLICATIONS TO DESIGN OPTIMIZATION

BY

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A DISSERTATION
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APPROVAL OF DISSERTATION

AN ANALYSIS OF
THE PASSENGER VEHICLE INTERFACE
OF STREET TRANSIT SYSTEMS WITH
APPLICATIONS TO DESIGN OPTIMIZATION

FOR

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
NEW JERSEY INSTITUTE OF TECHNOLOGY

BY

FACULTY COMMITTEE

APPROVED: ______________________________

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ABSTRACT

This research analyzes the Passenger Vehicle Interface of the street transit systems and presents applications for design optimization. The Passenger Vehicle Interface (PVI) is defined as the interaction between the passenger and vehicle elements of the street transit system.

Human observer and photographic studies were conducted in 17 cities in the United States and Canada to measure the time for queues of passengers to board various transit vehicles. The data were analyzed by considering seven factors that affect the Passenger Vehicle Interface: Human Factor, Modal Factor, Operating Practices, Operating Policies, Mobility, Climate and Weather, and Other System Elements. Those effects which could be quantified were divided into the categories of direction of flow, method of fare collection, and door characteristics and use. A series of equations for each of these categories was developed to predict passenger service time when the number of alighting or boarding passengers is known or estimated. A range of values was developed for the parameters of each equation to reflect the effects of unquantifiable factors such as the type of passenger, physical characteristics of the passenger, passenger preferences, baggage carried, seating configuration, and congestion. The use of Passenger Influence Zones has indicated that passenger service time can range from approximately six to 14 percent of total trip time, depending upon vehicle type, door use, and method of fare collection. These zones have also been used to indicate how vehicle door use and characteristics can increase berth requirements by up to 200 percent, and how different methods of fare collection can increase berth productivity in terms of passengers per hour by 87 percent.

Distributions of passenger service times through the vehicle doors were identified based on the analysis of photographic studies and determined to be represented by an Erlang function. The analysis also inferred that the K value in the Erlang function is equal to the number of doors on the vehicle and that the minimum service time is approximately equal to half the average service time. The validity of the Erlang functions was determined by using the special purpose simulation programming language, GPSS, and the Erlang functions to estimate the time requirements for queues of passengers to board vehicles. The simulated times were compared with observed times, and the differences were found to be not statistically significant at the 95 percent level.

A GPSS model was used to simulate the operations of a street transit loading area and to evaluate the effects of method of fare collection upon queue length and average waiting time under varying rates of passenger arrivals.

This research provides sufficient information to perform suboptimizations of several operations within the Passenger Vehicle Interface. Although not directed toward an optimization of street transit systems, it does provide the necessary information about the Passenger Vehicle Interface for others to perform this optimization after they have assembled comparable information on system elements and other interactions.

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CHAPTER I

INTRODUCTION

1.1 Study Objective

The objective of this research is to analyze the Passenger Vehicle Interface of street transit systems and to structure a framework of the Passenger Vehicle Interface as it relates to street transit systems. This objective was accomplished by evaluating the Passenger Vehicle Interface and quantifying passenger service time as a measure of the Passenger Vehicle Interface.

Street transit systems have played an important role in the development of our cities and they continue to do so, being the only form of mass transit in many areas. In recent years, patronage has been declining and operating deficits have been increasing. Federal programs are attempting to reverse these trends by improving service and efficiency of operation. However, before a system can be improved, its elements and the interaction among elements must be understood.

A street transit system can be defined as being comprised of five elements: vehicle, operating, line haul, passenger, and terminal. The Passenger Vehicle Interface is the interaction between the passenger and vehicle elements and, as described herein, can significantly affect the operations of street transit systems. These effects were determined quantitatively by evaluating passenger service time as a measure of

Passenger Vehicle Interface, and qualitatively by describing the direction of the effects where they cannot be quantified.

Human observer surveys and photographic studies were taken of passenger service times in seventeen cities in the U.S.A. and Canada. These indicated that passenger service time could be predicted by a multiple regression equation if the number of boarding and alighting passengers were known. The analysis also indicated that the method of fare collection, number of doors used, the direction of passenger flow, and the presence of standees had quantifiable effects on passenger service time. Qualitative factors were also observed, such as orientation of passengers with the system, physical characteristics of the passenger, amount of baggage carried, seating configuration and weather. All factors were considered in the development of Passenger Service Time Influence Zones, which can be used to predict passenger service time if the number of alighting and boarding passengers are known.

Passenger service rates through the bus door were investigated using the results of photographic studies taken in Montreal, Canada; New Brunswick, New Jersey; and San Diego, California. Based on this analysis, it was determined that these characteristics can be represented by an Erlang function.

A comparison between the service time studies and multiple regression studies was made using the special-purpose simulation programming language GPSS (General Purpose Simulation System).(1) The analysis accepted the hypothesis that the regression equations developed by simulation were the same as those obtained by field observation. Therefore, two tools were developed to evaluate the effects of passenger service times-- Multiple Regression Equations and Service Time Distributions. Both of these were used to indicate the quantifiable effects of passenger service time on the operations of street transit systems, and they provided a framework to analyze the Passenger Vehicle Interface.

1.2 Importance of Research

In order to operate a street transit system or to improve its service, it is necessary to understand the various system components and the interaction among components. This research analyzes the interaction between passengers and vehicles which has been termed the Passenger Vehicle Interface (PVI). Changes in PVI can have significant effects on the operations of street transit systems in many ways. Reliability of service is contingent upon operating dependable vehicles according to realistic schedules. Realistic schedules are developed by considering delay time, running time, layover time and the time required for passenger service. Passenger service time as a measure of PVI has been shown to account for 15 to 25 percent of total travel time and 50 to 80 percent of total delay time.

Any decrease in the variability of passenger service time or improved methods for its prediction will assist in the development of more realistic transit schedules. An example is contained herein that shows how passenger service time can range from 6.4 to 13.6 percent of total trip time depending upon vehicle type, door use, and method of fare collection.

The design of terminal facilities is also influenced by PVI, since the amount of platform space and the number of vehicle berths are contingent on the time required to load and unload passengers. These design considerations often govern the acceptability of a particular site, the layout of a proposed terminal, and the cost of such facilities. In the downtown areas of many cities (prime locations for terminals), space for transit facilities is severely limited. Miscalculating the number of loading berths or required platform space can result in using too much valuable land or cause inefficiencies in facility operations. Examples are contained herein that indicate 1) how vehicle door use and characteristics can increase berth requirements by up to 200 percent and 2) how different methods of fare collection can increase berth productivity, in terms of passengers per hour, by 87 percent.

This research is not directed toward an optimization of street transit systems, but it does provide the necessary information about PVI for others to perform the optimization after they have assembled comparable information on system elements and other interactions. Furthermore, it provides sufficient information to perform a sub-optimization of PVI.

1.3 Background of Research

1.3.1 The Importance of Street Transit Systems

Street transit systems have been and still are an important segment of the urban transportation network. They have exerted a positive influence on the way in which many cities developed, and that influence confronts us daily.(2)

In 1972, the American Transit Association estimated that of the 6.6 billion passengers carried on transit lines in the United States, 74 percent or 4.9 billion were carried on street transit systems. The greatest number of passengers used motor bus, as shown in Table 1.

TABLE 1

Total Passengers Carried on Street Transit Lines of the United States in 1972(3)

Mode	Number of Passengers (Millions)	Percent of Total
Surface Railway (Trolley)	211	4.3
Trolley Coach	144	3.0
Motor Bus	4,505	92.7
Total	4,860	100.0

It can be expected that the proportion of bus passengers will increase in the future due to increased bus usage brought about by the present focus of programs by the Urban Mass Transportation Administration of the U.S. Department of Transportation.(4) Furthermore, the Highway Users Federation estimates that there are at least 15,000 communities where buses are the only available means of public ground transportation. Even in cities with rail systems, 50 to 70 percent of public transportation travel is by bus.(5)

Many riders presently using street transit include the transportation disadvantaged (i.e., poor, elderly, young and handicapped) and are captive riders without available alternative modes of transportation. The California Department of Transportation has estimated the number of transit dependents (i.e., poor, elderly, and handicapped under 65) to be 2.5 million persons out of a 1975 statewide population of 21.1 million.(6) For this estimate a transit-dependent person was defined as one who made most of his trips by public transportation because he has no access to an automobile as a driver or a passenger (including taxis and carpools) for those trips made by transit.

1.3.2 The Need for Improved Service

Having continually lost other riders for several reasons, many bus systems are used primarily by a large portion of captive riders. The main reason transit has lost much of its past market has been the inability of traditional systems to provide a service comparable in speed, quality, availability and dependability with that of the private car.(7) Improvements have been made to elements of the system in hopes of improving service. In the case of bus transit, these have included giving buses preferential treatment and improving general traffic flow. By improving the flow of buses the public benefits in two ways:

1. As bus transit becomes more efficient, it should become more attractive, thus tending to reduce the number of private vehicles in the traffic stream.

2. The increased efficiency holds down transit operating costs, and thus lessens the need for fare increases or subsidy.(8)

Studies have shown that other time-related efficiencies can be made with the optimum location and organization of bus stops.(9) It has also been expressed that better vehicle design and more efficient fare collection systems would expedite loading and unloading and help to reduce travel time.(10) A proponent for no-fare transit has observed that bus drivers without fares or fare boxes are free to concentrate solely on driving, and passenger mobility in entering and leaving a vehicle is greatly increased. The results are shorter stops, faster runs, and more frequent service.(11)

The optimization of street transit systems in the past has dealt only with the optimization of some of the system elements. This was due to the difficulty in understanding the elements and their interaction with other elements. It was also difficult in many cases to determine which function to optimize. An optimization of operator's costs to maximize profits will not optimize service to the passenger. The Road Research Group of the Organisation for Economic Cooperation and Development concluded that optimization should be based on minimizing total community rather than operator's costs.(12) They also stated that research is needed to provide operators with all the information on a range of presently used passenger-handling systems and some possible new areas, to enable them to decide which systems suit their needs the best.

In consideration of these stated needs for improved service this research was undertaken to study the Passenger Vehicle Interface of street transit systems and to provide a framework to include it in system optimization.

1.3.3 Previous Research on the Passenger Vehicle Interface

Other studies of the Passenger Vehicle Interface have been performed, with the first appearing in an article entitled, "Geometric Design of Loading Platforms and Bus Runways for Local and Suburban Bus Terminals" in the January 1958 issue of Traffic Engineering Magazine.(13) It contained statistics on passenger headways for boarding and alighting patrons considering the amount of fare collected and the amount of baggage carried. This same information was repeated in the Highway Capacity Manual(14) and the Traffic Engineering Handbook.(15) Donald P. Downes, in a study of bus travel time in Newark, New Jersey, in 1959, determined the loading rates for Public Service Coordinated Transport buses with either a pay-leave, pay-enter, or fare receipt method of fare collection.(16)

Eugene J. Lessieu, in his article on bus terminal planning and design, stated that loading times can be "calculated on a unit time basis such as three seconds per passenger with a fare box, and six seconds per passenger with a fare register operation".(17) In 1968 and 1969, Thomas J. Boardman and Walter H. Kraft, while preparing NCHRP Report 113, "Optimizing Flow on Existing Street Networks"(9) determined that the time required to serve bus patrons at a stop could be predicted if adequate knowledge of the number of passengers boarding and/or alighting were available. The method of least squares was used to predict passenger service time for the three distinct situations: 1) when passengers were boarding, 2) when passengers were alighting, and 3) when passengers were simultaneously boarding and alighting. Equations were developed for two methods of fare collection (i.e., the cash and change system and the exact fare system.)(18)(19)

Stop time characteristics of a variety of one- and two-man operated bus types in the United Kingdom were studied by Cundill and Watts.(20) They recorded passenger service time measurements and developed equations to predict average stop time for a given number of passengers boarding and/or alighting, considering different bus types and methods of operation. Radelat,(21) during his preparation of a simulation model of urban bus operations in Washington, D.C., developed regression equations to predict passenger service time.

Other predictive regression equations were prepared by members of the Road Research Group for London, Toronto, Copenhagen, Dublin, Bordeaux, Toulouse and Paris.(12) The most recent work was done by Bergen and Kraft with their evaluation of passenger service time for buses, trolleys and trolley buses in ten cities in the United States.(22) They determined that the most significant factors affecting passenger service time were time of day, type of service, type of vehicle, method of fare collection, and type of passenger.

The aforementioned studies have dealt mainly with the quantitative aspects of PVI in terms of average passenger headways and passenger service times. Usually, they have been limited in scope and have not provided a comprehensive framework to include PVI in the optimization of street transit systems. The studies involving measurements of time per passenger used average values and did not consider the distributions of these values. Although the studies of passenger service time indicated the predictability of time under certain conditions, there still are other areas which should be investigated such as the effects of door characteristics and use, standees, type of passenger, type of service, type of vehicle, and methods of fare collection. Therefore, the results of these studies have been used as a basis from which this research proceeded by gathering and analyzing additional data to provide a comprehensive framework of PVI incorporating both quantitative and qualitative factors.

1.4 Passenger Service Time as a Measure of the Passenger Vehicle Interface

The performance of a system can be evaluated by comparing measures of effectiveness (MOE) for various system states. For the Passenger Vehicle Interface, passenger service time is a good measure of effectiveness since it is a quantity that can be easily and accurately measured. Generally, passenger service time can be defined as that time required for the boarding and alighting of passengers. Specifically for this research, passenger service time is defined as that time measured from the moment the street transit vehicle stopped and the door(s) opened until the last passenger in the initial queue alighted or boarded the vehicle.

Qualitatively, the influence of passenger service time on a person's trip can be illustrated by the following example. A typical trip from home to work by bus can be divided into the six parts shown in Table 2.

TABLE 2

Parts of a Typical Trip by Bus

Part	Action
1	walk to bus stop
2	wait for bus
3	board bus
4	ride bus
5	alight from bus
6	walk to destination

The time required for Parts 2 through 5 is partially dependent upon passenger service time.

Travel time of a bus on any particular route can be divided into the three categories of running time, traffic delay time and passenger service time. Running time is that time during which the bus moves without delay, at its normal operating speed. Traffic delay time includes time associated with traffic control devices, interactions with other vehicles or pedestrians, etc. Passenger service time has been defined above. In Parts 3 and 5 of Table 2, passenger service time is a direct measure of time required to perform the action; while during Parts 2 and 4, it represents a portion of the time. From this example it is obvious that passenger service time may represent a large portion of total trip time.

In 1958, the Providence, Rhode Island, Study Report indicated that passenger service time accounted for 17 to 26 percent of total travel time and 50 to 76 percent of total delay time.(23) Similar statistics were determined in 1959, during the conduct of the St. Louis Metropolitan Area Transportation Survey, as listed in Table 3.

TABLE 3

Classification of Transit Delays in 1959 for St. Louis Public Service(24)

Factor	Delay Time as % of Total Delay Time	Delay Time as % of Total Trip Time
Traffic Delays		
Traffic Signals	30.7	9.1
Stop Signs	1.9	0.6
Other Stops	7.2	2.1
Subtotal	39.8	11.8
Passenger Stops	60.2	17.9
Total	100.0	29.7

More recently, in 1970, the Los Angeles Department of Traffic, in its study of nearside and farside bus stops on Olympic Boulevard, found that with a) nearside bus stops, passenger service time accounted for 15 to 20 percent of total travel time and 48 to 57 percent of curb time, and b) farside bus stops, passenger service time accounted for 16 to 20 percent of total travel time and 67 to 77 percent of curb time.(25)

In general, it can be concluded that passenger service time can account for 15 to 25 percent of total travel time and 50 to 80 percent of total delay time. Of course, the exact percentages for any particular route or system will be dependent upon the configuration of that system (i.e., number of stops, length of run, etc.). What is important is that passenger service time represents a substantial portion of both total trip time and total delay time. A minimization of this portion will contribute toward system optimization.

1.5 Research Approach

1.5.1 Data Collection

From the foregoing sections it can be seen that the Passenger Vehicle Interface can have a significant effect on the operations of street transit systems. Since a review of previous research indicated a lack of information on the distribution of individual passenger service times and on the effects of factors affecting PVI such as method of fare collection, type of vehicle, time of day, type of passenger, and type of service, field surveys were conducted in seventeen cities in the U.S.A. and Canada. Techniques used for gathering data included manual counts and 8mm photographic studies (see Appendix A1). The survey locations were selected and data were gathered to provide information which could be used to quantify major effects.

Both the manual and photographic methods of data collection measured the time for passengers to pass through the door of a vehicle. The manual counts were used to measure the length of time for an entire queue to pass through the door; while the photographic studies were used to measure individual passenger service times.

The manual counts had the advantage of being simple to take, required only a stopwatch, clipboard, paper and pencil, could be done by one person, and involved little or no data summary. For single-door observations, one enumerator was sufficient; for coordinated two-door observations, two enumerators were necessary. A detailed description of the survey procedure is contained in Appendix A1. The data obtained by the manual counts were limited to the information observed and recorded by the enumerator, usually the number of people in the queue and total passenger service time.

The photographic studies were performed using a super 8mm movie camera operating at a nominal speed of 18 frames per second (see Appendix A1). These studies had the advantage of recording various passenger characteristics such as sex, amount and type of baggage carried, handicaps, and individual passenger service times. They also provided a permanent record that could be viewed again at any time. Disadvantages of the photographic studies included the need for proper light conditions and an advantageous viewing angle, increased cost, and increased data reduction requirements.

Both types of surveys were generally taken from curbside, although a limited number of manual counts for an analysis of the affect of standees were taken on-board buses.

The curbside surveys were conducted without interference to the flow of passengers at locations of high passenger activity. In this way, a large number of observations over a wide range of passenger service times were obtained. It is doubtful whether similar information could have been obtained by on-board surveys since 1) on-board crowding could block an enumerator's view and restrict coordination between front door and back door enumerators, 2) many more observations would be required to obtain similar data over the same range of values, and 3) photographic studies of passenger flows through the door would not be practical and would probably have interfered with passenger movements.

The survey methods used for this research provided sufficient data to analyze the effects of passenger service time on the operations of street transit systems.

1.5.2 Statistical Analysis

The analysis of survey data was performed using a number of statistical techniques. Previous research by the author indicated that if the number of passengers alighting and boarding were known, multiple regression analysis could be used to predict passenger service time by using the following model:(9)(19)(22)

$$T = a + b_1 X_1 + b_2 X_2 - b_3 (X_1 . X_2)$$

where

T = Passenger Service Time in Seconds
X_1 = Number of Alighting Passengers
X_2 = Number of Boarding Passengers
a = Constant
b_i = Coefficient

In this research the above model was used to develop an equation for each of the data sets obtained from the manual surveys. The following steps were taken to assist in analyzing the appropriateness of the regression model.

1. Residuals (differences between the observed and predicted values of passenger service time) were plotted against the dependent and independent variable to determine if the model was appropriately structured and if the variances were equal. The independent variables were transformed using a square root or logarithmic function where residuals were proportional to the dependent variable.
2. The coefficient of determination, R^2, was used as a measure of the amount of variability that was explained by the regression model.
3. An *F* test was used to test statistical significance of the regression of the dependent variable on the independent variable.

4. The standard error of estimate, S_E, was used as a measure of the variability of the residuals. It was also compared with the mean response as a percentage.
5. A *t* test was used to test if each of the b_i's were statistically different from zero.

After all of these steps were completed and satisfactory results were indicated, the regression model was accepted. The regression models were then compared to determine if they were statistically different, using an *F* test for comparison of the variances of estimate and a *t* test for comparison of slopes. All test statistics were compared with tabular values at the 95 percent level, a common procedure documented in accepted references on statistical analysis.(26)(27)(28)(29)

Multiple regression techniques with dummy variables were used to analyze some photographic studies where the dependent variable represented time per passenger and the independent variables represented the number of alighting and boarding passengers, the percentage of women, and the amount of baggage carried. In each case, the above five steps were checked to determine the appropriateness of the model. As would be expected with counting data, the residuals were proportional to the mean responses, and a logarithmic transformation was used to obtain homogeneity of variance.

The analysis of variance (ANOVA) technique was used to determine differences in time per passenger for both manual and photographic data. Again, a logarithmic transformation was used to obtain homogeneity of variance. An F test at the 95 percent level was used to determine the statistical significance of the major and interaction effects. Tukey's limits for multiple comparison at the five percent level were used to determine if differences between individual cell means were statistically significant.(30)

The results of the statistical analysis provided a framework from which the quantifiable effects of PVI on the operations of street transit systems were determined and inferences were made concerning the unquantifiable effects. These are portrayed in a series of Passenger Service Time Influence Zones.

1.5.3 Service Time Distribution Analysis

Summarized data from the photographic studies include the individual service times for each person to pass through the vehicle door. These times were tabulated and service time distributions were determined. The functions which could be used to represent these distributions were not known.

In the development of queuing models several types of service time distributions have been used, including the Gamma function, the Erlang function and the uniform distribution function. The one most commonly used is the negative exponential function, a special case of the Erlang function.(31)(32)(33) Consequently an Erlang distribution was developed for each service time distribution using the actual mean and variance of each distribution. The general form of the Erlang function used is as follows:

$$P\ (g \geq t) = \sum_{i=o}^{K-1} \left[\frac{K\ (t - \tau)}{(\bar{t} - \tau)}\right]^{i} \frac{e}{i!}^{-\frac{K\ (t - \tau)}{(\bar{t} - \tau)}}$$

where

K = a positive integer

t = any service time

$\bar{t}$ = average service time

τ = minimum service time

$P(g \geq t)$ = probability that time "g" is greater than or equal to time "t"

The actual distributions were compared with the Erlang distributions using a chi square test. In all cases, it was determined that the differences between the actual and Erlang distributions were not statistically significant at the 95 percent level.

1.5.4 Model Simulation

Model simulation was done by using the special-purpose simulation programming language GPSS (General Purpose Simulation System) because of its special features for reproducing the dynamic behavior of systems which operate in time, and in which changes of state occur at discrete points in time.(1) Prior programming experience is not necessary and programming convenience is offered by the many tasks which are automatically accomplished such as printing out data summaries at the end of a simulation.

GPSS was used in a test to determine the validity of the derived Erlang distributions. This was done by developing a simulation model of a bus stop where queues of varying lengths were waiting to board or alight from a bus according to the derived Erlang distributions. The output of the model, consisting of the total time for each queue to pass through the bus door, was used to develop a derived multiple regression equation for each condition. The derived equations were compared with equations developed from observed data by using an F test for the standard errors of estimate and a t test for the slopes. All F tests and four out of five t tests indicated that the differences were not statistically significant at the 95 percent level. The fifth t test indicated that the difference was not statistically significant at the 98 percent level.

GPSS was also used to develop a model of a typical boarding platform in a bus terminal. This was used to investigate the effects of method of fare collection and presence of standees upon queue length and average waiting time under varying rates of passenger arrivals.

1.5.5 Summary

The approach used for this research consisted of reviewing previous research, assessing data needs, conducting surveys, performing analyses, and developing conclusions. Two types of surveys were conducted in seventeen cities in the U.S.A. and Canada. These consisted of manual counts used to measure the length of time for an entire queue to pass through the door of a bus and photographic studies used to measure individual passenger service times. The survey results were analyzed using various statistical techniques, including multiple regression analysis and analysis of variance. As would be expected with counting data, the variances were proportional to the mean responses, and the data was transformed to obtain homogeneity of variance. Information obtained from the statistical analysis was used to develop a series of Passenger Service Time Influence Zones which can be used to estimate passenger service time if the number of alighting and boarding passengers are known.

Individual passenger service time distributions obtained from the photographic studies were analyzed and found to follow an Erlang distribution. A special-purpose simulation programming language (GPSS) was used to develop a model to determine the validity of the derived Erlang distributions. The derived distributions were compared with the observed distributions, and it was determined that the distributions were the same. GPSS was also used to develop a model of passenger activity at a boarding platform.

CHAPTER II

STREET TRANSIT SYSTEMS

Before the interaction between two system elements can be analyzed, it is necessary that the system be described. This will be done by briefly reviewing the history of street transit systems and then developing a conceptual system model.

2.1 History of Street Transit Systems

The history of street transit systems is closely related to the development of each of the system elements described in Section 2.3.1 Elements. Since the vehicle has been the most visible and the most predominant element, it will be the focus of the following brief history.

The earliest type of street transit vehicle was the omnibus, a horsedrawn wagon with seats to accommodate about 18 persons, that first appeared on the urban scene in 1827 in New York City(34) and in 1829 in London.(35) Other cities soon followed, with Philadelphia introducing service in 1831, Boston in 1835, and Baltimore in 1844.(36)

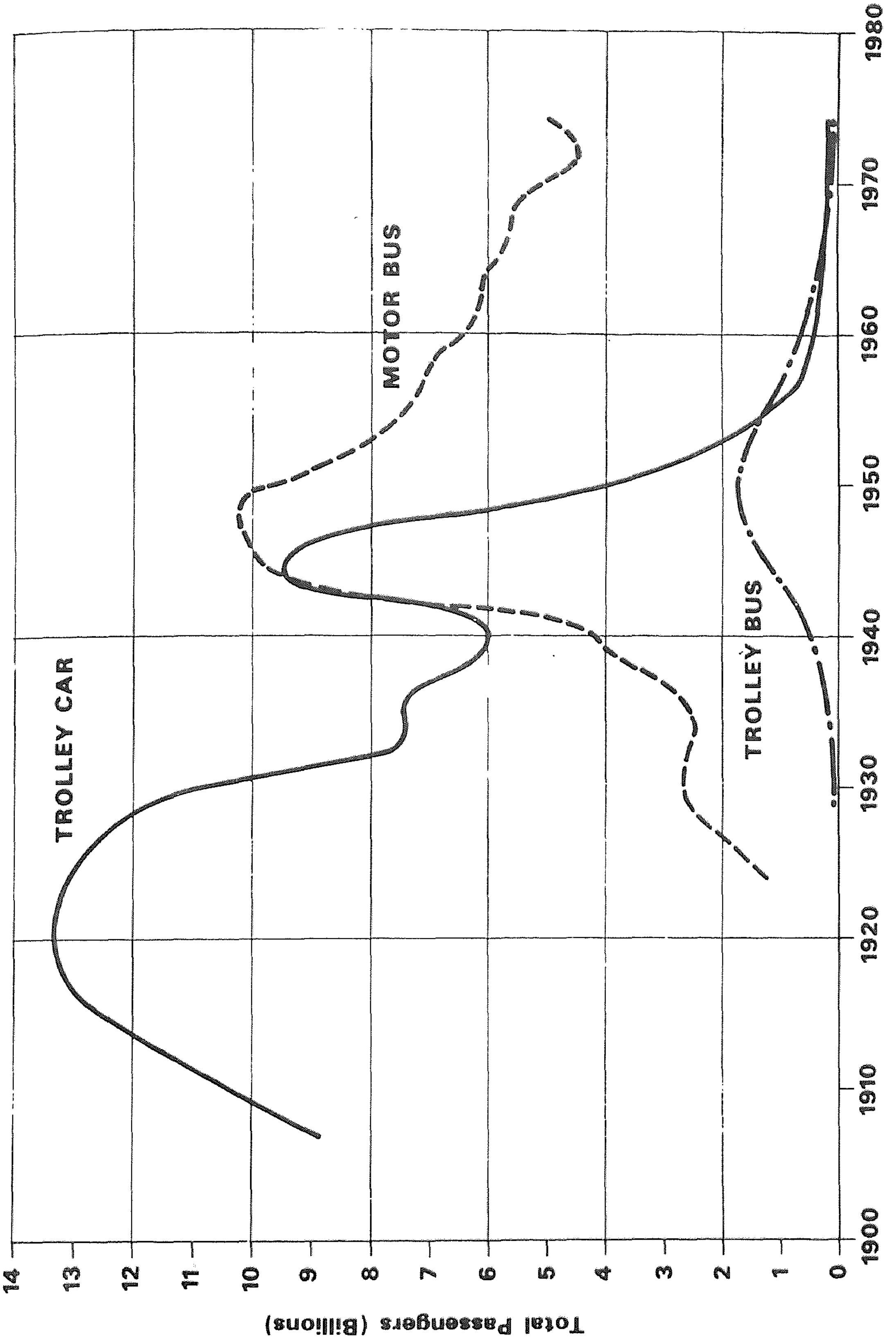
In 1832 horsecar service was started on Fourth Avenue in New York City.(34) This first form of street railway was an adaptation of the omnibus, with flanged wheels that traveled on steel rails laid in the middle of the street. The metal-on-metal contact permitted greater loads and higher speeds than was possible with the omnibus. As the popularity of the horsecar increased, so did its use. It was not unusual for cars with a seating capacity of 22 to carry 85 or 90.(34) Other present-day problems also concerned the horsecar traveler. A precaution suggested by one traveler:

> "Before boarding a car, prudent persons leave their purses and watches in the safe deposit company and carry bowie knives and derringers."(37)

The horsecar was quite popular and systems grew rapidly. By 1886, 100,000 horses and mules were in use on more than 500 street railways in over 300 cities in the United States.(34)

The cable car was the next form of street transit system to evolve. Service was initiated in San Francisco and soon spread to Chicago, Philadelphia, New York, St. Louis, Oakland, Denver, Kansas City, Washington, D.C., Seattle and Baltimore. By 1890 in the United States, 5,000 cars were in use on 500 miles of track carrying about 400 million passengers per year.(38) The relatively pollution-free cable car did not gain widespread popularity. Its high construction and maintenance costs limited its use to high transit demand areas and on streets where the operation of animal-drawn vehicles was impossible. San Francisco is presently the only U.S. city where cable cars are still in operation.

In 1880, Thomas Edison experimented with a small electric railway in Menlo Park, New Jersey, as an extension of experiments by Dr. Siemens in Berlin in 1879.(34) Not long after that, electric power replaced horse power and the electric streetcar or trolley was born. The trolley provided improved service and higher speeds, enabling home owners to live farther from the downtown business area. It provided the catalyst



Source: American Transit Association, Washington, D.C.

Figure 1 RIDERSHIP TRENDS IN THE U.S.

to urban expansion, and by the turn of the century over one million New Yorkers had resettled in outlying districts.(37) The trolley quickly became the primary mode of urban transportation, with its greatest use occurring around 1920 (see Figure 1). Presently, trolleys are still in use in Newark, San Francisco, Boston, Philadelphia, Cleveland, Fort Worth, Pittsburgh and New Orleans.

The motor bus was the next form of street transit to appear on the scene. New York was the first U.S. city to offer service with the operation of a 34-passenger double-deck bus on Fifth Avenue in 1905.(38) Bus transportation developed slowly. It was only after the pneumatic tire became available for large vehicles in 1916 and after the highway building boom of the 1920's that bus transportation increased in usage.(39) By the 1930's the motor bus was established as a significant form of transportation, but it took until the mid-1940's before it surpassed the trolley in total passengers carried (see Figure 1).

Around 1910, the trolley bus, a rubber-tired, electrically powered vehicle was developed. It never became very popular and reached its peak ridership around 1950 (see Figure 1). Presently, trolley bus systems are in operation in Boston, Philadelphia, San Francisco, Seattle and Dayton.

2.2 Present Street Transit Systems

In 1972, the American Transit Association reported that there were 1,045 transit systems in operation, as follows:

TABLE 4

Distribution of U.S Transit Systems in 1972$^{(3)}$

Type	Number
Rail Transit (including joint trolley bus and/or motor bus)	15
Trolley Bus and Motor Bus Operations Combined	2
Motor Bus Exclusively	1,028
Total	1,045

Of the above systems, 160 were publicly owned and carried 86 percent of all revenue passengers. It can be expected that public ownership will increase as operating expenses continue to increasingly exceed operating revenue. Increased efficiencies are therefore needed in the present trolley car, cable car, bus and trolley bus systems to minimize any deficits.

2.3 System Definition

It is first necessary to understand a system before its efficiency can be increased. To aid in this understanding a conceptual model of a street transit system was developed, which depicts its relationship to the community and the region (see Figure 2). The region can be thought of as a system comprised of a number of elements, one of which is the community. Likewise, the community can be defined as a system which contains the street transit system as an element. Each of the elements of a system have an effect on that system, and the system in

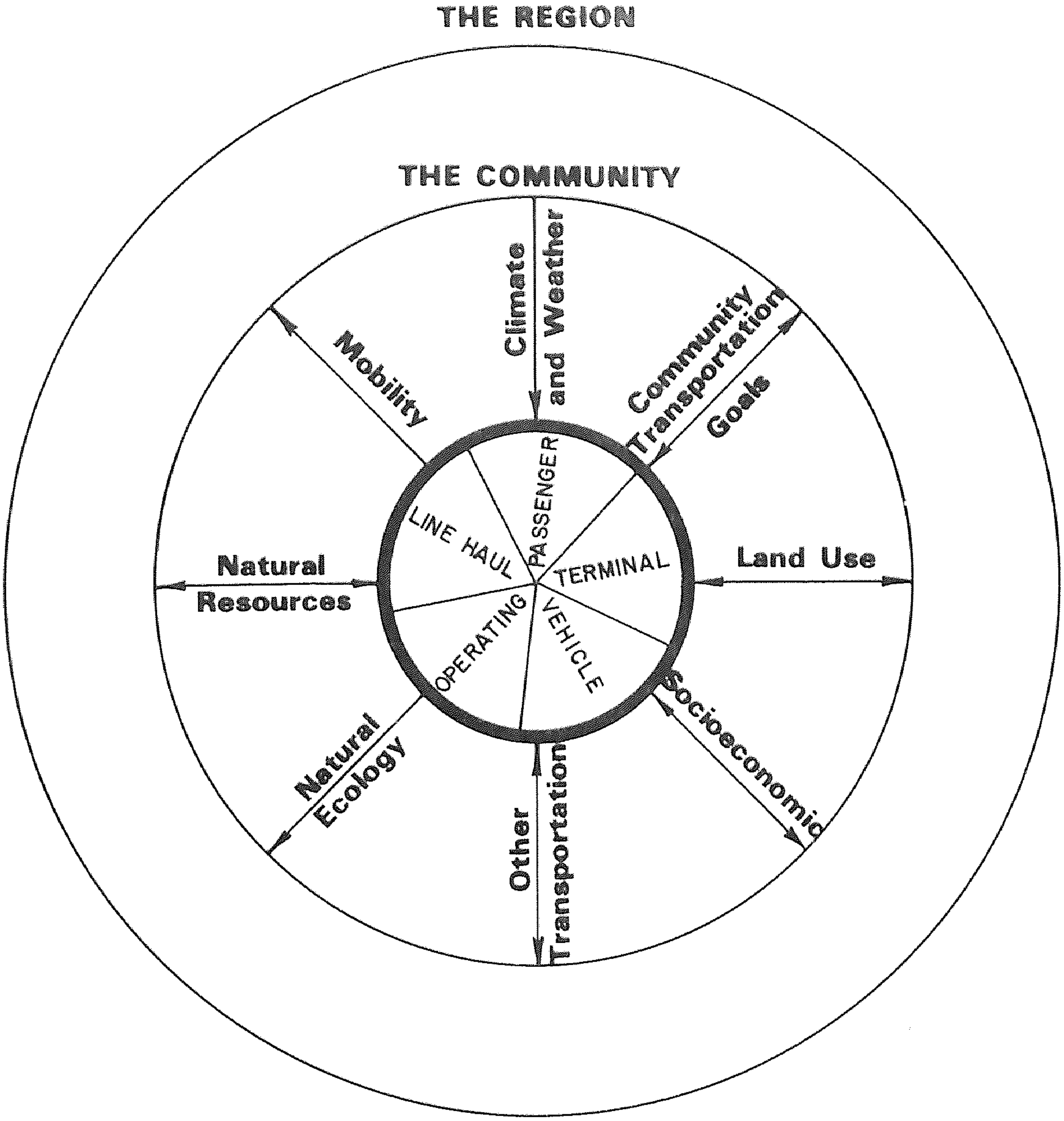


Figure 2 THE STREET TRANSIT SYSTEM

turn has an effect upon the larger system of which it is an element. In this way, an element of the street transit system can affect the region.

2.3.1 Elements

The street transit system shown in Figure 2 is divided into the five elements of passenger, terminal, vehicle, operating and line haul. The passenger element includes the physical and demand characteristics of the system's patrons. Physical characteristics consist of the sex, age, handicaps, etc., of the passenger; while demand characteristics consider the volume and time distribution of the user. The terminal element consists of the physical system providing for the transfer function. This could be a curbside platform or a multimodal facility. Figure A-9 in Appendix A5 contains pictures of the terminal element. The vehicle element consists of the physical characteristics of the vehicle, including operating characteristics, size, configuration, type, number of doors, etc. Figure A-10 in Appendix A5 contains pictures of various vehicles presently used in street transit systems. The operating element includes operating policies, schedules, hours of operations, maintenance, service areas, etc. It determines how the vehicles will be operated over the line haul element. The line haul element consists of the physical system of streets and traffic control devices over which the vehicle operates.

2.3.2 Environment

Each system has an environment consisting of that collection of systems, elements, and activities outside the system under study which affects and is affected by that system.(40) Figure 2 shows eight environmental systems affecting or being affected by the street transit system.

Community transportation goals both affect and are affected by a street transit system. Policies concerning vehicle replacement; maintenance of vehicles, terminals and line haul systems; fares; amount of subsidy; hours of operation; special equipment for the handicapped; etc., influence the street transit system. The system, in turn, influences community transportation goals by passenger opinion, method of operation, accidents and vehicle breakdowns. As was discussed at the beginning of this chapter, land use has affected and has been affected by street transit systems. In the past, the distance people could live from the downtown area was dependent upon the speed of the transit system and the distance a person could travel in approximately 30 minutes.(35) As speeds increased, urban areas spread. The spreading urban areas in turn permitted greater expansion of the transit system.

Socioeconomic conditions influence street transit systems by limiting the amount of fare that can be charged, dictating interior car design, restricting hours of operation, limiting service areas, and defining level of service. The transit system can, in turn, improve regional economy by providing semi-skilled employment. Other transportation systems both affect and are affected by street transit systems. Examples of this include the physical interaction of vehicles and the competition for funds. Transit systems have a definite effect on air, water, and noise pollution, on the life cycle of wild plants and animals, and on other aspects of natural ecology.

Natural resources are needed to build and operate a transit system. The types of resources available will have an effect on system configuration, its method of operation, and its cost to the passenger. The system, in turn, will use up natural resources in competition with other community or regional needs. The mobility of persons in the region will be affected by the street transit system. This is particularly true for the transportation disadvantaged (i.e., the poor, young, elderly, and handicapped). Their mobility is often limited to public transportation and transportation provided by others. Climate and weather affect the design, operation and maintenance of the transit system. For example, in cold climates, shelters must also serve a function as a wind breaker and may even be incorporated into buildings or internal circulation systems such as skyways.

2.4 Summary

An understanding of street transit systems is an important step in the analysis of the interaction between two system elements. As the brief history described, the omnibus that first appeared in New York City in 1827 was the earliest type of vehicle used for street transit service. This was followed by the horsecar, the cable car, the trolley, the motor bus and the trolley bus. The greatest passenger use occurred around 1920 with trolley service. At the present time, street transit vehicles consist of trolleys, cable cars, buses and trolley buses, with the predominant type of vehicle used being the bus.

A conceptual model of a street transit system was developed, consisting of five elements--passenger, terminal, vehicle, operating and line haul. The system environment consists of that collection of systems, elements, and activities outside the system under study which affects and is affected by that system. Eight environmental systems were identified--community transportation goals, land use, socioeconomic, other transportation, natural ecology, natural resources, mobility, and climate and weather. The history and description of system elements and environment as contained in this chapter, provide a basis for the analysis of the Passenger Vehicle Interface described in the next chapter.

CHAPTER III

THE PASSENGER VEHICLE INTERFACE

3.1 Definition

The Passenger Vehicle Interface is defined as the interaction between the passenger and vehicle elements of the street transit system. Its effects on the operations of street transit systems will be analyzed by evaluating changes to passenger service time caused by the factors affecting or being affected by PVI.

3.2 Factors Affecting the Passenger Vehicle Interface

For the purposes of this research and based on the author's judgment, the factors affecting or being affected by PVI have been divided into the seven categories shown in Figure 3. Each of these will be analyzed and the effects of each on PVI will be quantified where possible. Inferences will be made where the effects cannot be quantified. The effect of each of the factors on PVI, as measured by passenger service time, will have a similar effect upon the operations of street transit systems. For example, consider the following model of time for a typical street transit trip.

$$\text{Total Trip Time} = \text{Running Time} + \text{Delay Time} + \text{Passenger Service Time}$$

Assuming that running time and delay time remain the same, any change in passenger service time will have a concomitant change in total trip time. The relationship between the change in passenger service time and the total trip time will be reflected by the magnitude of

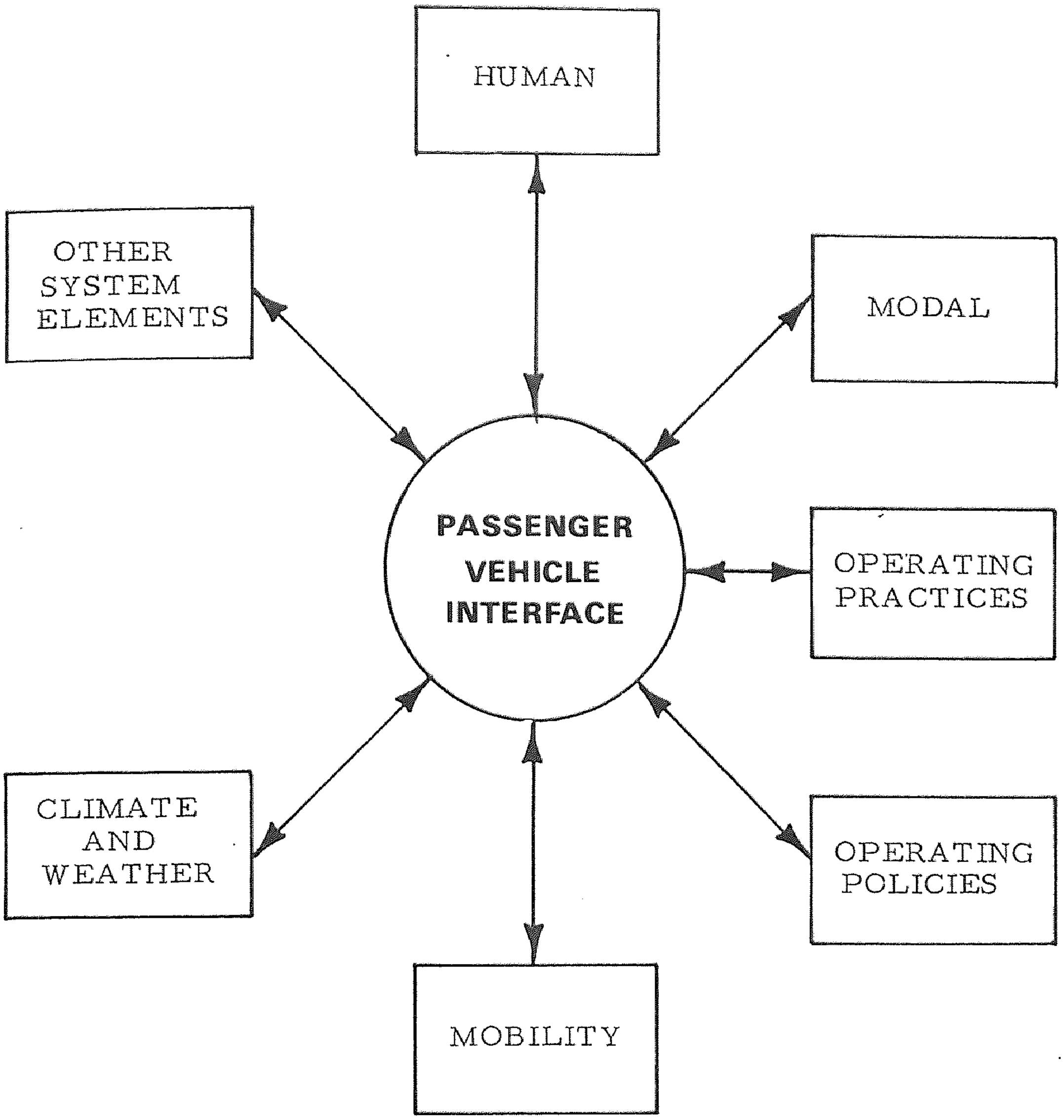


Figure 3 - FACTORS AFFECTING OR BEING AFFECTED BY THE PASSENGER VEHICLE INTERFACE

their relationship before a change is made. This relationship should be kept in mind while reading the remaining portions of this Chapter.

The approach used to determine the effects of each of the factors consisted of conducting manual surveys in seventeen cities in the United States and Canada and analyzing the data. The surveys, which are described in Appendix A1, provided information on the time for a queue of passengers to board the street transit vehicle. Photographic studies were also used to provide similar data. The data were analyzed using the procedures described in Chapter I, Section 1.5.2, Statistical Analysis. In most cases, an F test was used to compare the variances of estimate and a t test for comparison of slopes. In some cases, the multiple regression technique with dummy coding was used to analyze combined effects. All test statistics were compared with tabular values at the 95 percent level unless otherwise indicated.

3.2.1 Human Factor

The human factor consists of all characteristics of the passenger and can be divided into the five areas of type of passenger, physical attributes, passenger preferences, baggage carried, and passenger demand.

3.2.1.1 Type of Passenger - The type of passenger is an important consideration because the commuter, shopper and tourist exhibit different characteristics. These differences have been expressed as being due to time of day or day of week, but they are actually due to differences in passenger type. The author, in his study with Bergen, concluded that passenger service time requirements for morning and afternoon peak periods were similar and were less than those for off-peak (see Table 5).(22) During peak periods, the commuter is the predominant type of passenger, while during off-peak periods more shoppers and tourists use the system. For the equations shown in Table 5, the differences in the slopes of the equations for the AM and PM peak periods are not statistically significant at the 95 percent level for each direction of flow, while the slopes between midday and either the AM or PM periods are statistically significant at the 95 percent level. The variability of the data as measured by the standard error of estimate, S_E, exhibits similar characteristics except for the PM peak period of the boarding-only category. The increased variability of this category is probably due to the greater mix of passenger types and a wider range of observed queues.

The difference between peak and off-peak operations was also reported by a study of bus systems in the United Kingdom. It indicated an increase in time per passenger of up to 52 percent for off-peak operation.(20)

The effects of passenger type were also investigated by comparing passenger service times for weekdays and weekends. Table 6 contains information taken during the PM peak period at the Port Authority Bus Terminal in New York City on a Sunday and on two different weekdays. Both the time requirements and variability are greater for Sunday than for the weekday.

TABLE 5

Time of Day Characteristics for Local Buses with Exact Fare Method of Fare Collection(22)

Item	Alighting Only			Boarding Only		
	A.M. Peak	Midday	P.M. Peak	A.M. Peak	Midday	P.M. Peak
Equation	$T = 2.3 + 1.0A$	$T = 2.5 + 1.4A$	$T = 2.5 + 1.1A$	$T = 1.5 + 1.9BDF$	$T = 0.7 + 2.7BDF$	$T = 2.4 + 2.2BDF$
Range	$1 \leq A \leq 19$	$1 \leq A \leq 20$	$1 \leq A \leq 30$	$1 \leq BDF \leq 25$	$1 \leq BDF \leq 20$	$1 \leq BDF \leq 56$
n	170	119	66	50	94	257
R^2	0.68	0.62	0.85	0.94	0.89	0.90
S_E	2.39	3.42	2.73	2.41	3.95	6.41
$S_{E}/\bar{t}$	0.30	0.44	0.41	0.23	0.34	0.31
F Test	361.36	194.65	377.06	737.80	735.58	2392.85
F Statistic @ 95% Level	3.90	3.92	4.00	4.04	3.96	3.84

A = Number of Passengers Alighting

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 6

Day of Week Characteristics for Suburban Buses with a Cash and Change Method of Fare Collection During the P.M. Period at the Port Authority Bus Terminal in New York City

Item	Day Sunday	 Weekday
Equation	$T = 6.6 + 8.1BDF$	$T = 2.1 + 7.0BDF$
Range	$2 \leq BDF \leq 49$	$6 \leq BDF \leq 56$
n	13	25
R^2	0.93	0.92
S_E	39.44	27.96
$S_E/\bar{t}$	0.21	0.19
F Test	144.42	282.22
F Statistic @ 95% Level	4.84	4.28

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

Inherent with the type of passenger is his orientation. By observation, it was determined that the unoriented or confused passenger required more time to board and alight. This observation is quite logical when one considers that the commuter is well oriented with the system and the tourist is not. The shopper may be just as well oriented as the commuter but baggage may increase his passenger service time.

From the above, it is concluded that the degree of passenger orientation is inversely proportional to the amount and variability of passenger service time.

3.2.1.2 Physical Attributes - The physical attributes of the passengers include consideration of sex, age and handicaps. It has been observed by the author that old and handicapped people require higher than average boarding and alighting times. These observations have not been quantified because of the difficulty of categorizing age and handicaps and in obtaining sufficient data. Extreme values noted in the analysis of regression equations could not be determined as being due to age or handicaps because they may have been due to a lack of orientation and/or amount of baggage.

A survey conducted in Washington, D.C., indicated that 53 percent of the elderly and disabled sampled have at least some difficulties coping with the vertical movement aspects of bus boarding and exiting, and 24 percent of those sampled are totally unable to ride the bus because of these difficulties.(41) The survey report recommended a standard that "a passenger should be able to board a bus from either the street or a curb-side waiting area and not be required to propel himself through a vertical change of level greater than two inches." Presently, most buses require passengers to board using stairs. A few, such as the Flexette Coach manufactured by the Flexible Company of Londonville, Ohio, have a hydraulic lift that can be used by persons in wheelchairs.

No analytical differences were determined between the passenger service time requirements for men and women except for those described under Section 3.2.1.6, Combined Effects. However, it was determined that there were significant differences in the proportion of men and women using buses in Montreal, New Brunswick, and San Diego, as shown in Table 7.

TABLE 7

Sex of Bus Passengers during P.M. Peak Period
(Percent)

	City		
Sex	Montreal	New Brunswick	San Diego
Male	30	80	55
Female	70	20	45
Total	100	100	100

3.2.1.3 Passenger Preferences - Preferences of passengers concerning seat location and standing have an effect on PVI. Although no quantitative estimates can be given, passengers have been observed alighting against the flow of boarding passengers from the bus that they had just boarded when they found no seat available. Orderly queues have also been disrupted when passengers did not board because there was standing room only. The preference regarding seat location is less obvious. Many passengers have preferred seats that they use in a specific order. If their preferred seats are taken, it takes them longer to be seated and therefore contributes toward congestion inside the vehicle. The congestion, in turn, tends to increase passenger service time.

3.2.1.4 Baggage Carried - The amount of baggage carried directly affects PVI. This fact was first reported for alighting passengers in 1959 and is shown in Table 8. A similar effect was observed for boarding passengers.

TABLE 8

Effect of Baggage on Alighting Passengers(13)

Amount of Baggage	Time per Passenger (Seconds)
Very little hand baggage and parcels; few transfers	1 1/2 to 2 1/2
Moderate amount of hand baggage or many transfers	2 1/4 to 4
Considerable amount of baggage from racks	4 to 6

The amount of baggage carried is different for each area. Analysis of data for passengers in Montreal, New Brunswick, and San Diego indicated that the number of items carried was different for each city for both men and women. The items that were recorded included briefcase or bag, jacket or coat, newspapers, package, and umbrella. As would be expected, women carried more items than men, as listed in Table 9.

The type of passenger also has an effect on the number of items carried. In Montreal and New Brunswick a majority of passengers observed were white collar workers. They carried a greater number of items than the mixed variety of passengers observed in San Diego.

3.2.1.5 Passenger Demand - PVI has been shown to be directly influenced by passenger demand. Studies using regression analysis have produced equations and graphs for the estimation of time when the number of boarding and alighting passengers is known. Graphs developed for bus operations in Louisville, Kentucky, are shown in Figures 4 - 6. The use of these illustrations is best explained by example. Using Figure 4, suppose it is known or estimated that the average number of alighting passengers at one stop is 10 ($A = 10$); then the average passenger service time would be 13 seconds ($T = 13$). The 95 percent confidence intervals can be used in the following manner. One would expect to find 95 percent of the time that the mean service time for any particular number of alighting passengers is between the outer two lines. Using the previous example for $A = 10$, the maximum expected service time (outer limits) would be 19 seconds, while the minimum service time would be six seconds. However, if all buses were observed for a day at the same location and the average number of passengers

TABLE 9

Number of Items Carried by Bus Passengers

(Percent)

Sex	Number of Items Carried	City Montreal	 New Brunswick	 San Diego
Male	0	53	21	79
	1	44	59	20
	2+	3	20	1
	Total	100	100	100
Female	0	3	6	17
	1	66	52	66
	2+	31	42	17
	Total	100	100	100
Total	0	18	18	51
	1	59	58	41
	2+	23	24	8
	Total	100	100	100

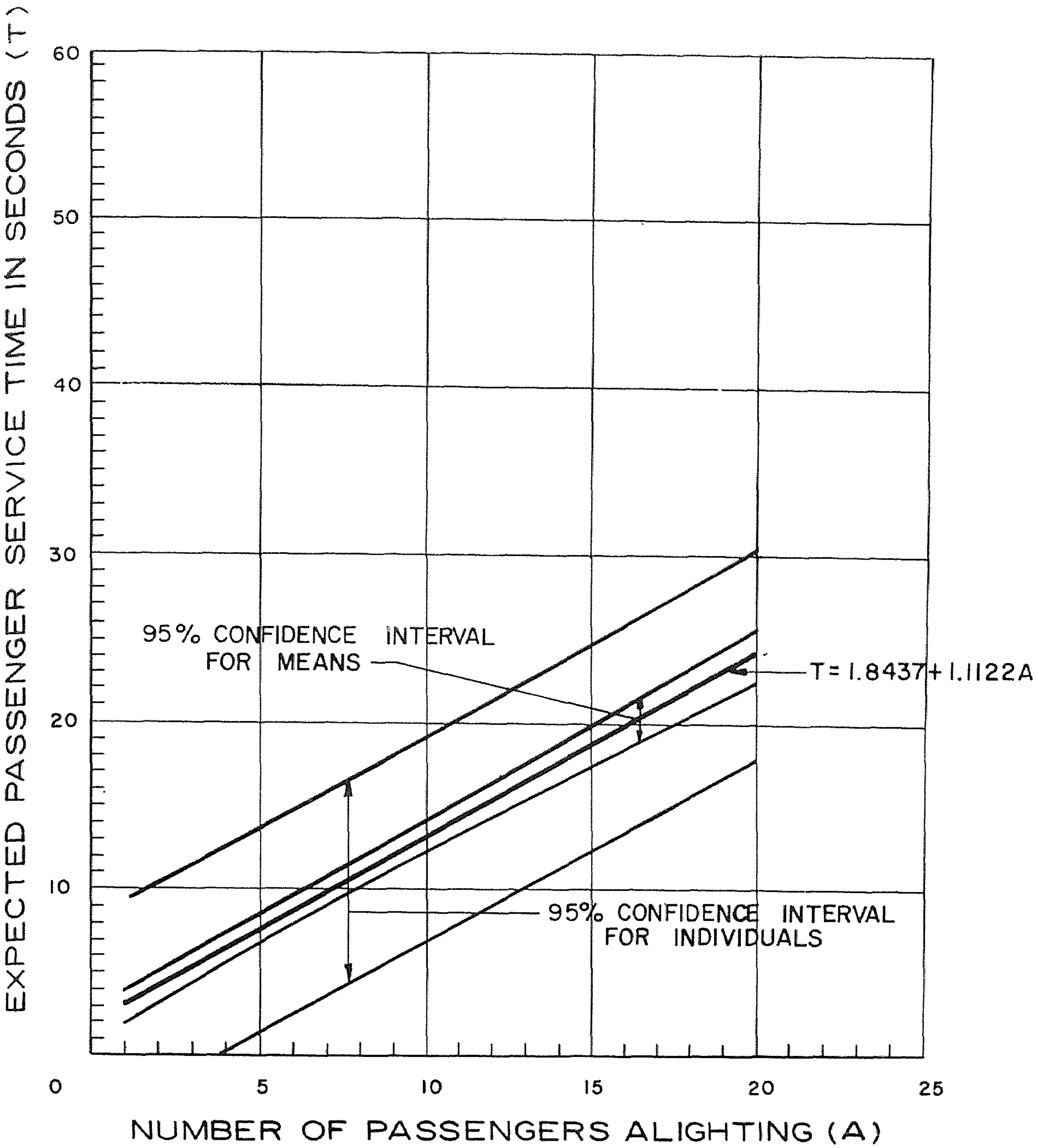


Figure 4 LOUISVILLE, KENTUCKY - CASH AND CHANGE (9)

BUS — ALIGHTING ONLY

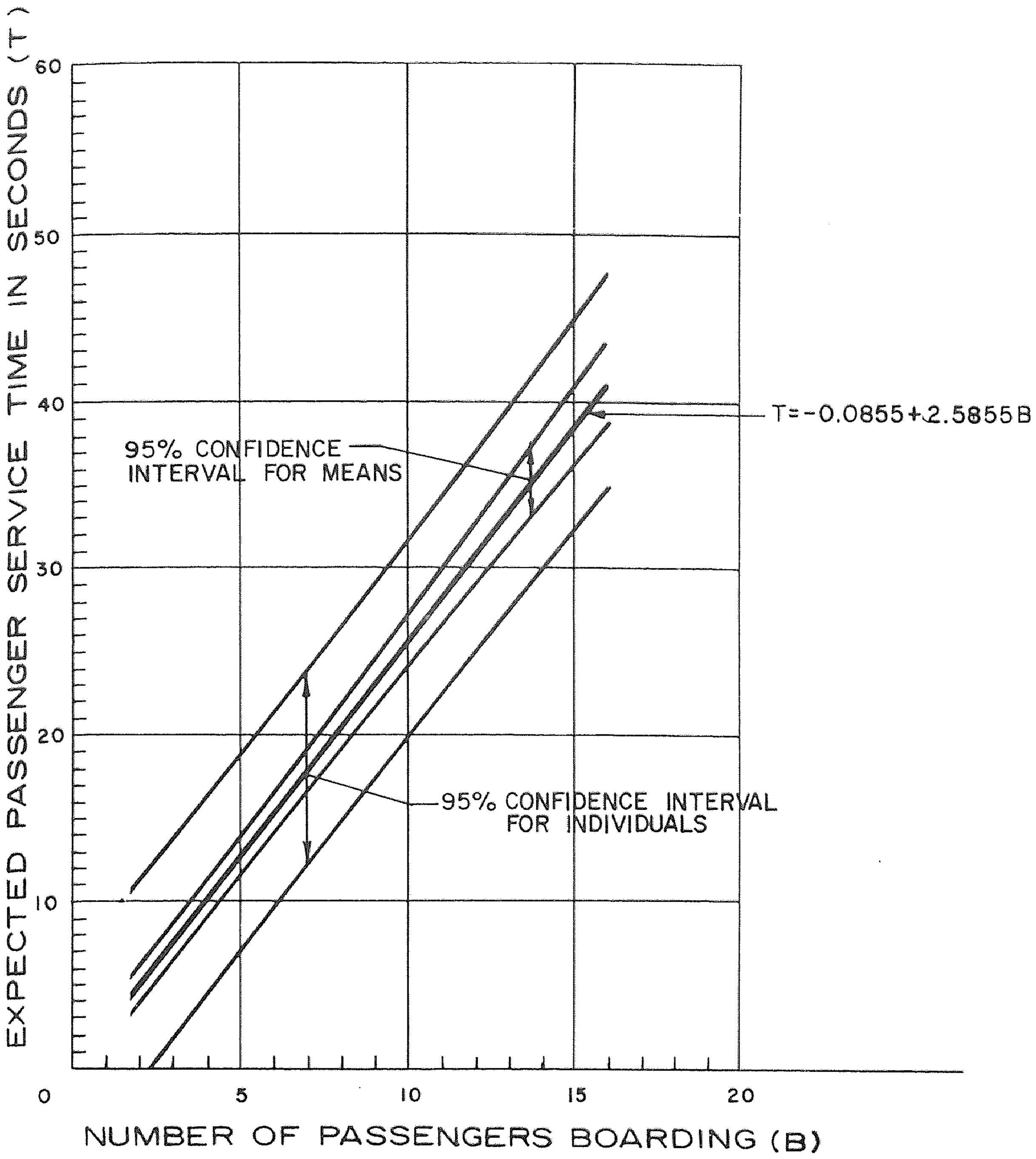


Figure 5 LOUISVILLE, KENTUCKY - CASH AND CHANGE (9) BUS — BOARDING ONLY

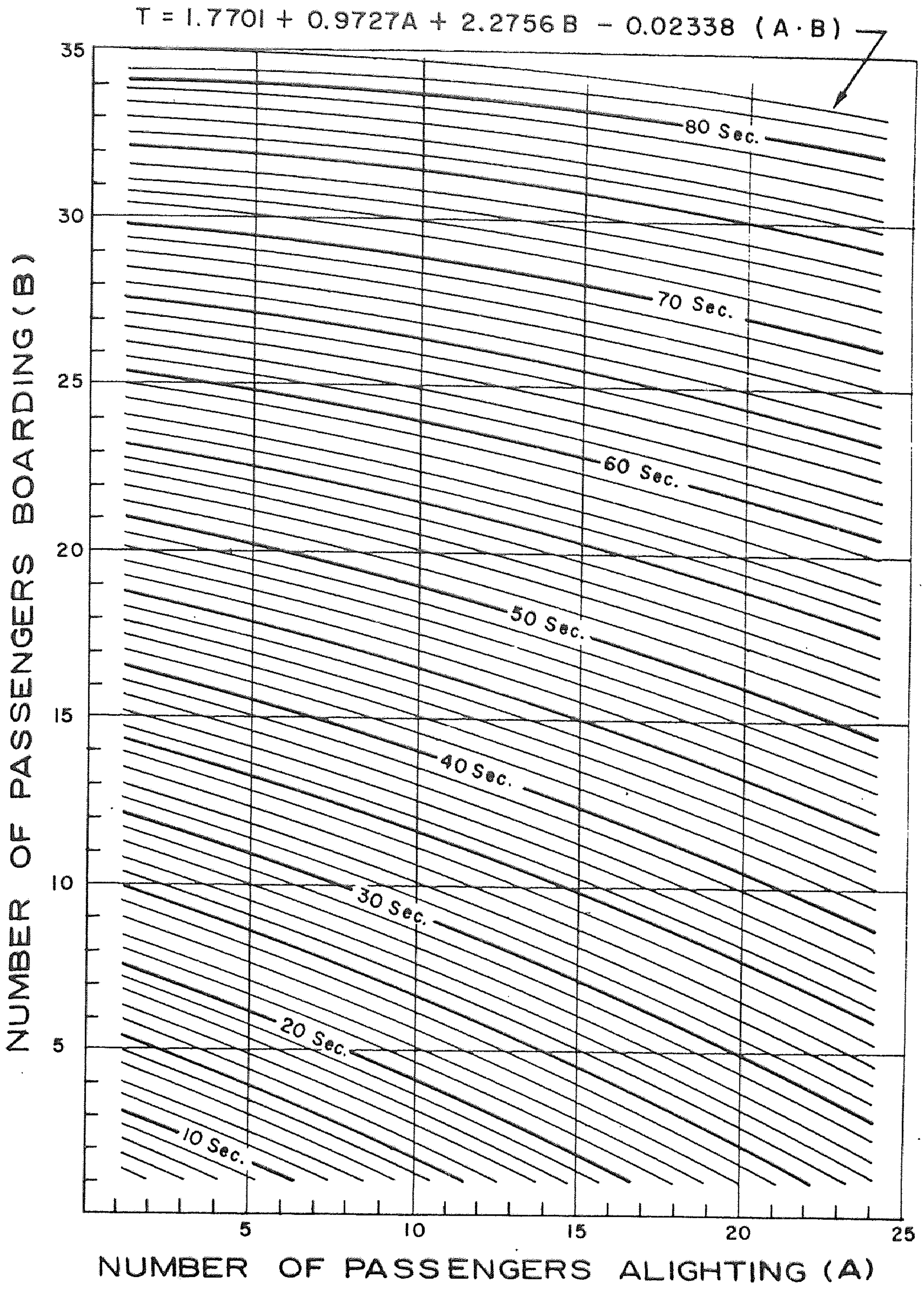


Figure 6 LOUISVILLE, KENTUCKY - CASH AND CHANGE (9)
BUS—BOARDING AND ALIGHTING

was A = 10, then the inner limits would be used to determine a maximum passenger service time of 14 seconds and a minimum time of 12 seconds. Similar use could be made of Figure 5 for boarding passengers.

Figure 6 presents curves that can be used to estimate passenger service time when the number of boarding and alighting passengers is known. For example, suppose it is estimated that 12 passengers will alight and 15 passengers will board at a particular stop. Using Figure 6, the average passenger service time is 43 seconds.

Other relationships have been developed between passenger service time and passenger demand. Many of these are contained in Appendix A3.

3.2.1.6 Combined Effects - Data summarized from the photographic studies included information on the passenger service times for individual passengers categorized by sex and amount of baggage carried. The data were analyzed using multiple regression techniques with dummy coding as shown in Table 10. The dependent variable was time per passenger in seconds. Table 11 lists the results of the regression analysis. As shown by the coefficient of determination, R^2, only 45 percent of the variability has been explained by the regression equation. The magnitude of the equation coefficients indicate their degree of contribution. The two largest coefficients account for increased time due to boarding with the multiple fare-cash and change method of fare collection. The other coefficients indicate that the number of alighting passengers and the percentage of women and children have a negative effect on time per

TABLE 10

Coding Scheme for Multiple Regression Analysis on Film Data of Bus Passengers Through the Front Door

Direction of Flow	B_1 New Brunswick, New Jersey Cash & Change Multiple Fare	B_2 Montreal, Canada Cash & Change Flat Fare	B_3 San Diego, California Exact Fare Flat Fare
A_1 Alighting	A_1 B_1	A_1 B_2	A_1 B_3
A_2 Boarding	A_2 B_1	A_2 B_2	A_2 B_3
A_3 A & B	A_3 B_1	A_3 B_2	A_3 B_3

Cell	Code							
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
A_1 B_1	1	0	0	0	0	0	0	0
A_2 B_1	0	1	0	0	0	0	0	0
A_3 B_1	0	0	1	0	0	0	0	0
A_1 B_2	0	0	0	1	0	0	0	0
A_2 B_2	0	0	0	0	1	0	0	0
A_3 B_2	0	0	0	0	0	1	0	0
A_1 B_3	0	0	0	0	0	0	1	0
A_2 B_3	0	0	0	0	0	0	0	1
A_3 B_3	0	0	0	0	0	0	0	0

X_9 = Number of Alighting Passengers

X_{10} = Number of Boarding Passengers

$X_{11} = (X_9 \cdot X_{10})$

X_{12} = % Women & Children

X_{13} ≡ % Carrying Nothing

X_{14} = % Carrying Something

X_{15} = % Carrying More Than 1 Item

TABLE 11

Results of Multiple Regression Analysis on Film Data of Bus Passengers Through the Front Door

Item	Statistic
Equation	$T/P = 2.2149 + 1.0313X_2 + 0.5826X_3 - 0.0176X_9 + 0.0190X_{10} - 0.0103X_{12} + 0.0112X_{15}$
n	73
R^2	0.43
S_E	0.39
$S_{E/\bar{t}}$	0.19
F Test	8.27
F Statistic @ 95% Level	2.62

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T/P = Time per Passenger in Seconds

X_i = Independent Variable Defined in Table 10 passenger and that the number of boarding passengers and the percentage of passengers carrying more than one item have a positive effect.

3.2.2 Modal Factor

The modal factor consists of the physical features of the vehicle used to transport passengers. It can be divided into the three areas of type of vehicle, service and physical characteristics. The first two are descriptive in nature and interact greatly with the third.

3.2.2.1 Type of Vehicle - Many types of vehicles are being used in street transit systems, including the bus, trolley and trolley bus. Each has unique physical features that affect passenger service time, such as number of doors, width of door, aisle width and seating configuration. These effects are described in Section 3.2.2.3, Physical Characteristics.

3.2.2.2 Service - The service that the various types of vehicles can be assigned to include local, suburban, intercity, airport, shopper, campus, shuttle, demand-response and express. The bus, being the most versatile type of vehicle, can be assigned to each type of service. However, buses with certain types of physical characteristics are better suited for certain types of service than others. For example, suburban coaches usually have one door, narrower aisles, and more comfortable seats than the equipment used for local service. Vehicles used for shopper service should have wider doors and wider aisles to permit easy movement by passengers carrying baggage. Service requirements should dictate vehicle requirements.

A comparison of express and local service was performed using data gathered by a manual survey of bus operations in Detroit, as shown in Table 12. Using an F test for comparison of the variances of estimate and a t test for comparison of slopes, it was determined that the differences were statistically significant at the 95 percent level.

3.2.2.3 Physical Characteristics - Those physical characteristics affecting passenger service time include the dimensions and number of doors, the dimensions and number of stairs, aisle width, seating configuration and gate configuration. Most street transit vehicles presently in use have either one or two doors and require a passenger to climb or descend three steps. Some characteristics of vehicles are contained in Appendix A4.

The effect of door characteristics upon passenger service time was investigated by analyzing the effects of number of doors and door width. The differences between front and rear door alighting times were surveyed during the conduct of NCHRP Report 113 for buses in Louisville, Kentucky, as shown in Table 13. Although no statistical tests were performed, it appeared that the differences between front and rear door alighting times would not be significant. This conclusion has been confirmed by the author and Bergen(22) and by analysis of manual count data obtained of the Newark Subway, as shown in Table 14. The effects of using more than one door and using double stream doors are also shown in Table 14.

TABLE 12

Comparison of Boarding Times for Bus Passengers Using Local and Express Service in Detroit, Michigan

Item	Service	
	Local	Express
Equation	$T = -0.9 + 2.2BDF$	$T = -3.3 + 2.6BDF$
Range	$1 \leq BDF \leq 28$	$2 \leq BDF \leq 25$
n	20	26
R^2	0.94	0.93
S_E	4.19	4.59
$S_{E/\bar{t}}$	0.17	0.20
F Test	308.95	308.63
F Statistic @ 95% Level	4.41	4.26

BDF = Numbers of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 13

Average Alighting Times of Bus Passengers in Louisville, Kentucky(9)

Period	Average Time, Seconds per Passenger Front Door	 Rear Door
7 AM - 9 AM	1.8	1.6
9 AM - 4 PM	2.3	2.0
4 PM - 6 PM	2.2	2.0
7 AM - 6 PM	2.2	1.9

Comparing the coefficients in Table 14, it can be seen that using both doors to alight requires more than one-half the time that it does for one door. This phenomenon is due to passenger circulation within the vehicle and the movement through each door. In most cases, both doors were not used to capacity at the same time.

The effects of rear and front door boarding on passenger service time were studied using the data from the Newark Trolley Survey shown in Table 15. The results indicated that rear door boarding times were 0.4 second per passenger faster than for the front door. This result is most likely due to internal vehicle circulation. The two streams entering through the back door can each go to opposite ends of the vehicle, while the double stream entering through the front door must turn left and go toward the rear of the vehicle. The use of both doors required less time than one door; but, as was observed before, the time required for two doors was more than half that required for one door.

TABLE 14

Alighting Characteristics of Bus and Trolley Passengers During Peak Periods

Item	San Diego, California	New Brunswick, New Jersey	Louisville, Kentucky	Newark, New Jersey				
Service	Local	Suburban	Local	Local	Local	Local	Local	Local
Vehicle	Bus	Bus	Bus	Bus	Trolley	Trolley	Trolley	Trolley
Door	Front Single	Front Single	Both Single	Both Single	Front Double	Rear Double	Either Double	Both Double
Equation	$T = 0.2 + 1.5ALF$	$T = 1.0 + 1.9ALF$	$T = 2.1 + 1.2A$	$T = 3.3 + 1.1A$	$T = 2.8 + 0.9ALF$	$T = 2.2 + 0.8ALF$	$T = 3.0 + 0.8A$	$T = 4.3 + 0.5A$
Range	$1 \leq ALF \leq 14$	$1 \leq ALF \leq 30$	$1 \leq A \leq 17$	$1 \leq A \leq 11$	$3 \leq ALF \leq 29$	$2 \leq ALF \leq 36$	$2 \leq A \leq 36$	$2 \leq A \leq 54$
n	11	21	23	64	70	87	157	70
R^2	0.95	0.91	0.66	0.76	0.76	0.91	0.85	0.77
S_E	1.57	5.73	3.15	1.55	2.76	1.94	2.41	2.70
$S_{E/\bar{t}}$	0.27	0.51	na	0.22	0.21	0.12	0.16	0.16
F Test	168.10	197.72	na	192.37	213.49	844.76	885.95	249.78
F Statistic @ 95% Level	5.12	4.38	na	4.00	3.99	3.96	3.92	3.99

A = Number of Passengers Alighting

ALF = Number of Passengers Alighting Through Front Door

n = Number of Observations

na = Information Not Available

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 15

Boarding Characteristics of Newark Subway (Trolley) Passengers During the A.M. Peak with Fare Collected Outside the Vehicle

	Door		
Item	Front	Rear	Both
Equation	$T = 0.5 + 1.3BDF$	$T = 1.6 + 0.9BDR$	$T = 1.5 + 0.7B$
Range	$1 \leq BDF \leq 9$	$2 \leq BDR \leq 29$	$4 \leq B \leq 38$
n	12	51	12
R^2	0.92	0.93	0.89
S_E	0.95	1.30	2.32
$S_{E/\bar{t}}$	0.22	0.17	0.23
F Test	129.48	613.25	82.23
F Statistic @ 95% Level	4.96	4.03	4.96

B = Number of Passengers Boarding

BDF = Number of Passengers Boarding Through Front Door

BDR = Number of Passengers Boarding Through Rear Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

No comparison could be made concerning the effects due to the number of steps because most vehicles are similar. However, a comparison was made of the effect of varying the height of the first step by observing passengers boarding from platform and from ground level--a difference of about eight inches. As shown in Table 16, the slope of the curve for boarding from the platform level was 0.4 second faster than for the ground level. However, the differences in slopes are not statistically significant at the 95 percent level due to the large variations expressed by the standard errors of estimate.

The effects of aisle width and seating configuration are difficult to quantify because of their interaction with other elements. Their effects have been observed, and it can be concluded that they do affect passenger service time. The aisle width for suburban coaches is usually narrower than for local coaches (see Figure A-6 in Appendix A4). The narrower width causes some passengers to walk sideways, particularly those with baggage. This, in turn, slows internal movement. Time requirements for suburban passengers at the Port Authority Bus Terminal in New York City boarding with a pay leave method of fare collection were observed to be greater than for some loadings of local transit passengers boarding with a pay enter-cash and change method of fare collection as shown in Table 17.

Transit buses operated by the Montreal Urban Community Transit Commission have a seating configuration that provides for an extra-wide aisle with double seats on one side of the coach and single seats on

TABLE 16

Effect of Height of First Step on Boarding Time of Bus Passengers

	Level	
Item	Platform	Ground
Equation	$T = 2.1 + 7.0\ BDF$	$T = -18.5 + 7.4\ BDF$
Range	$6 \leq BDF \leq 56$	$3 \leq BDF \leq 19$
n	25	13
R^2	0.92	0.97
S_E	27.96	7.43
$S_{E/\bar{t}}$	0.19	0.20
F Test	282.22	313.13
F Statistic @ 95% Level	4.28	4.84

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 17

Effect of Aisle Width on Boarding Suburban Bus Passengers

	Location	
Item	Port Authority Bus Terminal, New York City	Newark, New Jersey
Method of Fare Collection	Pay Leave	Pay Enter, Cash & Change
Equation	$T = -36.4 + 4.6BDF$	$T = 3.2 + 3.3BDF$
Range	$11 \leq BDF \leq 63$	$1 \leq BDF \leq 48$
n	31	157
R^2	0.93	0.87
S_E	21.31	13.87
$S_{E/\bar{t}}$	0.27	0.32
F Test	395.12	1057.08
F Statistic @ 95% Level	4.18	3.90

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

the other side. Service times for passengers boarding these buses with a pay enter-cash and change method of operation have been almost equal to boarding times with the pay enter-exact fare method of fare collection recorded in other areas. A comparison is contained in Table 18.

All observations reported in Table 18 were for General Motors Corporation buses. The buses in San Diego, Detroit, and Irvington had narrower aisles (26 inches vs. 42 inches) and double seats on each side of the bus (see Figure A-7 in Appendix A4). A comparison of the estimates of variance with F tests indicated that the differences were statistically significant at the 95 percent level between the Montreal data and the data for San Diego and Detroit.

3.2.3 Operating Practices

Operating practices consist of all aspects involving the movement of the passenger into and out of vehicle. They have been divided into the three areas of type of fare, method of fare collection and access.

3.2.3.1 Type of Fare - Many types of fare could be used, including cash, tickets, transfers, tokens, passes and credit cards. Some systems are even using no fare. The most common type of fare is the use of cash or tokens combined with paper transfers. The effect of type of fare was first reported in 1958 in Traffic Engineering magazine and is shown in Table 19.

TABLE 18

Effect of Seating Configuration on Boarding Local Bus Passengers

Item	Montreal, Canada	San Diego, California	Detroit, Michigan	Irvington, New Jersey
Method of Fare Collection	Pay Enter Cash & Change	Pay Enter Exact Fare	Pay Enter Exact Fare	Pay Enter Exact Fare
Equation	$T = 4.5 + 2.4BDF$	$T = 0.7 + 2.1BDF$	$T = 0.9 + 2.2BDF$	$T = 1.8 + 2.8BDF$
Range	$6 \leq BDF \leq 26$	$1 \leq BDF \leq 33$	$1 \leq BDF \leq 28$	$2 \leq BDF \leq 14$
n	18	23	20	12
R^2	0.98	0.92	0.94	0.94
S_E	2.54	5.12	4.19	3.38
$S_{E/\bar{t}}$	0.09	0.21	0.17	0.18
F Test	687.47	246.59	308.95	161.46
F Statistic @ 95% Level	4.49	4.32	4.41	4.96

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 19

Approximate Headways for Boarding Passengers(13)

Situation	Headway in Seconds
Single Coin or Token - Fare Box	2 to 3
Odd-Penny Cash Fares	3 to 4
Multiple-Zone Fares (pre-purchased tickets) including Registration by Driver	4 to 6
Multiple Fares (cash) Including Registration by Driver	6 to 8

Generally, it can be concluded that passenger service time increases with increased driver involvement, and the least amount of passenger service time for boarding passengers occurs with no fare being collected. There are also other advantages with a no fare system. Bus drivers without fares or fare boxes are free to concentrate solely on driving, and passenger mobility in entering and leaving a vehicle is greatly increased.(42) The effect of no fare upon boarding was observed by a manual survey at the Port Authority Bus Terminal in New York City and is shown in Table 20.

As listed, the boarding time requirements for the pay leave situation are significantly less, which is not necessarily the case with alighting passengers. There should be no effect upon passenger service time by the different types of fare when passengers are alighting, except that the situation of no fare collected when boarding does require a

TABLE 20

Effect of Fare Collection on Boarding Passengers at the Port Authority Bus Terminal in New York City

	Fare	
Item	Cash & Change Multiple Zones	Pay Leave
Equation	$T = 2.1 + 7.0BDF$	$T = -36.4 + 4.6BDF$
Range	$6 \leq BDF \leq 56$	$11 \leq BDF \leq 63$
n	25	35
R^2	0.92	0.93
S_E	27.96	21.31
$S_{E/\bar{t}}$	0.19	0.27
F Test	282.22	395.12
F Statistic @ 95% Level	4.28	4.18

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

collection of fare while alighting if a fare is charged. While no quantitative data were obtained, it was observed that passenger service time was increased when fares were collected from alighting passengers. This increase was minimal when the driver collected the fare before the bus stopped.

3.2.3.2 Method of Fare Collection - Three major areas are of concern with the method of fare collection: 1) when the fare is collected, 2) how the fare is collected, and 3) where the fare is collected. The effect of when the fare is collected was first recorded by Donald Downes in 1959 and is shown in Table 21.

TABLE 21

Bus Passenger Entry Rates for Various Means of Fare Collection(16)

Type of Collection	Seconds per Passenger	Passengers per Minute
Pay Leave	2	30
Pay Enter	3	20
Fare Receipt	4	15

This same result was shown in Table 20. When compared with the pay enter system, the time for boarding passengers with the pay leave system has been about one-third less.

The question of how the fare is collected again includes consideration of driver involvement. Lessieu reported that boarding times can be "calculated on a unit time basis such as three seconds per passenger with a fare box and six seconds per passenger for a fare register operation."(17) Examples of fare collection equipment are shown in Figure A-8 in Appendix A4. For many years the pay enter-cash and change method of fare collection was common, where the driver collected the fare and gave change when necessary. In recent years, because of driver and passenger safety, many systems have adopted the exact fare method in which the driver does not handle the fare. With the exact fare method, passengers deposit the exact fare into a sealed box as they enter the vehicle. In some systems, the driver gives redeemable scrip for an overpayment. Generally, the effect on passenger service time has been a reduction in time. In Louisville, Kentucky, and Newark, New Jersey, the exact fare method of fare collection showed a saving of about 0.6 second per passenger. Table 22 contains the before and after passenger service time equations for boarding.

Similar time savings were observed by the author in other cities, with the amount of savings being dependent upon 1) the number of passengers that normally carried exact fare when the cash and change plan was in operation, and 2) the number of passengers requesting transfers.

The influence upon passenger service time of passengers requiring change was studied for the Newark Subway (Trolley) System. As shown in Table 23, the number of persons requiring change was a stronger influence on passenger service time than passengers with exact fare.

The place where the fare is collected can occur off the vehicle or on the vehicle. On-board fare collection can be done by the driver or

TABLE 22

Comparison of Methods of Fare Collection for Boarding Passengers in Louisville, Kentucky and Newark, New Jersey(19) (43)

Item	Louisville, Kentucky		Newark, New Jersey	
Method of Fare Collection	Cash & Change	Exact Fare	Cash & Change	Exact Fare
Equation	$T = -0.1 + 2.6BDF$	$T = 0.6 + 2.0BDF$	$T = 3.2 + 3.3BDF$	$T = 2.3 + 2.7BDF$
Range	$1 \le BDF \le 16$	$1 \le BDF \le 25$	$1 \le BDF \le 48$	$1 \le BDF \le 38$
n	41	31	157	110
R^2	0.94	0.94	0.87	0.95
S_E	2.91	2.70	13.87	5.70
$S_{E/\bar{t}}$	0.25	na	0.32	0.24
F Test	na	na	1057.08	1648.76
F Statistic @ 95% Level	na	na	3.90	3.94

BDF = Number of Passengers Boarding Through Front Doors

n = Number of Observations

na = Information Not Available

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 23

Influence of Passengers Requiring Change While Boarding Through the Front Door of the Newark Subway (Trolley) during Off-Peak Periods(44)

Item	Statistic
Equation	$T = 6.9 + 1.2PEC + 7.5PRC$
Range	$0 \leq PEC \leq 15$ $0 \leq PRC \leq 10$
n	23
R^2	0.95
S_E	5.03
$S_{E/\bar{t}}$	0.14
F Test	na
F Statistic @ 95% Level	na

n = Number of Observations

na = Information Not Available

PEC = Passengers with Exact Fare

PRC = Passengers Requiring Change

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

a conductor. The latter condition requires a two-man crew and is not usually used in the U.S. In England, even the traditional two-man operation is being converted to one-man operation because of staffing problems.(20)

Although no quantitative data is available for a comparison of on-vehicle and off-vehicle fare collection, the comparison should be similar to that described above for the pay leave and pay enter methods.

3.2.3.3 Access - There are 15 possible categories of movement into and out of a street transit vehicle, as shown in Figure 7. The most common of these do not include boarding through the rear door. Rear door boarding can be used effectively with a pay leave or no fare system or with fares being collected by a conductor. Since most systems in the U.S. do not use rear door boarding, analysis of this type was limited to available data from the Newark Subway (Trolley) System survey. The results are shown in Table 15 and have been discussed in Section 3.2.2.3 Physical Characteristics.

Comparisons of boarding and alighting characteristics have indicated that passenger service time requirements for boarding exceed those for alighting.(22) The amount of difference is influenced by the factors described herein.

Various forms of equations have been developed to predict passenger service time when simultaneous alighting and boarding occur. Many of these are shown in Appendix A3. The effect on alighting of the presence

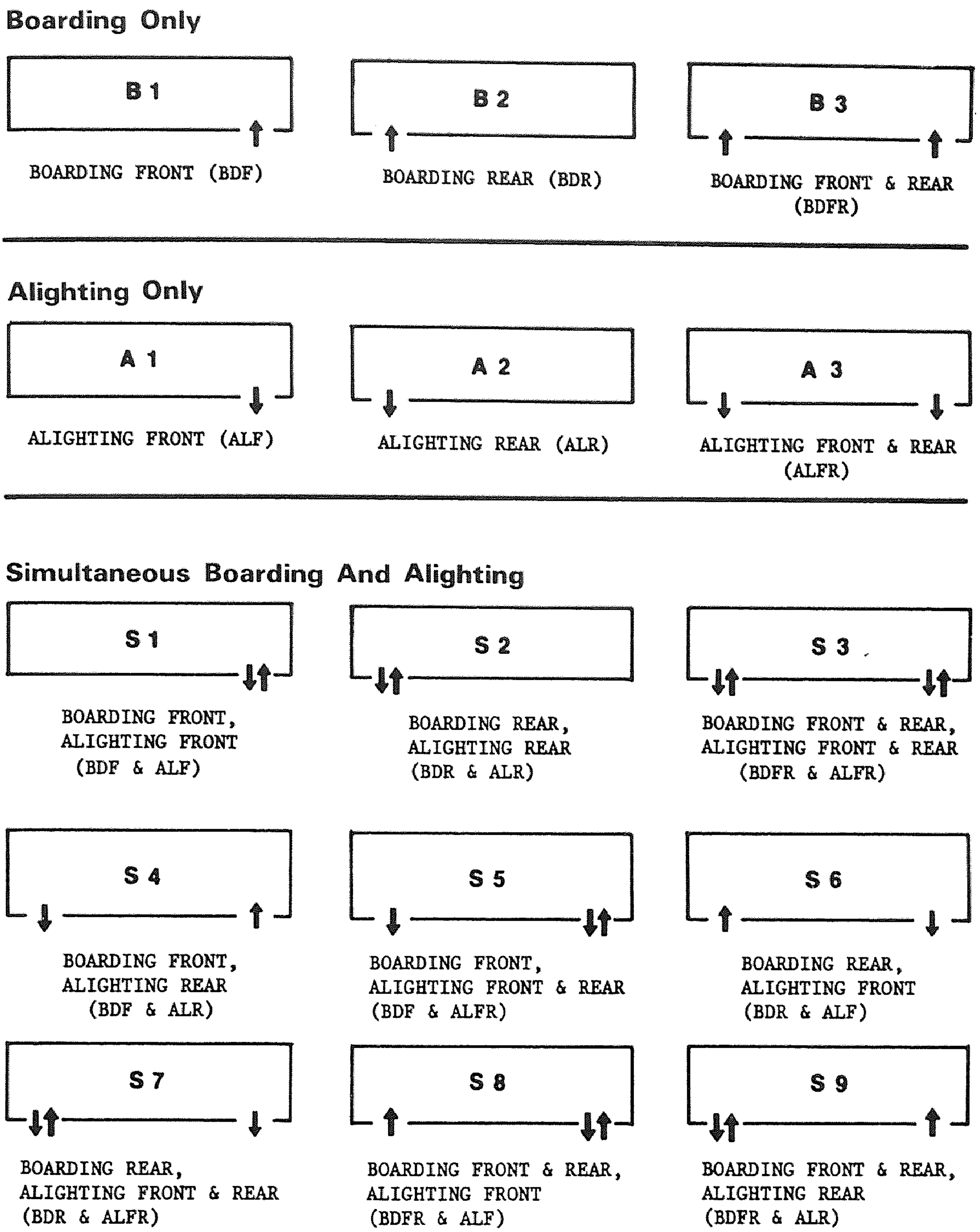


Figure 7 PASSENGER SERVICE TIME CATEGORIES

or absence of boarding was studied for the Newark Subway (Trolley) System. As shown in Table 24, alighting times were significantly greater at the 10 percent level when boarding passengers were present.

The effect of internal and external vehicle congestion was observed at a number of locations. Congestion outside the vehicle was observed to delay boarding and alighting; however, no quantitative data could be obtained because of the difficulty in isolating this effect. Generally it was observed that fewer delays occurred when the boarding queues were organized and orderly.

Internal congestion was studied by Radalet, who concluded that "no definite effect can be detected from the presence of standees... It could be possible that the retarding effect of the standees is stronger as their number increases, but this possibility could not be investigated for lack of data."(21)

Observations of alighting passengers at the Port Authority Bus Terminal in New York City were classified into three categories of congestion--none, some, and much. Although the limits of each category were subjective, they indicated the degree that internal congestion interfered with alighting. Table 25 lists regression equation data developed for the three categories of congestion at the bus terminal. Statistical comparisons of the slopes and variances of the equations indicated that there was no difference between the categories of "none" and "some" congestion, but that the category of "much" was different

TABLE 24

Effect of Boarding on Passengers Alighting Through the Front Door of the Newark Subway (Trolley)

	Situation	
Item	With Boarding	Without Boarding
Equation	$T = 2.0 + 1.1ALF$	$T = 2.8 + 0.9ALF$
Range	$3 \leq ALF \leq 19$	$3 \leq ALF \leq 29$
n	17	70
R^2	0.93	0.76
S_E	1.43	2.76
$S_{E/\bar{t}}$	0.11	0.21
F Test	211.29	213.49
F Statistic @ 95% Level	4.54	3.99

ALF = Number of Passengers Alighting Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 25

Effect of Internal Congestion on Alighting Passengers at the Port Authority Bus Terminal in New York City

Item	Congestion None	 Some	 Much
Equation	$T = 6.8 + 2.0ALF$	$T = 15.6 + 1.8ALF$	$T = 12.2 + 3.1ALF$
Range	$7 \leq ALF \leq 50$	$10 \leq ALF \leq 50$	$3 \leq ALF \leq 47$
n	22	11	8
R^2	0.94	0.94	0.74
S_E	6.24	5.60	30.34
$S_{E/\bar{t}}$	0.27	0.19	1.13
F Test	338.06	144.69	17.00
F Statistic @ 95% Level	4.35	5.12	5.99

ALF = Number of Passengers Alighting Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

from the other two. Some of the congestion was due to passengers removing coats or baggage from the overhead storage racks.

As a further analysis of the effect of standees, human observer surveys were conducted of passengers boarding and alighting buses on Bloomfield Avenue in Newark, New Jersey. For these surveys two enumerators rode each bus and recorded the number of standees, the number of persons alighting and/or boarding by each door and the passenger service time for each door. The data were summarized to represent the average passenger service time, as shown in Table 26.

TABLE 26

Effect of Standees on the Average Service Time per Passenger for Buses on Bloomfield Avenue in Newark, New Jersey, during the PM Peak Period

Door	Direction of Flow	Presence of Standees: No		Presence of Standees: Yes	
		Average Time in Seconds	Number of Observations	Average Time in Seconds	Number of Observations
Front	Alighting	2.38	50	3.45	27
	Boarding	2.41	19	2.85	12
	Alighting and Boarding	2.60	19	2.54	12
Rear	Alighting	1.46	10	1.74	26
Both	Total	2.21	98	2.65	77

The analysis of variance technique was used to determine differences in time. As would be expected with counting data the standard deviations of each cell were proportional to the cell means. A logarithmic transformation was used to obtain homogeniety of variance. The results of the analysis, as shown in Table 27, indicated that both row and column effects were significant at the 95 percent level.

TABLE 27

Approximate ANOVA Table of Bus Data for Bloomfield Avenue in Newark, New Jersey, during the PM Peak Period

Source	Degrees of Freedom	F-Ratio	F-Statistic @ 95% Level
Total	7		
Rows (Door Use and Direction of Flow)	3	12.469	2.60
Columns (Presence of Standees)	1	5.261	3.84
Interaction	3	0.671	2.60
Within Group Error	167		

The strongest difference is shown for Door Use and Direction of Flow. Using Tukey's limits(30) at the five percent level, it was determined that the rear door alighting times were less than the times for the front door categories. With respect to standees the average time with standees was 19.5 percent greater than without standees.

During the conduct of the survey it was observed that the standees did not always interfere with the boarding and alighting of passengers. It was also observed that frequently passengers would move through standees toward a door before the bus stopped and would be ready to alight when it did.

3.2.4 Operating Policies

Operating policies affect PVI in a number of ways, including vehicle procurement and fare structure. The policy concerning the types of vehicles used and their characteristics has a pronounced effect. As an example, consider the possible effect that the number of doors and door width has on passenger service time. Many buses of the Montreal Urban Community Transit Commission were procured with wider rear doors, while buses with single-width rear doors are usually procured in the United States. As was discussed earlier in this chapter, passenger service time is less for double stream doors than for single stream doors.

Policies concerning type of fare, amount of fare, and zone systems also affect PVI. A flat fare permits, where appropriate, the organization of flows within a vehicle to front door boarding and rear door alighting. A zone fare requires that all movements be made through the front door.

Another effect is the policy concerning reduced fares for students and the elderly. Some systems require these passengers to display proper identification to ride free or at a reduced fare. To reduce delays during peak periods, some systems limit the use of reduced fares to off-peak operations. The specific policy concerning reduced fares has a great effect on passenger service time.

3.2.5 Mobility

The effect of PVI on the mobility of individual passengers has been described in Section 3.2.1.2, Physical Attributes. The sum of these individual effects has an effect upon the mobility of a region. Noakes has stated that 20 percent of the population of the United States is physically handicapped and includes people with below average powers, senses and mobility, either permanently or temporarily as a result of an accident, age, birth defects, or disease.(45) A study prepared by the Transportation Systems Center of the U.S. Department of Transportation has estimated that there are 14,800,000 elderly and handicapped persons living in urbanized areas.(46) Of those who have transit available, 4,600,000 are physically able to use the existing system, 700,000 can go out but cannot use the system, and about 1,000,000 cannot leave their residence.

The existing PVI may be the reason that some of the 700,000 persons cannot use existing transit systems. Although changes can be made, the effect of these changes upon the present users should also be considered. For example, equipping all existing buses with hydraulic lifts for passengers in wheelchairs would probably result in increased system costs, fewer seats, and longer travel times.

3.2.6 Climate and Weather

Little information is available concerning the effects of climate and weather on PVI, probably due to the difficulty of obtaining quantitative data. Seventeen percent of the observations for Experiment F63 described in NCHRP Report 113 "Optimizing Flow on Existing Street Networks" were taken when rain was falling. As shown in Table 28, there seems to be no change in passenger service time with rain. More observations are needed before a conclusion can be reached.

TABLE 28

Effect of Rain on the Average Service Time per Passenger for Buses in Louisville, Kentucky(9)

	Average Time per Passenger, Seconds		
	Alighting		Boarding
Weather	Rear	Front	Front
Rain	2.0	2.3	2.6
No Rain	1.9	2.2	2.6

It has been reported that the passenger mix changes during inclement weather. In Washington, D.C., elderly and handicapped persons indicated they traveled less during inclement weather (icy, snowy, rainy, cold or hot) and during late night or morning and evening rush hours.(41)

3.2.7 Other System Elements

Other elements of the street transit system affect and are affected by the Passenger Vehicle Interface. The demand characteristics associated with the passenger element have a definite effect on PVI. During peak periods, maximum demand is made of PVI because of increased passenger use. The characteristics of the passengers that will influence PVI include how willing they are to carry exact fare and the manner in which they form a queue to board the bus. In Montreal, the passengers at curbside formed very orderly queues and the loading proceeded smoothly. In San Diego and Newark, passengers often were observed to cluster around the door without forming a queue. This resulted in pushing, shoving, and disruption in the boarding process. In 1959, Traffic Engineering magazine contained the recommendation that for the typical rush hour situation, even for small accumulations of patrons, queueing is necessary 1) to avoid crowding and disorder, and 2) to enable high-capacity or maximum use of space available.(13)

Inadequate or improper use of terminal facilities has an adverse effect on PVI. Introduction of fast vehicles which operate without stops over the mechanized portion of the passenger's trip will not necessarily result in a door-to-door trip time (speed) that is competitive with the car unless trip-end delays are effectively minimized.(7) Loading platform space and arrangement is of major importance in terminal operations where rush hour conditions prevail.(13) All aspects of the terminal affect the PVI. Even curb height is an important factor in the use of loading areas and should be between six inches and nine inches high. Also, a severe cross slope can obstruct the use of a lane as a loading area.

The method of operating the vehicle will affect PVI. Much of this effect is attributed to the attitudes of the drivers and their methods of dealing with the passengers. Responsive answers to questions and stopping the vehicle where loading can take place efficiently will help PVI. In Newark, drivers often stopped five to 10 feet away from the curb, requiring passengers to step off the curb and into the street to board the bus. In Montreal, the driver frequently asked passengers to alight through the rear door only when he stopped for a large number of boarding passengers. The effects of these two contrasting examples are evident.

The effects of the line haul element can best be described by considering the effect of signal delay on passenger service time. Near-side bus stops have an advantage if signal delay is incurred and passenger service operations can be performed during the delay. The effects of signal delay and the use of near-side and far-side stops become particularly important in designing bus routes through interconnected traffic signal systems.

3.3 Summary

PVI has been defined as the interaction between the passenger and vehicle elements of the street transit system. Its effect on the operations of street transit systems has been analyzed by evaluating the factors affecting or being affected by PVI. The factors were divided into the following seven categories:

1. Human Factor
2. Modal Factor
3. Operating Practices
4. Operating Policies
5. Mobility

6. Climate and Weather
7. Other Sytem Elements

Each of these factors was subdivided into selected areas for analysis. Where possible, the effects of each of the factors on PVI were quantified. Information on the time for queues of passengers to alight and/or board a vehicle was obtained by manual surveys and photographic studies. Regression equations were developed and compared by using an F test for the variances of estimate and a t test for slopes. The multiple regression technique with dummy coding and the analysis of variance technique were also used. Where the magnitude of the effect could not be quantified, its direction was indicated.

The effects of each of the factors on PVI are also reflected on the operations of street transit systems by the following model of time for a typical street transit trip.

Total Trip Time = Running Time + Delay Time + Passenger Service Time.

Any change in passenger service time in the above model will have a concomitant change in total trip time. This relationship should be remembered when studying the effects of the following factors.

The <u>human factor</u> consists of all characteristics of the passenger and was divided into the five areas of:

1. Type of passenger
2. Physical attributes
3. Passenger preferences

4. Baggage carried
5. Passenger demand

The type of passenger considers the different characteristics of the commuter, shopper and tourist. These differences have been expressed as being due to time of day or day of week, but are actually due to the degree of passenger orientation with the system. Based on the analysis contained herein, it was concluded that the degree of passenger orientation is inversely proportional to the amount and variability of passenger service time. Increases in time and variability of 52 and 168 percent, respectively, are reported herein.

The physical attributes of the passenger include consideration of sex, age, and handicaps. The only quantifiable effect was observed for the percentage of women and children recorded in the photographic studies. It indicated that the average time per passenger should be reduced by 0.0103 times the percentage of women and children. The effects of the attributes of age and handicaps were not quantified because of the difficulty in categorizing these attributes and in obtaining sufficient data. However, it was observed that old and handicapped passengers increased passenger service time.

The factor of passenger preferences considered seat location and the presence of standees. Although no quantitative effects were obtained, passengers have been observed alighting against the flow of boarding passengers from the bus that they had just boarded when they found no seat available. Orderly queues were also disrupted when passengers did not board because there was standing room only. Internal congestion was observed to increase because some passengers could not use their preferred seats. The resultant effect of passenger preferences is an increase in passenger service time.

The amount of baggage carried affects PVI. Previous research indicated time requirements for alighting passengers with a considerable amount of baggage to be up to 33 percent greater than for passengers with very little hand baggage. Analysis of photographic studies indicated that the percentage of passengers carrying more than one item will increase the time per passenger by 0.0112 times the percent of passengers carrying more than one item. The net result is that an increase in the amount of baggage carried increases passenger service time.

Passenger demand has been shown to directly influence passenger service time. In other words, the greater the number of passengers, the greater will be the passenger service time requirements. Studies using regression analysis have produced equations and graphs for the estimation of passenger service time when the number of alighting and boarding passengers is known. Many of these equations are contained in Appendix A3.

The modal factor consists of the physical features of the vehicle used to transport passengers and has been divided into the three areas of:

1. Type of Vehicle
2. Service
3. Physical Characteristics

Buses, trolleys and trolley buses are the most common types of vehicles used in street transit systems. Each has distinctive physical features, such as number of doors, width of doors, etc., that affect PVI to varying degrees as described in other sections of this Chapter.

The service to which a vehicle can be assigned includes local, suburban, intercity, airport, shopper, campus, shuttle, demand responsive and express. It has been concluded that service requirements should dictate vehicle requirements.

Physical characteristics of vehicles that affect PVI include the dimensions and number of doors, the dimensions and number of stairs, aisle width, seating configuration and gate configuration. The effect of door characteristics was investigated by analyzing changes to passenger service time due to number of doors and door width. The results of these investigations indicated:

1. There is no difference between front door and rear door alighting times.
2. Using both doors to alight requires more than one-half the time than it does to alight from one door. Time reductions of 27 to 80 percent have been observed.
3. For alighting passengers, double stream doors have been observed to require 27 to 46 percent less time than single stream doors.
4. Rear door boarding times for double stream doors were observed to be 0.4 second per passenger faster than for double stream front doors, a reduction of 30 percent.

5. The use of boarding through both doors required less time than for one door, but the time requirements for two doors was more than half that required for one door.

It was difficult to determine the effects of aisle width and seating configuration because of their interaction with other elements. However, it was concluded that decreased aisle width increases passenger service time and that reducing the double seats on each side of the vehicle to a single seat on one side of the vehicle may result in reduced passenger service time.

<u>Operating practices</u> consist of all aspects involving the movement of the passengers into and out of the vehicle. They have been divided into the three areas of:

1. Type of fare
2. Method of fare collection
3. Access

Many types of fare can be used, including cash, tickets, transfers, tokens, passes and credit cards. Some systems even use no fare. Those systems that do require the collection of a fare have driver involvement. Generally, it was concluded that passenger service time increases with increased driver involvement and the least amount of passenger service time for boarding passengers occurs with no fare being collected.

The method of fare collection was analyzed for the three considerations of:

1. When the fare is collected
2. How the fare is collected
3. Where the fare is collected

Previous studies have indicated that the time per boarding passenger can increase up to 200 percent with a pay-enter type of fare collection system over a pay-leave system, and that a fare register type of operation can increase the time per boarding passenger by 100 percent over a fare box method of collection. Comparisons between the exact fare method of fare collection and the cash and change method of fare collection indicated that the exact fare method could result in a saving of about 0.6 second per passenger, a decrease of nine to 23 percent. It was also observed that the amount of this time saving will be dependent upon the number of passengers that normally carry exact fare when the cash and change method was in operation and the number of passengers requesting transfers. A study of the Newark subway system indicated that the number of passengers requiring change was a stronger influence on passenger service time than passengers with exact fare.

Fares can be collected both on and off the vehicle. Although no quantitative data were obtained for a comparison, it was generally concluded that off-vehicle fare collection would result in decreased passenger service time.

In the analysis of passenger access to the vehicle, it was indicated that there are 15 possible categories of movement. These can be reduced to six if those categories with rear door boarding are excluded, a situation found in most systems in the United States. Conclusions obtained from the analysis of access included:

1. Boarding service time requirements exceed those for alighting.
2. Alighting times are greater when boarding passengers are present.
3. Fewer delays to alighting and boarding passengers occurred when boarding queues were organized and orderly.
4. The presence of standees increases passenger service time. Observations of bus operations on Bloomfield Avenue in Newark, New Jersey, indicated an increase of 20 percent in boarding and alighting times when standees were present. It was observed that standees did not always interfere with the boarding and alighting of passengers.

Operating policies affect PVI in a number of ways, including vehicle procurement and fare structure. Policies concerning the number of doors and the width of doors have a significant impact upon PVI as described in the previous section. Policies concerning the type of fare, amount of fare, zone systems, and reduced fares for students and the elderly also affect PVI. A flat fare permits organization of flow within the vehicle to front door boarding and rear door alighting, a situation not possible with a zone system. The display of proper identification for free or reduced fare increases passenger service time.

PVI has an effect upon the mobility of individual passengers in a region, since it may exclude certain passengers from using the system. However, a change to the system to make it available for use by all passengers could increase passenger service time, system costs, and travel times.

The effects of climate and weather on PVI require further research. Previous research has indicated that no change occurred between rain and no-rain conditions. Another study has indicated that fewer elderly and handicapped persons travel in inclement weather. From these results it would seem that climate and weather affect PVI; however, additional research is needed to quantify these effects or indicate their direction.

Other system elements both affect and are affected by PVI. Passenger demands make maximum use of PVI during peak periods. PVI is also influenced by the characteristics of these passengers in terms of how willing they are to carry exact fare or what their habits are concerning forming orderly queues. All aspects of the terminal affect PVI. Inadequate or improper use of terminal facilities has an adverse effect upon PVI. Curb height can preclude the use of a lane as a loading area. The operations of a vehicle will affect PVI by considering the attitudes of the drivers and their methods of dealing with passengers. Effects of the line haul element can best be described by considering the effect of signal delay on passenger service time.

Based on the analyses in this chapter, it can be concluded that the Passenger Vehicle Interface can have a significant effect upon the operations of street transit systems. While not all of these effects could be quantified, their direction has been indicated. Those effects which could be quantified can be categorized into the three areas of:

1. Direction of flow
2. Method of fare collection
3. Door characteristics and use

These categories will be used in the next chapter to develop a series of equations to predict passenger time when the number of alighting and boarding passengers is known or estimated.

CHAPTER IV

PASSENGER SERVICE TIME CHARACTERISTICS

Considering the factors affecting PVI, a series of equations was developed to predict passenger service time when the number of alighting and boarding passengers is known or estimated. These equations were developed considering the range of values for the constants and coefficients of the regression equation derived from observed data and have been categorized by the major effects identified in Chapter III, as listed below.

1. Direction of Flow
    a. Alighting
    b. Boarding
    c. Simultaneous Alighting and Boarding
2. Method of Fare Collection
    a. Pay Enter
        (1) Cash and Change - Multiple Zone Fare
        (2) Cash and Change - Flat Fare
        (3) Exact Fare - Flat Fare
    b. No Fare or Pay Leave
3. Door Characteristics and Use
    a. One-door vehicle
    b. Two-door vehicle
        (1) One single door used
        (2) Two single doors used

(3) One double door used

(4) Two double doors used

A range of values has been developed for the parameters of each equation to reflect the effects of those unquantifiable factors not listed above, such as the type of passenger, physical characteristics of passengers, passenger preferences, baggage carried, seating configuration, congestion, etc. The lower limit represents a maximum flow condition for each of the major effects, which could occur during peak periods with well-oriented passengers carrying little or no baggage where no congestion is present. The area between the lower and upper limits represents the influence of these other factors. An understanding of the prevailing local conditions is needed to select the appropriate parameters for any particular system.

4.1 Alighting Only

Passenger Service Time Influence Zone parameters for alighting passengers, are listed in Table 29 and are depicted in Figure 8. It is interesting to note that there is a clear definition between categories. The major category as shown indicates whether one stream or two streams of passengers can move through the door. The next most important consideration is how many doors on the vehicle are being used.

As can be seen in Figure 8, there is no clear definition between categories for low (less than 10) passenger volumes. This situation can

TABLE 29

Passenger Service Time Influence Zone Parameters

Alighting Passengers Only

Width of Doors	Number of Doors on Vehicle	Number of Doors Used	Parameters C_1	Parameters C_2	Observed Range of Passengers
Single	1	1	1.0 to 13.5	1.9 to 2.8	1 to 69
	2	1	0.2 to 1.0	1.5 to 1.9	1 to 20
	2	2	1.9 to 2.0	0.9 to 1.2	1 to 37
Double	2	1	1.8 to 1.9	0.8 to 0.9	2 to 36
	2	2	3.7 to 4.0	0.4 to 0.5	6 to 54

$\bar{T} = C_1 + C_2 A$

where

T = Passenger Service Time in Seconds

A = Number of Passengers Alighting

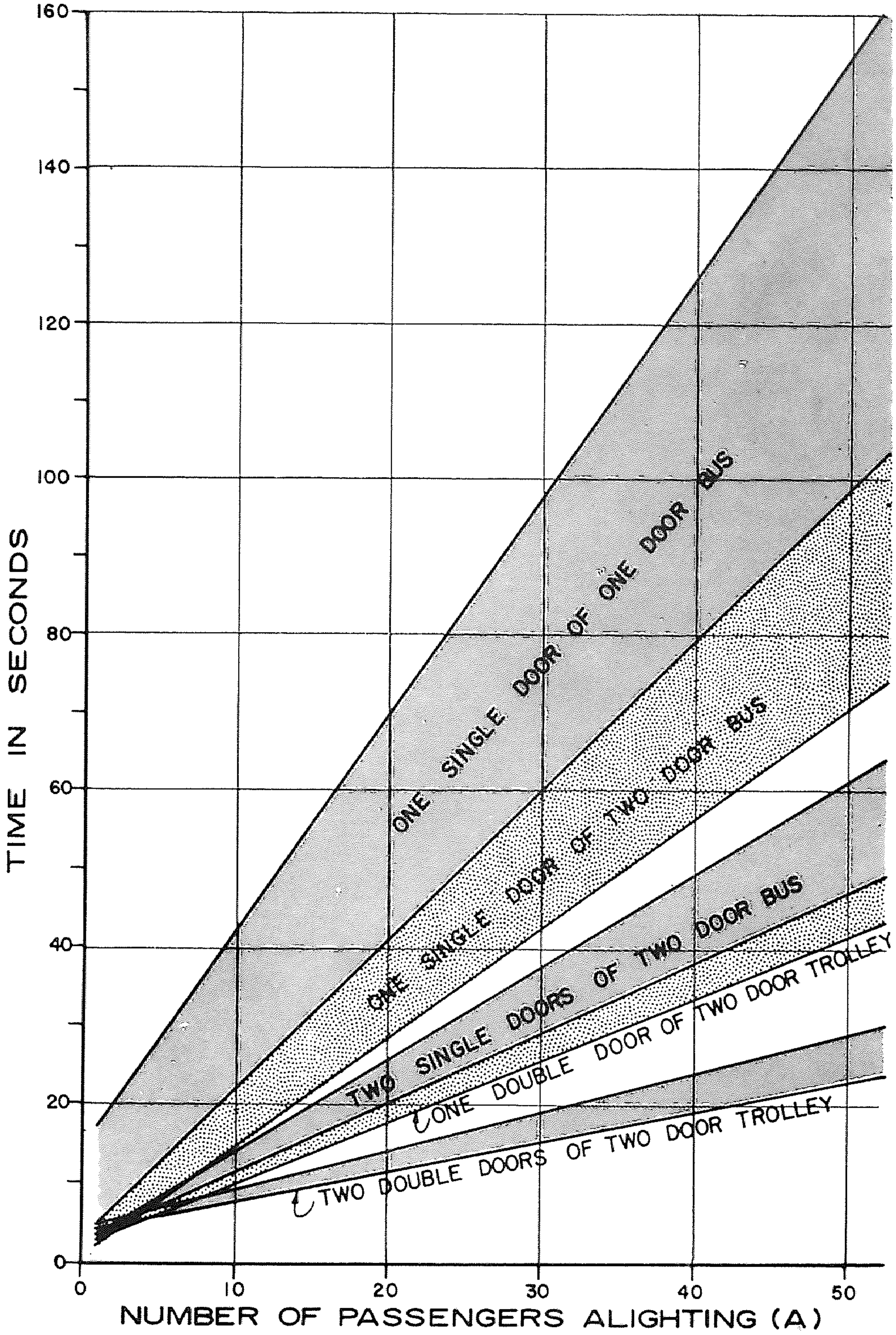


Figure 8 PASSENGER SERVICE TIME INFLUENCE ZONES ALIGHTING PASSENGERS ONLY

be observed for all of the Passenger Service Time Influence Zones presented herein and is due to the variability in time measurements for low passenger volumes. It should also be noted that in some cases the limits of the influence zones have been extended beyond the range of the observed number of passengers listed in Table 29.

The range between the limits of each parameter is shown to increase with increased passenger service time, a condition common with counting data. The range of parameters for movement through one single-width door of a one-door bus is wider than the other ranges because that time is greatly affected by internal congestion.

Figure 8 is a good representation of the effects of door characteristics and use. The greatest amount of time is shown for a single door on a one-door vehicle. This time is progressively reduced with increased door usage and width. In other words, passenger service time and its variability decreased with increased number and width of doors.

No information is given for passenger service time requirements for the payment of a fare when alighting, since no data were obtained. It is the author's contention that these time requirements would be between the limits of the curves shown in Figure 8. It has been observed that for single passengers alighting under a pay-leave method of fare collection the time requirements were similar to a single person alighting under a pay-enter system, since the passenger usually paid before the bus stopped. It is only when more than one person is alighting that the effect of fare collected may become significant. Additional research is needed in this area to determine those conditions that increase alighting time because of payment of a fare.

4.2 Boarding Only

Passenger Service Time Influence Zone parameters for boarding passengers were divided into two areas: one with a payment of fare and the other with no payment of fare.

4.2.1 Pay Enter

The parameters for the condition of payment of a fare while boarding through the front door are listed in Table 30 and are shown in Figure 9.

The major category influencing passenger service time is the method of fare collection. This is further subdivided by the width of the door to permit either single or double stream movement and the type of fare. The greatest amount of passenger service time is indicated for a single-door bus where multiple-zone fares are collected by the cash and change method. In general, it is shown that for single-door vehicles, passenger service time requirements increase with increased driver involvement.

The overlap of the cash and change method with the exact fare method, as shown in Figure 9 is interesting. It may be due to a number of factors, including the number of passengers that normally carry exact fare when the cash and change method is used, the number of transfers, baggage, passenger orientation, etc.

TABLE 30

Passenger Service Time Influence Zone Parameters

Front Door Boarding with Payment of Fare

Method of Fare Collection	Width of Door	Type of Fare	Parameters		Observed Range of Passengers
			C_1	C_2	
Cash and Change	Single	Multiple Zone	-20.0 to -6.6	6.1 to 8.1	2 to 63
	Single	Flat	- 3.0 to 1.0	2.3 to 3.6	1 to 52
	Double	Flat	3.4 to 9.2	0.9 to 3.9	1 to 25
Exact Fare	Single	Flat	1.0 to 4.3	1.8 to 2.9	1 to 49

$T = C_1 + C_2 B$

where

T = Passenger Service Time in Seconds

B = Number of Passengers Boarding

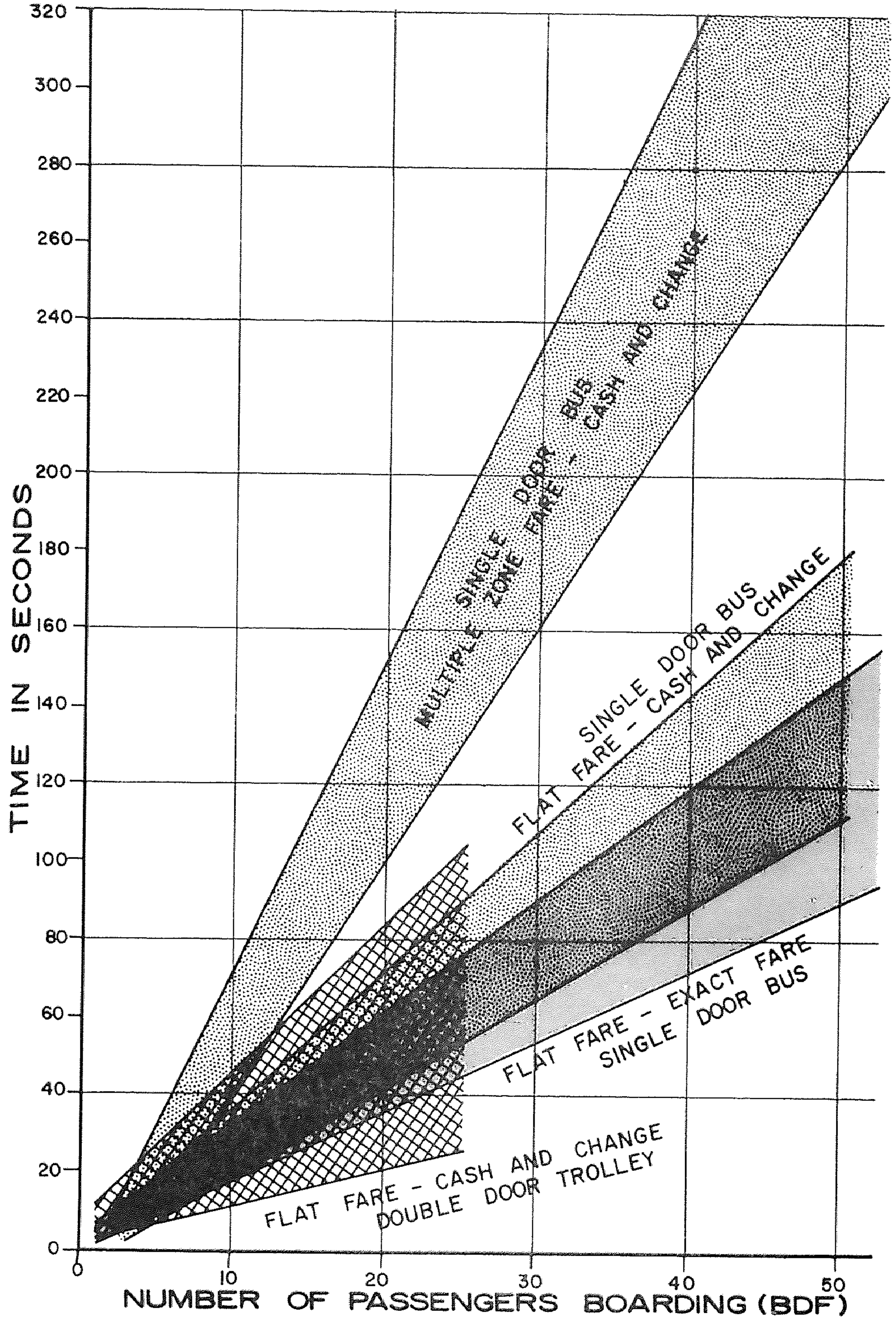


Figure 9 PASSENGER SERVICE TIME INFLUENCE ZONES
FRONT DOOR BOARDING PASSENGERS WITH PAYMENT OF FARE

The greatest range in parameters is shown for the double-door trolley and is due to the amount of passenger utilization. The lower limit represents double stream movement, while the upper limit represents single stream movement through the double doors.

4.2.2 No-Fare

A no-fare condition while boarding could occur on a free system or where the passenger must pay while alighting. In both cases, no driver involvement is necessary except to answer questions. The Passenger Service Time Influence Zone parameters for the no-fare condition are listed in Table 31 and are depicted in Figure 10.

The categories dividing the parameters in Table 31 are the same as those used for the condition of alighting only shown in Table 29. Other similarities between no-fare boarding and alighting only can be observed by comparing in Figures 8 and 10 the relationship of the categories. In both cases passenger service time and its variability decreased with increased numbers and widths of doors. Another comparison is that the passenger service time requirements are greater for the no-fare boarding categories than for comparable categories of alighting.

4.3 Simultaneous Alighting and Boarding

Simultaneous alighting and boarding can occur under two conditions: (1) when the movement is restricted to the front door and (2) when boarding occurs through the front door and alighting occurs through both the front and rear doors.

TABLE 31

Passenger Service Time Influence Zone Parameters

Boarding Passengers with No Payment of Fare

Width of Doors	Number of Doors on Vehicle	Number of Doors Used	Parameters C_1	Parameters C_2	Observed Range of Passengers
Single	1	1	-2.0 to 3.2	2.9 to 3.9	11 to 63
	2	1	-3.0 to -2.0*	2.4 to 2.9*	-
	2	2	2.6 to 3.1*	1.1 to 1.4*	-
Double	2	1	1.6 to 2.6	0.9 to 1.1	1 to 29
	2	2	0.5 to 0.6	0.7 to 0.8	4 to 38

$T = C_1 + C_2 B$

where

T = Passenger Service Time in Seconds

B = Number of Passengers Boarding

*Estimated parameters developed by author based on available information.

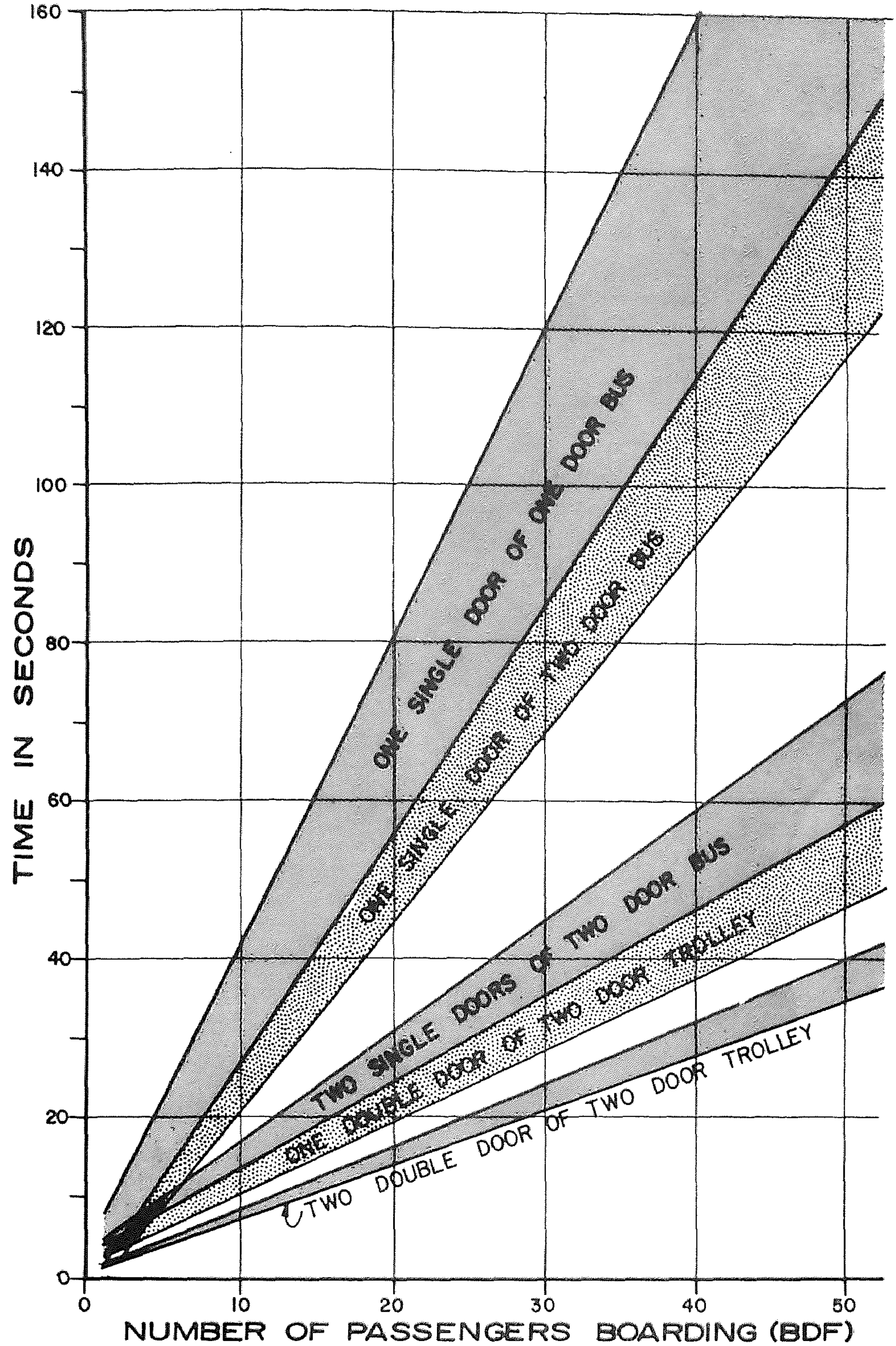


Figure 10 PASSENGER SERVICE TIME INFLUENCE ZONES
BOARDING PASSENGERS WITH NO PAYMENT OF FARE

4.3.1 Front Door Alighting and Boarding

As was described in Chapter III, alighting times are slightly greater when boarding passengers are present. This condition is reflected in the Passenger Service Time Influence Zone parameters shown in Table 32. No illustration was prepared to depict the influence zones, since they could not be compared visually by using two-dimensional models. Three-dimensional models would be required.

4.3.2 Alighting through Both Doors and Boarding through Front Door

Predictive equation parameters when alighting occurs through both doors and boarding occurs through the front door are listed in Table 33. Again, no comparative illustration was prepared, since three-dimensional models would be required. As listed in Table 33, the parameters for the exact fare method of fare collection are generally less than those for the cash and change method.

The equation associated with Table 33 contains a negative adjustment for the combined operation of boarding through the front door and alighting through both doors (A · BDF). This term is logical and has been reported by others.(9)(18)(21) It indicates that it does not take proportionally as long to serve both boarding and alighting passengers as for each operation separately when two doors are used for alighting and the front for boarding.

4.4 Summary

Considering the factors affecting the Passenger Vehicle Interface a set of Passenger Service Time Influence Zone parameters were developed

Table 32

Passenger Service Time Influence Zone Parameters Passenger Alighting and Boarding Through the Front Door with Payment of a Flat Fare

Method of Fare Collection	Parameters		
	C_1	C_2	C_3
Cash and Change	1.0 to 2.0	1.2 to 2.0	2.3 to 4.5
Exact Fare	0.5 to 1.5	1.0 to 1.9	1.8 to 2.9

$$T = C_1 + C_2\,ALF + C_3\,BDF$$

where

T = Passenger Service Time in Seconds

ALF = Number of Passengers Alighting Through Front Door

BDF = Number of Passengers Boarding Through Front Door

TABLE 33

Passenger Service Time Influence Zone Parameters Passengers Alighting Through Both Doors and Boarding Through The Front Door with Payment of a Flat Fare

Method of Fare Collection	Parameters C_1	C_2	C_3	C_4
Cash and Change	-0.1 to 3.6	0.9 to 2.2	2.3 to 4.9	0.02 to 0.5
Exact Fare	0.5 to 2.4	1.0 to 1.4	2.1 to 2.9	0.02 to 0.1

$$T = C_1 + C_2 A + C_3 BDF - C_4 (A \cdot BDF)$$

where

T = Passenger Service Time in Seconds

A = Number of Passengers Alighting

BDF = Number of Passengers Boarding Through Front Door utilizing the range of values for the constants and coefficients of the regression equations derived from observed data. These were categorized by the major effects of direction of flow, method of fare collection, and door characteristics and use. A range of values was developed for each parameter to reflect the effects of those unquantifiable factors such as type of passenger, physical characteristics of passengers, passenger preferences, baggage carried, congestion, etc. The lower limit of the range of parameters represents a maximum flow condition.

The range of parameters was depicted in a series of Influence Zones which portrayed the differences between the passenger service time requirements of major effects. These were developed for the conditions of Alighting Passengers Only, Front Door Boarding Passengers with Payment of Fare, and Front Door Boarding Passengers with No Payment of Fare. Influence zones were not developed for the condition when passengers were alighting and boarding at the same stop, since visual comparisons could not be made by use of two-dimensional models.

The Passenger Service Time Influence Zone parameters are valuable tools to be used to estimate passenger service time and to evaluate changes to the operations of street transit systems.

CHAPTER V

PASSENGER SERVICE TIME DISTRIBUTIONS

As with other portal systems, the door of a street transit vehicle can be viewed as a single server queueing model. Passengers arrive at a certain rate, pass through a service area, and depart at another rate. The rate of departure is dependent upon how fast they can pass through the service area. A simulation model of such a system for transit stations has been developed by Fausch,(33) using generalized arrival and departure rates.

5.1 Bus Door Capacity

Simulation models of the type developed by Fausch are powerful tools that can be used in evaluating the operations of street transit terminals. Necessary information for such a simulation includes data on bus door capacity and should include information on the arrival and service time distributions of passengers. Under maximum capacity conditions the arrival of either alighting or boarding passengers occurs as a group. In other words, when a bus arrives at a stop, the boarding passengers are already waiting. The same is true for alighting passengers, except that they are waiting in the vehicle. The service time distribution is not the same for boarding and alighting passengers and is dependent upon the factors affecting PVI as described in Chapter III.

5.2 Photographic Studies

To evaluate and understand the service time distributions of passengers, photographic studies were undertaken. These consisted of filming individual passengers alighting and boarding from the front door of buses in San Diego, California; Montreal, Canada; and New Brunswick, New Jersey. The survey methods and data summary procedures are described in Appendices A1 and A2, respectively.

Two topics of analysis were undertaken. One was to study the time sequence of passengers in the order that they boarded the bus; the other was to determine the distribution characteristics of service times for boarding and alighting passengers.

5.2.1 Time Sequence of Passengers

The average service times of the first 18 passengers in the sequence that they boarded were analyzed for observations taken in San Diego and Montreal. The analysis of variance (ANOVA) technique was used to detect differences. As might be expected with counting data, it was determined that the cell variances were not equal and were proportional to the cell means. Homogeniety of variance was obtained by using a logarithmic transformation and a two-factor ANOVA was performed. A plot of the cell means is depicted in Figure 11. As shown, the time for the first passenger is generally less than for the succeeding passengers. This is due to the storage area on the steps between the bus door and the driver and could be changed by recording the starting time differently.

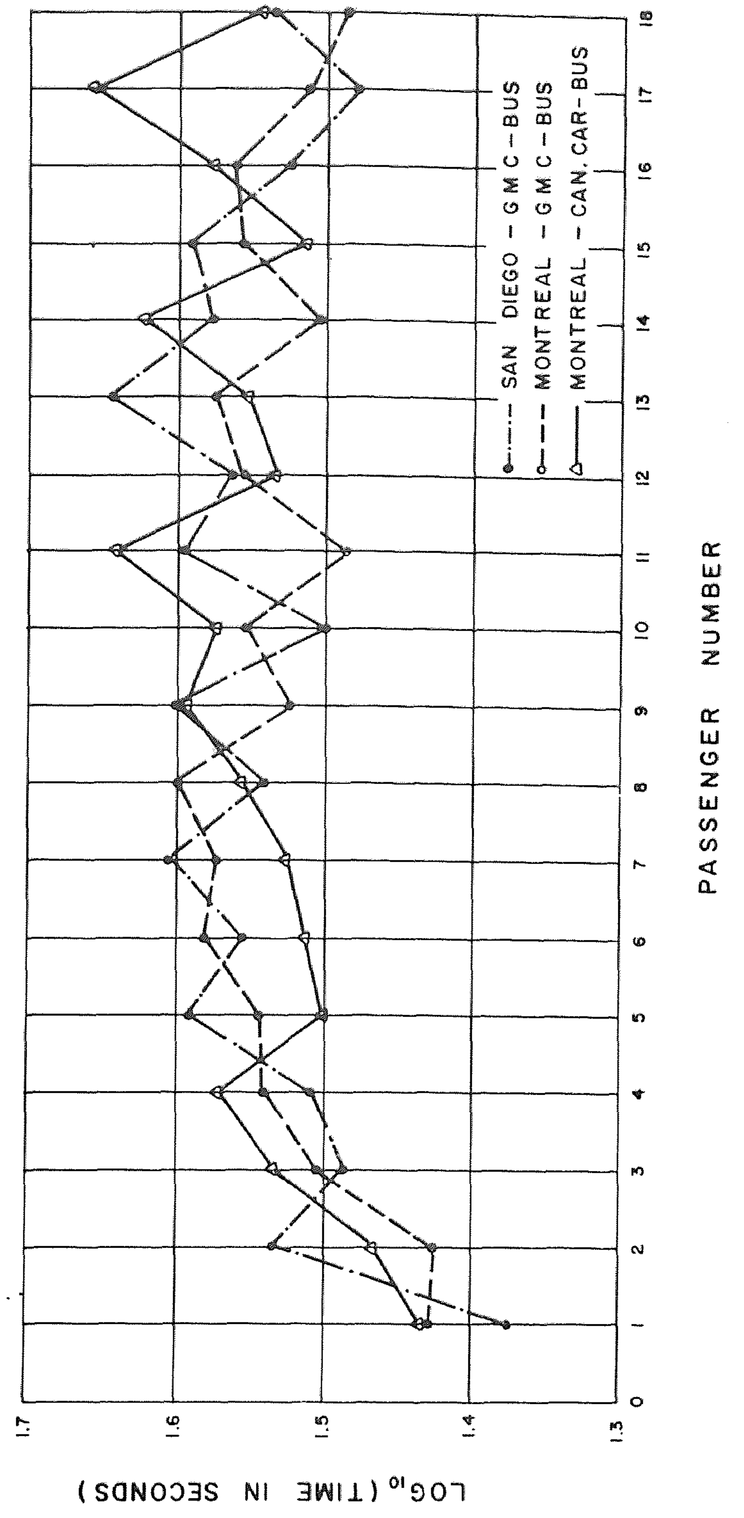


Figure 11 AVERAGE SERVICE TIMES OF PASSENGERS IN THE SEQUENCE THAT THEY BOARDED

Using the results of ANOVA and analyzing Tukey's limits for multiple comparisons at the five percent level, it was determined that the time differences between the first and third through the n^{th} passenger were statistically significant at the 95 percent level. The time differences between the second and all other passengers were not statistically significant at the 95 percent level.

5.2.2 Service Time Distribution

Since the data summarized from the photographic studies included the time for each successive person to pass through the vehicle door, it was possible to prepare a tabulation of service time distributions. The means and variances of each of these distributions were calculated, as shown in Table 34, to assist in the determination of which function could be used to represent these distributions.

TABLE 34

Means and Variances of Observed Passenger Service Time Distributions

Location	Direction of Flow	Bus Type	Doors on Bus	Time in Seconds	
				Mean	Variance
Montreal, Canada	Boarding	Can.Car	2	2.097	0.727
Montreal, Canada	Boarding	GMC	2	2.034	0.834
New Brunswick, New Jersey	Alighting	GMC	1	1.972	1.045
New Brunswick, New Jersey	Boarding	GMC	1	3.471	3.499
San Diego, Cal.	Alighting	GMC	2	1.472	0.403
San Diego, Cal.	Boarding	GMC	2	2.180	0.868

Several types of service time distributions have been used in the development of queueing models, including the Gamma function, the Erlang function, and the uniform distribution function. The one most commonly used is the negative exponential function, a special case of the Erlang function.(31)(32)(33)

The probability density functions of each of the distributions were plotted to view their general shape. From these observations, it was hypothesized that the distributions could be described by the following Erlang function:(31)

$$P\ (g \geq t) = \sum_{i=o}^{K-1} \left[\frac{K\ (t - \tau)}{(\bar{t} - \tau)}\right]^{i} \frac{e^{-\frac{K\ (t - \tau)}{(\bar{t} - \tau)}}}{i!}$$

where

$P\ (g \geq t)$ = probability that time "g" is greater than or equal to time "t"

K = a positive integer

t = any service time

$\bar{t}$ = average service time

τ = minimum service time

Using the individual means and variances, an Erlang function was calculated for each distribution. Integer values of K were estimated from the mean ($\bar{t}$), variance (s^2) and minimum service time (τ) by the following:

$$K \approx \frac{(\bar{t} - \tau)^2}{s^2}$$

These initial K values were adjusted, as necessary, to improve the goodness of fit between the observed and calculated distributions. Table 35 lists the individual parameters for each function.

TABLE 35

Parameters of Erlang Functions Derived from Observed Passenger Service Time Distributions

Location	Direction of Flow	Bus Type	Doors on Bus	Parameters K	$\bar{t}$	τ
Montreal, Canada	Boarding	Can.Car.	2	2	2.097	0.90
Montreal, Canada	Boarding	GMC	2	2	2.034	1.25
New Brunswick, New Jersey	Alighting	GMC	1	1	1.972	0.95
New Brunswick, New Jersey	Boarding	GMC	1	1	3.471	1.75
San Diego, California	Alighting	GMC	2	2	1.472	0.75
San Diego, California	Boarding	GMC	2	2	2.180	0.75

K = a positive integer

$\bar{t}$ = average service time

τ = minimum service time

As indicated by the K value of 1, the two distributions for the one-door buses are represented by a special case of the Erlang function--the negative exponential function. Figures 12 through 17 depict the observed values and the calculated functions.

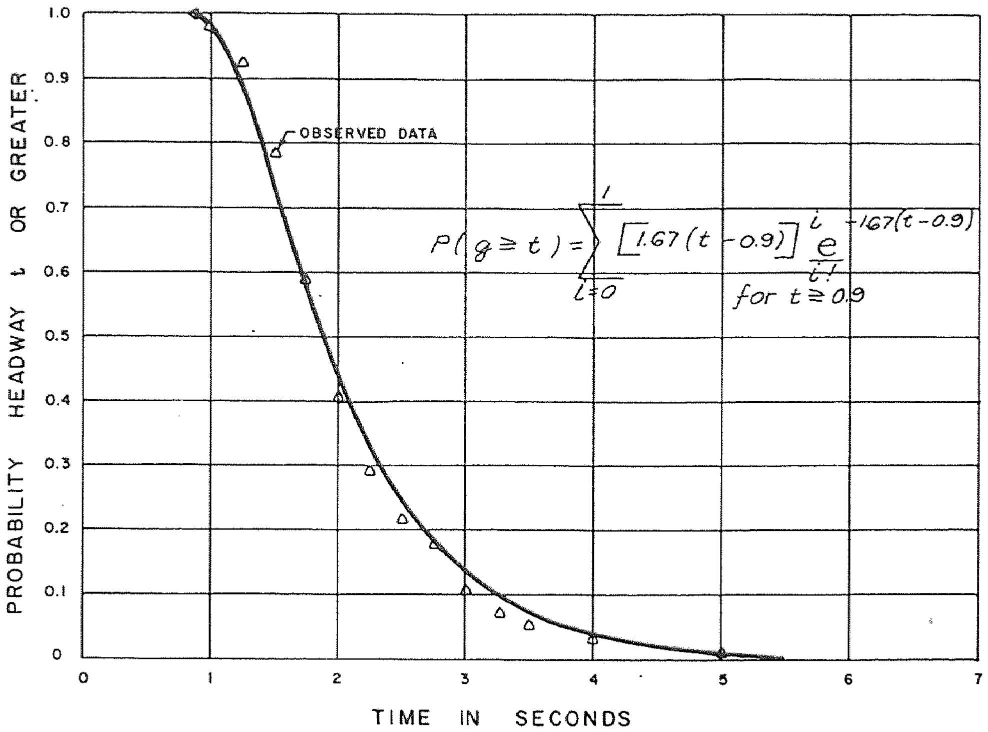


Figure 12 SERVICE TIME DISTRIBUTION OF PASSENGERS BOARDING CANADIAN CAR BUSES IN MONTREAL, CANADA

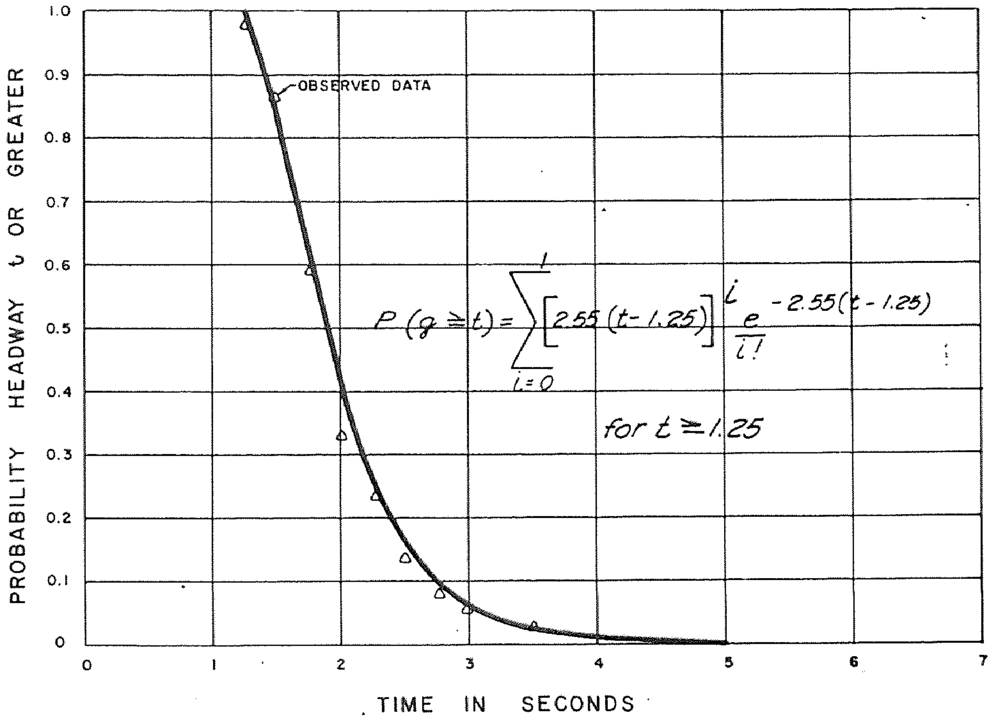


Figure 13 SERVICE TIME DISTRIBUTION OF PASSENGERS BOARDING GENERAL MOTORS CORPERATION BUSES IN MONTREAL, CANADA

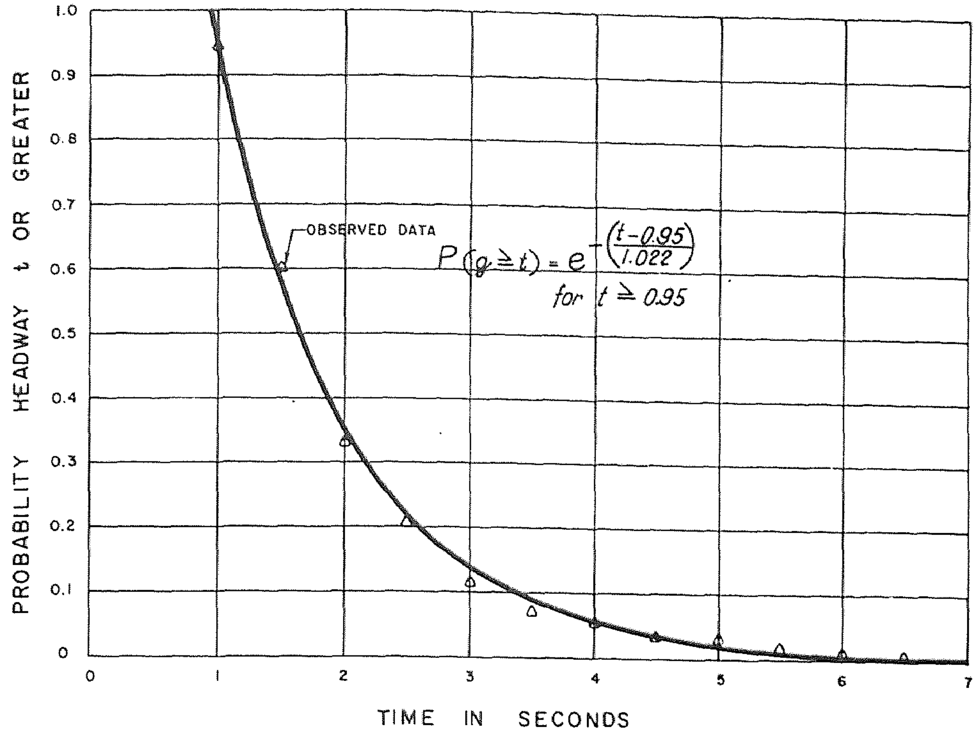


Figure 14 SERVICE TIME DISTRIBUTION OF PASSENGERS ALIGHTING FROM BUSES IN NEW BRUNSWICK, NEW JERSEY

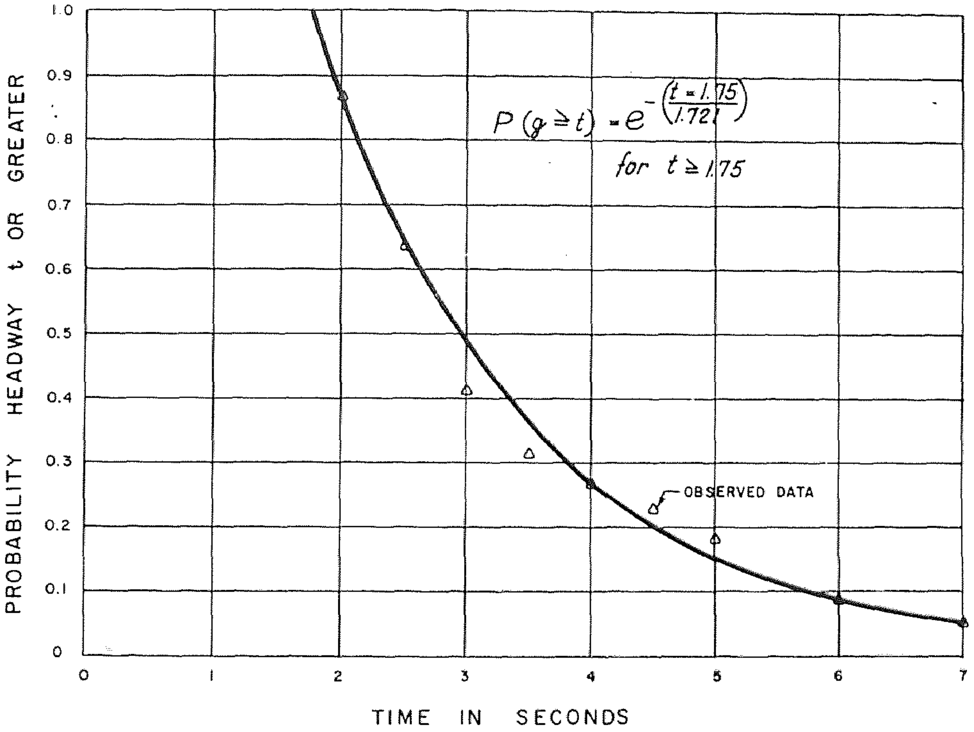


Figure 15 SERVICE TIME DISTRIBUTION OF PASSENGERS BOARDING BUSES IN NEW BRUNSWICK, NEW JERSEY

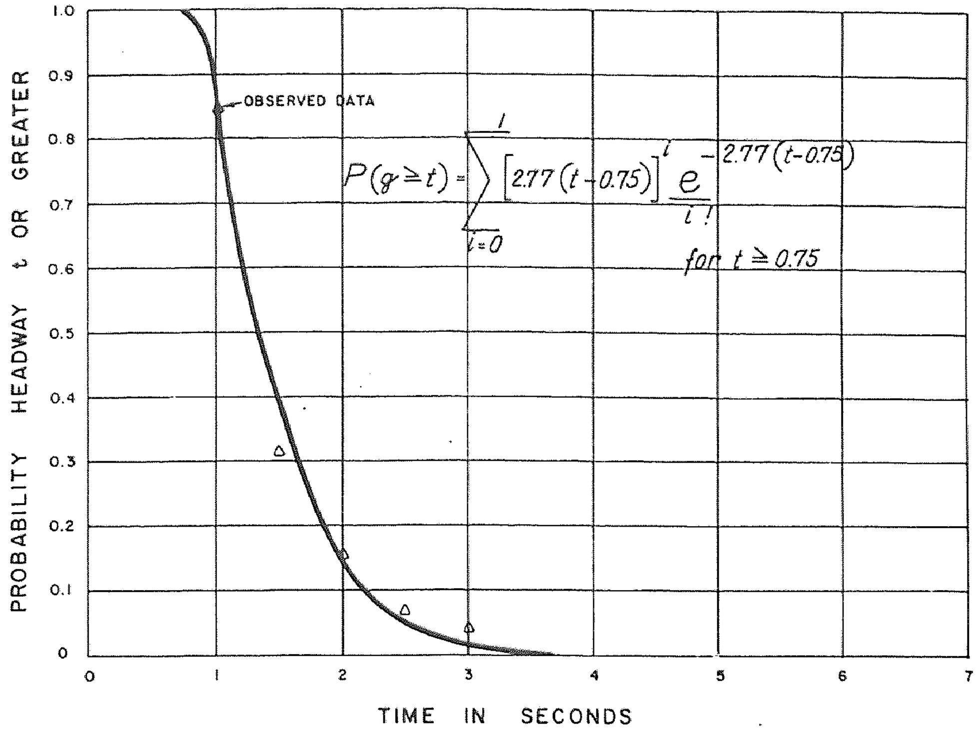


Figure 16 SERVICE TIME DISTRIBUTION OF PASSENGERS ALIGHTING FROM BUSES IN SAN DIEGO, CALIFORNIA

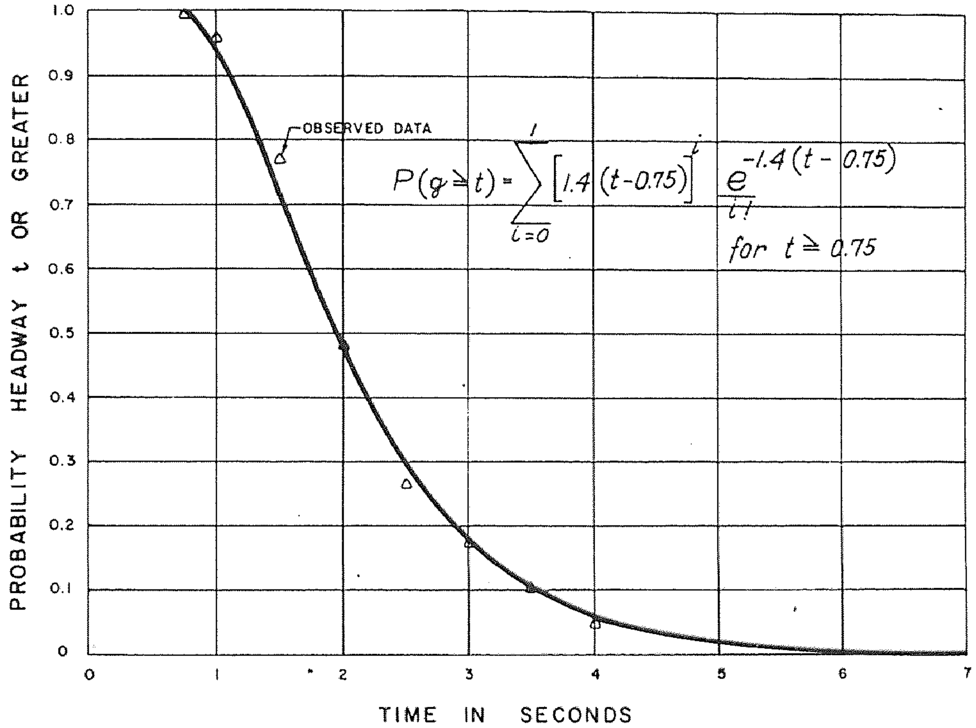


Figure 17 SERVICE TIME DISTRIBUTION OF PASSENGERS BOARDING BUSES IN SAN DIEGO, CALIFORNIA

To test the mathematical validity of these results, the distributions of the observed and calculated functions were compared by a chi square test. The test results, as shown in Table 36, did not reject the hypothesis that the distributions were the same at the 95 percent level.

TABLE 36

Comparison of Observed and Calculated Erlang Distributions

Location	Direction of Flow	Bus Type	Doors on Bus	Chi Square Test	Chi Square Statistic @ 95% Level
Montreal, Canada	Boarding	Can.Car.	2	2.67	7.81
Montreal, Canada	Boarding	GMC	2	7.74	9.48
New Brunswick, New Jersey	Alighting	GMC	1	10.61	14.07
New Brunswick, New Jersey	Boarding	GMC	1	1.15	5.99
San Diego, California	Alighting	GMC	2	1.82	3.84
San Diego, California	Boarding	GMC	2	9.87	11.07

From the information contained in Tables 35 and 36, it can be concluded that passenger service time distributions can be represented by an Erlang function. It also infers that the value of K is equal to the number of doors on the vehicle and that the minimum service time (τ) is approximately equal to half the average service time ($\bar{t}$). These results can be used to estimate any particular passenger service time distribution if the minimum and average service times are known and an estimate is made of K.

5.3 Summary

The photographic studies provided data on the successive time for each person to pass through the vehicle door. This information was used to analyze the individual time sequences and service time distributions of alighting and boarding passengers.

The individual time sequence analysis of the first 18 passengers indicated that the individual service time required for the first boarding passenger was less than that required for the third through n^{th} passenger. There was no difference in individual service times between the second and all other passengers.

Analysis of the distributions of individual service times indicated that these distributions can be represented by an Erlang function. The two distributions representing the single-door buses were found to follow a special case of the Erlang function--the negative exponential function. These results are important, since they indicate that passenger service time distributions can be estimated by using an Erlang function when the average and minimum service times are known or estimated.

CHAPTER VI

ANALYSIS OF RESULTS

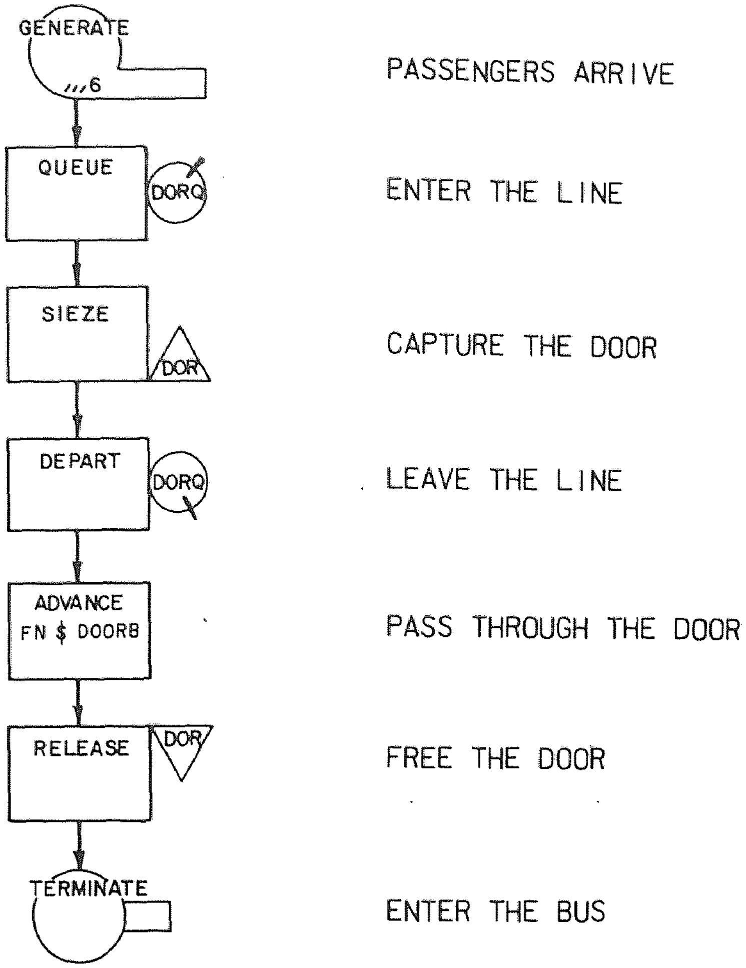
To analyze the results of this research, two approaches were taken. One included a comparison between the data obtained by manual surveys of the time for an entire queue to board the vehicle and the data obtained by the photographic studies of individual passenger service time. The second included a comparison between service time distributions and stairway service standards.

6.1 Comparison of Service Time Distribution with Multiple Regression Equations

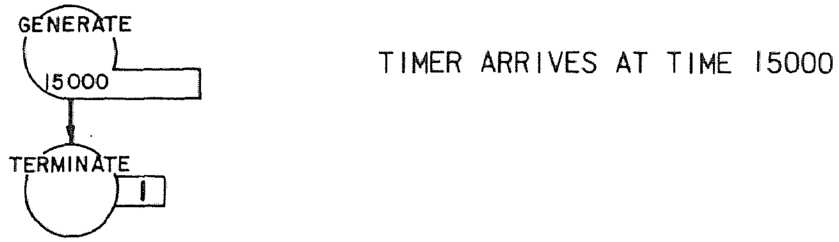
Since it has been determined that the individual service times can be represented by an Erlang distribution, it should then be possible to derive regression equations of the time required for varying sizes of queues to enter a bus. The validity of these derived equations could then be determined by comparing them with the equations developed from observed data. Toward this end, a simulation model was developed that could be used to determine the amount of time that it would take a specified number of passengers to board a bus.

6.1.1 Development of Simulation Model

The model was constructed as a single sequence of blocks, as shown in Figure 18. The definition of GPSS entities is contained in Table 37.



a. MODEL SEGMENT 1



b. MODEL SEGMENT 2

Figure 18 BLOCK DIAGRAM OF SIMULATION MODEL FOR VALIDATION TESTS

TABLE 37

Table of Definitions for Simulation Model for Validation Tests

GPSS Entity	Interpretation
Transactions	
Model Segment 1	Passengers
Model Segment 2	A Timer
Facilities	
DOR	The Bus Door
Queues DORQ	The queue used to gather statistics on the waiting experience of passengers.

Time Unit: One-hundredth of a second.

Basically, the model generates any specified number of passengers to arrive at the bus instantaneously. The first passenger in line then captures the door, leaves the line and passes through the door, based on a randomly selected value from the Erlang service time functions derived in the previous Chapter. He then frees the door and enters the bus. At that time, the next passenger captures the door and the process continues.

Model Segment 2 is a timer that puts a limit on the amount of time the model can simulate. The maximum time is usually set at the maximum amount that could be expected if all maximum service times were used. A partial program listing is shown on Figure A-11 in Appendix A6.

6.1.2 Comparison of Simulated versus Observed Results

The simulation model was run twice for each integer in the range of values for the observed regression equations. In other words, if the original observed regression equation had values ranging between six and 25, then the derived regression equations were run twice for each of the values between six and 25. Comparisons between the observed and simulated equations and other statistics are contained in Tables 38 through 42. As can be seen, each of these simulated equations were appropriately structured and are statistically significant. It should be noted that only four of the five Erlang functions were simulated, the reason being that the observations of the boarding passengers in New Brunswick were too few in number and clustered in too narrow a range to develop a meaningful observed regression equation. Therefore, this comparison was not made.

The simulated equations were compared with the observed equations by using an *F* test for the variances of estimate and a *t* test for the slopes. This comparison is contained in Table 43. As shown, all *F* tests and four out of five *t* tests indicated that the differences were not statistically significant at the 95 percent level. The fifth test indicated that the difference was not statistically significant at the 98 percent level. It was therefore concluded that the simulation produced results consistent with observed data.

6.2 Comparison of Service Time Distributions with Stairway Service Standards

In his work, Fruin determined that the maximum flow volumes for persons ascending and descending stairs were 18.9 and 20.0 persons per minute

TABLE 38

Validation Test Equations for Passengers Boarding Canadian Car Buses in Montreal, Canada

	Observed	Simulated
Equation	$T = -3.3720 + 2.3359\ BDF$	$T = 0.8462 + 2.0790\ BDF$
n	12	38
R^2	0.97	0.95
S_E	2.64	2.64
$S_{E/\bar{t}}$	0.09	0.08
F Test	334.90	708.02
F Statistic @ 95% Level	4.96	4.12

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 39

Validation Test Equations for Passengers Boarding

General Motors Corporation Buses in Montreal, Canada

	Observed	Simulated
Equation	$T = -4.4992 + 2.3724\ BDF$	$T = -0.2363 + 2.0767\ BDF$
n	18	43
R^2	0.98	0.95
S_E	2.54	3.07
$S_{E/\bar{t}}$	0.09	0.09
F Test	687.47	747.81
F Statistic @ 95% Level	4.49	4.08

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 40

Validation Test Equations for Passengers Alighting from Buses in New Brunswick, New Jersey

	Observed	Simulated
Equation	$T = 0.9563 + 1.9453\ ALF$	$T = -1.1492 + 2.1191\ ALF$
n	21	61
R^2	0.91	0.94
S_E	5.73	4.59
$S_{E/\bar{t}}$	0.15	0.15
F Test	197.72	1004.00
F Statistic @ 95% Level	4.38	4.00

ALF = Number of Passengers Alighting Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 41

Validation Test Equations for Passengers Alighting from Buses in San Diego, California

	Observed	Simulated
Equation	$T = 0.1968 + 1.4545$ ALF	$T = 0.1511 + 1.4781$ ALF
n	11	29
R^2	0.95	0.95
S_E	1.57	1.44
$S_{E/\bar{t}}$	0.27	0.13
F Test	168.10	522.77
F Statistic @ 95% Level	5.12	4.21

ALF = Number of Passengers Alighting Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 42

Validation Test Equations for Passengers Boarding Buses in San Diego, California

	Observed	Simulated
Equation	$T = 0.6997 + 2.1308\ BDF$	$T = 0.7662 + 2.1432\ BDF$
n	23	66
R^2	0.92	0.97
S_E	5.12	3.92
$S_{E/\bar{t}}$	0.21	0.10
F Test	246.59	1826.10
F Statistic @ 95% Level	4.32	4.00

BDF = Number of Passengers Boarding Through Front Door

n = Number of Observations

R^2 = Coefficient of Determination

S_E = Standard Error of Estimate

$\bar{t}$ = Mean Response

T = Passenger Service Time in Seconds

TABLE 43

Comparison of Test Statistics with Tabular Values for Validation Tests

			Test			
			F		*t*	
Location	Direction of Flow	Bus Type	Test	Statistic @ 95% Level	Test	Statistic @ 95% Level
Montreal, Canada	Boarding	Canada Car	1.00	2.91	1.72	2.02
Montreal, Canada	Boarding	GMC	1.46	2.15	2.33	2.39*
New Brunswick, New Jersey	Alighting	GMC	1.56	1.75	1.26	2.00
San Diego California	Alighting	GMC	1.19	2.25	0.60	2.03
San Diego, California	Boarding	GMC	1.71	1.73	0.10	1.99

**t* Statistic @ 98% Level

per foot of stair width, respectively.(47) These results were similar to the values of 19 and 21 recommended by Hankin and Wright as design criteria for London Subways.(48) The average service times previously discussed in Chapter V were transformed into similar flow rates, as shown in Table 44.

TABLE 44

Maximum Observed Flow Rates Through Front Door of Bus

Direction of Flow	Fare	Percent Passengers Carrying One Item or More	Maximum Observed Flow in Persons Per Minute Per Foot
Alighting (Down)	Flat, Exact Fare*	55	16.30
	Multiple Zone Cash and Change*	82	12.17
Boarding (Up)	Flat, Exact Fare	52	11.01
	Flat, Cash and Change	81	11.80
	Multiple Zone Cash and Change	78	6.90

*No fare was collected from alighting passengers.

For both directions of flow, the maximum observed values are less than those observed by Fruin and recommended by Hankin. These results are quite logical for a number of reasons. The riser height on bus stairs is normally higher than building stairs (nine to 10 inches vs. six to eight inches) and would be expected to result in slower climbing speeds. Since the fare or method of fare collection should have no effect on alighting, the different flows shown in Table 44 for alighting are probably due to the effect of baggage. The boarding flows are different because they are affected by baggage, fare, and method of fare collection.

6.3 Summary

The results of this research were analyzed by two methods. One was done by the development of a simulation model where queues of varying lengths were waiting to board or alight from a bus according to an Erlang distribution. The output of the model, consisting of the total time for each queue to pass through the bus door, was used to develop a derived multiple regression equation for each observed situation. Using an F test for the variances of estimate and a t test for the slopes, the derived equations were compared with equations developed from observed data. All F tests and four of the five t tests indicated that the differences were not statistically significant at the 95 percent level. The fifth t test indicated that the difference was not statistically significant at the 98 percent level. It was, therefore, concluded that the simulated results were the same as the observed results.

The second method of analyzing results consisted of comparing passenger service times standards with stairway service standards. Although no direct statistical comparison was made, it was observed that the bus passenger service time standards in terms of persons per minute per foot of flow were less than the stairway service standards, as would be expected.

CHAPTER VII

APPLICATION

Based on the results of the analyses described in previous chapters, it can be concluded that the Passenger Vehicle Interface definitely influences the operations of a street transit system. This conclusion can best be demonstrated by examples to evaluate the degree of influence for various conditions. Since all existing street transit systems are different, the peculiarities of each, such as passenger demand, vehicles used, methods of operating, etc., will provide results different from those of the following examples.

There are many applications for the research results reported herein. Earlier works by the author have been used by Fausch in his development of a simulation model of pedestrian movements in a transit terminal,(33) by Radelat in his simulation of urban bus operations on signalized arterials,(21) and by Levinson, Adams and Hoey in their development of planning and design guidelines for efficient bus utilization of highway facilities.(49) Application of the results reported herein by the above persons should improve their research results and enable the tools that they have developed to be more universally applicable.

The usefulness of this research will be demonstrated by examples in three areas that are of interest to street transit system planners and operators. The first is terminal design, where the amount of platform space, the number of bus berths, and transit vehicle schedules are contingent upon the time required to serve patrons. These design considerations often govern the acceptability of a particular site, the layout of a proposed terminal, and the cost of such facilities. The prime locations for terminals are in the downtown areas, where space for transit facilities is severely limited. Miscalculating the number of loading berths or required platform space can result in using too much valuable land and cause inefficiencies in facility operations.

The second area is in optimizing street transit operations for a typical route. The third area is in the development of simulation models where a model of a typical terminal loading area will be developed.

7.1 Terminal Operations

Two examples will be given of the effects of the PVI on terminal operations. One will be for alighting operations, and the other for boarding.

7.1.1 Example 1 - Unloading Platform

An intermodal transfer facility is being constructed in a downtown area to provide for the transfer of persons between a street transit system and a rail rapid transit system. It is estimated that vehicles from the street transit system will enter the facility and each discharge 50 passengers. To aid in planning the facility, it is necessary to know the number of unloading berths that will be required if the vehicles enter at one-minute headways.

Since the type of vehicle has not been given, the required number of berths will be determined for each type, using the information given in Table 29 and Figure 8. First, the minimum (lower limit) and maximum (upper limit) passenger service times for each vehicle are determined. Next, the probable headways between vehicles are determined by increasing the minimum and maximum passenger times by the clearance time required for one vehicle to maneuver out of the berth and for another to maneuver in. For this example, a clearance time of 20 seconds has been used. The required number of berths is then calculated by dividing the probable headways by the operating headway. The results of these calculations are shown in Table 45. As shown, berth requirements decrease with increased door use.

TABLE 45

Example 1 - Unloading Platform Requirements

Width of Door	Number of Doors on Vehicle	Number of Doors Used	Passenger Serv. Time per Vehicle in Seconds		Probable Vehicle Headway in Seconds		Required Number of Berths for One Minute Vehicle Headways
			Min.	Max.	Min.	Max.	
Single	1	1	96	154	116	174	3
	2	1	75	96	95	116	2
	2	2	47	62	67	82	2
Double	2	1	42	47	62	67	2
	2	2	24	29	44	49	1

7.1.2 Example 2 - Loading Platform

A suburban bus route originates from a single berth of a downtown terminal. Upon boarding, passengers pay their fare based on a multiple zone system, and a bus leaves every five minutes during the afternoon peak period. Since passenger demands are increasing, the terminal operator wishes to know the maximum number of passengers per hour that can be sent out of that berth.

For this analysis, it will be assumed that only full buses of 49 passengers will be sent out and that a clearance time of 20 seconds will be needed from the time one bus stops loading until the next bus is ready. Since peak hour passengers are being considered, the lower limit of each influence zone will be used. Using Figure 9, 49 passengers will require 279 seconds to board, resulting in a minimum vehicle headway of 299 seconds. This headway represents 12 buses per hour and 588 passengers per hour. If a pay leave system were used, the berth capacity would be 22.5 buses per hour or 1,102 passengers per hour. These values were obtained using Figure 10 where 49 passengers will require 140 seconds to board, resulting in a minimum vehicle headway of 160 seconds. Table 46 lists the results of this example.

TABLE 46

Example 2 - Loading Platform Requirements for a Multiple Fare Zone - Cash and Change Method of Fare Collection

Method Fare Collection	Maximum Capacity	
	Buses per Hour	Passengers per Hour
Pay Enter	12	588
Pay Leave	22.5	1,102

7.2 Street Transit Operations

The effects of PVI on street transit operations will be shown by two examples. In each case, the time required for a vehicle to travel between points A and F will be considered. This time will be divided into the three parts of running time, traffic delay time, and passenger service time. It will be assumed that the running time between each stop is 240 seconds and that traffic delay time for each stop (including the time to enter and leave the bus stop) is 25 seconds. The passenger demands for each stop are shown in each example.

7.2.1 Example 3 - Suburban Service

Although a pay leave method permits higher berth capacities as shown in Example 2, its effect upon the total system should be studied. Toward this end, a comparison was made using the influence zones shown on Figures 8 through 10. Since no data were obtained for alighting passengers with a pay leave method of fare collection, the upper limits of the influence zones were used as an approximation. Table 47 lists the passenger demands at each stop and the predicted passenger service times. As indicated, the total trip times for both methods of payment are almost the same, with the pay enter method being about two percent higher. The net result is an improvement in terminal operations with practically no change in total trip time. Local conditions will, of course, provide different results.

TABLE 47

Example 3 - Comparison of Method of Fare Collection for Suburban Service

	Number of Passengers		Passenger Service Time in Seconds	
Stop	Alighting	Boarding	Pay Leave Method	Pay Enter Method
A	-	49	140	279
B	15	-	56	31
C	10	-	42	22
D	5	-	28	12
E	8	-	36	18
F	11	-	45	386
Subtotal			347	386
Running Time			1,200	1,200
Traffic Delay Time			125	125
Total Trip Time			1,672	1,711

7.2.2 Example 4 - Local Service

A local street transit system operates a route with passenger demands for stops A through F as listed in Table 48. Passenger service time requirements were calculated for each stop, using the lower limits of the parameters in Tables 29, 30, 32, and 33. The equations in Appendix A3 were used to calculate passenger service times for simultaneous alighting and boarding for double stream doors. The passenger service times and total trip times for two methods of fare collection and door use are shown in Table 49. For the cash and change method of fare collection, the least amount of time is shown for a two-door vehicle with double stream doors. The most time is shown for a two-door vehicle with a single stream vehicle being used, an increase of 126 percent for passenger service time and eight percent in total trip time. For the exact fare method of fare collection, the passenger service times and total trip times are almost the same for the use of either one or two doors. Similar comparisons can be made for any street transit system.

TABLE 48

Example 4 - Passenger Demand

	Number of Passengers	
Stop	Alighting	Boarding
A	-	30
B	5	10
C	8	12
D	9	-
E	15	5
F	20	-

7.3 Model Simulation

A model of a typical terminal loading platform was developed using the special purpose language GPSS (General Purpose Simulation System).(1) The initial work was done using GPSS/360; however, due to a change in computer facilities, the model was completed using GPSS/V. This conversion did not affect the basic model building except for the default values of the random number generator. The initial multiplier for each random number generator is 1 for GPSS/360; for GPSS/V the initial multiplier is 37.

TABLE 49

Example 4 - Comparison of Door Use and

Method of Payment

Fare Collection	Width of Door	Number of Doors Used	Passenger Service Time A	B	C	D	E	F	Sub-Total	Running Time	Traffic Delay Time	Total Trip Time
Cash and Change	Single	1	66	30	38	15	31	28	208	1200	125	1533
		2	66	26	33	11	23	20	179	1200	125	1504
	Double	1	32	22	28	10	28	18	138	1200	125	1463
		2	32	12	15	7	15	11	92	1200	125	1417
Exact Fare	Single	1	55	24	30	11	25	28	173	1200	125	1498
		2	55	26	31	15	24	20	171	1200	125	1496

7.3.1 Example 5 - Simulation of Terminal Loading Platform

At a typical terminal loading platform, empty buses arrived at the platform every five minutes. Each bus starts to receive passengers as soon as it has stopped and its front door has been opened. Passengers continue to board for four minutes and 30 seconds. Then the last passenger is permitted to finish boarding, the door closes, and the bus departs. The next bus arrives five minutes from when the first bus arrived.

Passengers arrive at the platform in a Poisson stream at a rate of 300 to 1,100 passengers per hour. Passengers board the empty bus until all 50 seats are filled and then continue to board at a slower rate due to the effect of standees. For this problem, it is assumed that boarding times are 20 percent greater when standees are present. Both boarding service time distributions follow a negative exponential function as follows:

$$P\ (g \geq t) = e^{-\frac{(t - \tau)}{(\bar{t} - \tau)}}$$

where

$P\ (g \geq t)$ = probability that time "g" is greater than or equal to time "t".

t = any service time

$\bar{t}$ = average service time

τ = minimum service time

The parameters used for each function in the simulation model are shown in Table 50. As shown, the minimum service times were assumed to be equal to one-half the average service time. This assumption is consistent with the information contained in Chapter V.

TABLE 50

Example 5 - Parameters for Service Time Distributions

Method of Fare Collection	Presence of Standees	Parameters	
		$\bar{t}$	τ
Pay Enter	No	7.06	3.53
	Yes	8.50	4.25
Pay Leave	No	3.70	1.85
	Yes	4.44	2.22

The sequence for boarding is on a first-come, first-served basis. Any persons who arrive at the stop while a bus is loading will be able to get aboard during the four-minute-and-30-second period that the bus accepts passengers. Those not able to board the bus must wait in the queue until the next bus arrives and opens its door. It should be noted that the model does not limit the number of passengers that can board due to the capacity of the bus. If bus capacity is a critical factor then appropriate changes to the model should be made. Bus capacity was not a critical factor in this example because of the passenger flows used.

The simulation model is built in two segments. Model Segment 1 simulates the passengers who arrive at the bus stop, wait for the bus, and board. Model Segment 2 simulates the bus. Table 51 contains the definitions of each of the GPSS entities. A partial program listing is contained in Figure A-12 in Appendix A6.

TABLE 51

Example 5 - Table of Definitions

For Simulation Model of Terminal Loading Platform

GPSS Entity	Interpretation
Transactions	
Model Segment 1	A Passenger
Model Segment 2	A Bus
Functions	
XPDIS	Exponential Distribution Function
DOORN	Distribution of Boarding Service Times - No Standees
DOORS	Distribution of Boarding Service Times - With Standees
Logic Switches	
BUS	When set indicates that the bus is at the stop and is ready to load passengers.
Queues	
LINE	The queue in which people wait until the bus has come and they can board.
Savevalues	
NOWON	A counter to keep track of the number of people on the bus.
Tables	
INQUE	The table used to estimate the in-queue residence time distribution.

Time Units: One-hundredth of a second

7.3.2 Model Segment 1

Passengers are generated at a rate of from 300 to 1,100 passengers per hour by hundred-passenger increments. The first passenger arrives after four minutes and 30 seconds from the start of the simulation. This permits queuing for 30 seconds until the bus arrives, thereby obtaining a steady-state condition almost immediately. Passengers have been given a priority level of 1 so that if a passenger arrives at the same time that the bus is ready to close its door, the passenger is given priority and will be permitted to board. The number of parameters for each transaction (boarding passenger) has been reduced to one to minimize the amount of core storage that will be used.

After the passenger is generated, he enters the queue and waits until the bus gate is opened. After the gate is opened, he leaves the line and a test is made to determine if more than 50 passengers are on the bus. If there are fewer than 50, he boards according to the DOORN distribution. If there are more than 50 (indicating standees), he boards according to the DOORS distribution. After the passenger has boarded, the number of persons on the bus is updated by one and the passenger gate is opened for the next passenger if the bus is not ready to depart. A block diagram of Model Segment 1 is shown on Figure 19.

7.3.3 Model Segment 2

A bus arrives every five minutes, opens its door and loads for a period of four minutes and 30 seconds. A test is then made to see if the last person is still boarding. The bus waits until the last person has

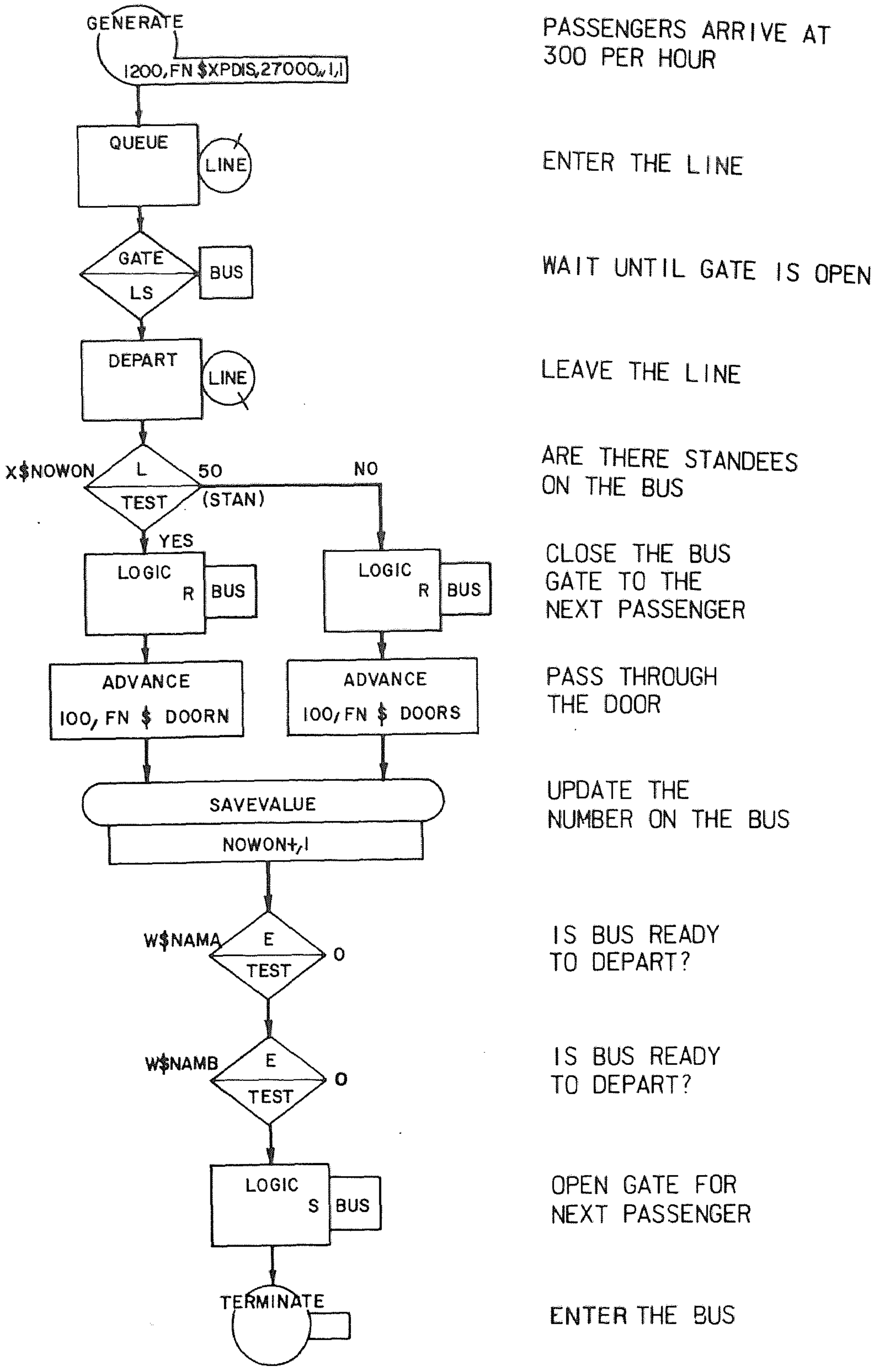
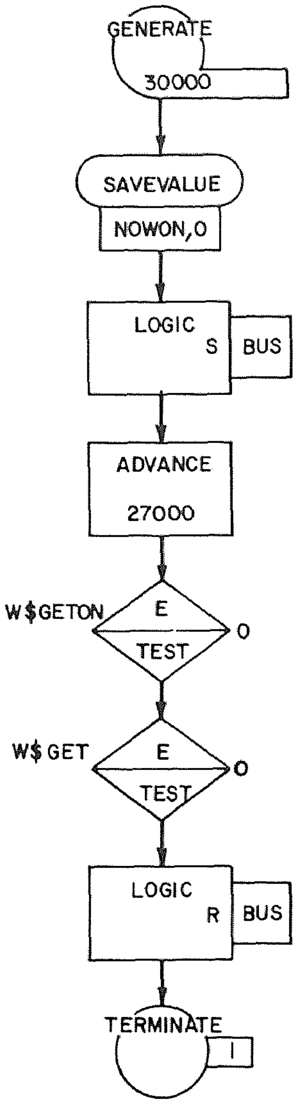


Figure 19 EXAMPLE 5- BLOCK DIAGRAM FOR PASSENGER MODEL



BUS ARRIVES EVERY 5 MINUTES

SET NUMBER ON BUS
EQUAL TO ZERO

OPEN THE BUS DOOR (GATE)

BUS LOADS FOR
4 MINUTES 30 SECONDS

LET LAST PERSON ON

LET LAST PERSON ON

CLOSE THE BUS DOOR (GATE)

BUS DEPARTS

Figure 20 EXAMPLE 5- BLOCK DIAGRAM FOR BUS MODEL

boarded and then the bus gate is closed. The bus then leaves the model. A block diagram for the bus model is shown on Figure 20.

7.3.4 Program Output

The simulation model was run for both the pay-enter and pay-leave methods of fare collection. In each case, 12 buses were loaded with passenger arrivals ranging from 300 per hour to 1,100 per hour at 100 passenger-per-hour increments.

The output of each of the model runs included information on total passengers in the queue, total passengers on the bus, number of standees, number of zero entries (i.e., the number of passengers that could board without waiting in the queue), the percent of zero entries, maximum queue, average queue, average time per passenger in the queue in seconds, and a frequency distribution of in-queue residence time. This information, except for the distribution of in-queue residence time, is contained in Tables 52 and 53 for each of the model runs. As would be expected, the total number of passengers on the bus, the number of standees, maximum queue, average queue, and average time in-queue increased with increased passenger demand. Conversely, the number of zero entries (i.e., the number of passengers that could board without waiting in the queue) decreased with increased passenger demand.

The information contained in Tables 52 and 53 is useful for both planning and evaluating the operations of a boarding platform. Table 52 indicates that for passenger flows above 300 per hour, not all passengers will be able to board a bus. It also indicates that the maximum number

TABLE 52

Example 5 - Program Output for Pay Enter Method of Fare Collection

Statistic	Passengers Per Hour 300	400	500	600	700	800	900
Total Passengers Arriving	318	407	495	582	682	778	884
Total Passengers On Bus	318	391	478	563	574	574	574
Number of Standees	0	2	2	10	13	13	13
Number of Zero Entries	61	7	1	0	0	0	0
Percent of Zero Entries	19.1	1.7	0.2	0	0	0	0
Maximum Queue	30	43	33	55	117	204	310
Average Queue	5.08	15.67	15.10	26.15	61.08	104.90	149.51
Average Time Per Passenger in Queue, Seconds	62.76	149.04	118.10	173.88	346.57	521.81	654.54

TABLE 53

Example 5 - Program Output for Pay Leave Method of Fare Collection

Statistic	Passengers Per Hour 300	400	500	600	700	800	900	1000	1100
Total Passengers Arriving	313	407	498	582	683	778	884	987	1095
Total Passengers On Bus	313	407	498	582	682	778	842	845	845
Number of Standees	0	0	2	32	89	178	242	245	245
Number of Zero Entries	170	200	214	189	142	63	2	0	0
Percent of Zero Entries	54.3	49.1	42.9	32.4	20.7	8.0	0.2	0	0
Maximum Queue	6	8	7	10	13	30	49	143	255
Average Queue	0.29	0.52	0.51	1.15	2.41	6.50	25.83	68.15	114.95
Average Time Per Passenger in Queue, Seconds	3.62	4.93	4.00	7.62	13.69	32.36	113.20	267.30	406.41

of persons that can board the 12 buses is 574 passengers. Similar statistics from Table 53 are 800 and 845 passengers per hour, respectively.

The information on average and maximum queues can be used to design adequate loading platforms or in changing operating procedures to avoid overcrowding on an existing platform. The values of average time per passenger in the queue can be compared with desired service standards and appropriate operational changes made, if necessary.

With the use of GPSS, other models can be developed to simulate the operation of other bus stops. The model developed herein is intended to be an example and not a model for all cases. However, it can be adapted to other cases by changing the distributions of passenger arrival and service times, as well as the time allocated for each bus to load passengers.

7.4 Summary

The usefulness of the results of this research has been demonstrated by examples in three areas of interest to street transit system planners and operators. The first area involved terminal operations where the passenger service time influence zones were used to analyze an unloading platform and a loading platform. Analysis of the unloading platform indicated that berth requirements decrease with increased door use. For the loading platform, it was determined that berth capacity in buses per hour could be increased by 87.5 percent if the method of fare collection is changed from pay enter to pay leave.

The second area investigated street transit operations where the passenger service time influence zones were used to investigate suburban service and local service. The example of suburban service compared the effects upon total trip time of the pay leave and pay enter methods of fare collection. It was concluded that although the pay leave method can result in reduced terminal loading requirements, it may not reduce total trip time. The example of local service concluded that the exact fare method of fare collection required less time than the cash and change method. Also, double-width doors required less time than single-width doors.

The third area involved the use of GPSS to develop a model of a typical boarding platform in a bus terminal. Two series of simulation runs were made to investigate the effects of method of fare collection upon queue length and average waiting time under varying rates of passenger arrivals.

The use of the Passenger Service Time Influence Zones and the simulation model have demonstrated some of the effects of the Passenger Vehicle Interface on the operations of street transit systems.

CHAPTER VIII

CONCLUSIONS AND RESEARCH RECOMMENDATIONS

The objectives of this research have been to analyze the Passenger Vehicle Interface of street transit systems and to structure a framework of the Passenger Vehicle Interface as it relates to street transit systems. The accomplishment of these objectives has resulted in a better understanding of the effects of passenger service time, as described in the next section on general conclusions. It has also raised additional questions that are worthy of future research. The work contained in this dissertation can be used as a framework for future research on the Passenger Vehicle Interface.

8.1 General Conclusions

Conclusions that can be drawn from this research are:

1. Street transit systems have played an important role in the development of our cities and will continue to do so being the only form of mass transit in many areas. Federal programs are attempting to reverse the loss of patronage and the increases in operating deficits experienced in recent years by improving service and efficiency of operation. However, before a system can be improved, its elements and the interaction among elements must be understood.
2. A street transit system can be defined as being comprised of five elements: vehicle, operating, line haul, passenger, and terminal.

3. The Passenger Vehicle Interface is the interaction between the passenger and vehicle elements. It can have a significant effect upon the operations of street transit systems. This effect can be measured by evaluating passenger service time as a measure of the Passenger Vehicle Interface. Analysis of human observer surveys and photographic studies taken in 17 cities in the United States and Canada indicated that passenger service time could be predicted by a multiple regression equation when the number of boarding and alighting passengers are known.
4. Seven factors have been identified as affecting or being affected by the Passenger Vehicle Interface system. These include:
   a. Human factor
   b. Modal factor
   c. Operating practices
   d. Operating policies
   e. Mobility
   f. Climate and weather
   g. Other system elements.
5. The major quantifiable factors affecting the Passenger Vehicle Interface can be grouped into the categories of:
   a. Direction of flow
   b. Method of fare collection
   c. Door characteristics and use.

6. Passenger service time can be predicted when the number of alighting and boarding passengers are known by the use of a series of influence zones. The influence zones contain a series of equations categorized according to the major effects affecting the PVI. A range of values has been developed for the parameters of each of the equations to reflect the effects of unquantifiable factors such as the type of passenger, physical characteristics of passenger, passenger preferences, baggage carried, seating configuration, congestion, etc. Besides estimating passenger service time, the influence zones can be used to evaluate changes to the operations of street transit systems.

7. There is no difference in the average service time for each successive passenger to board, except that the first passenger may require less time due to the storage area on the steps between the bus door and the driver.

8. The distribution of service times for individual passengers to pass through the vehicle door can be represented by the following Erlang function:

$$P\ (g \geq t) = \sum_{i=0}^{K-1} \left[\frac{K\ (t - \tau)}{(\bar{t} - \tau)}\right]^{i} \frac{e^{-\frac{K\ (t - \tau)}{(\bar{t} - \tau)}}}{i!}$$

where

$P\ (g \geq t)$ = probability that time "g" is greater than or equal to time "t"

K = a positive integer

t = any service time

$\bar{t}$ = average service time

τ = minimum service time

The value of K seems to be equal to the number of doors on the vehicle and the minimum service time is approximately equal to half the average service time.

9. The passenger service time influence zones can be used to evaluate changes to terminal operations or the operations of street transit systems.
10. The special purpose programming language (GPSS) and estimates of passenger service time distribution functions can be used to model typical loading and unloading areas of street transit systems. These can be used to evaluate the effects of method of fare collection upon queue length and average passenger waiting time under varying rates of passenger arrivals.

In general, the conclusions of this research have indicated the Passenger Vehicle Interface of street transit systems can be analyzed through the use of passenger service time influence zones and computer simulation modeling.

8.2 Future Research

Six areas for additional research have been defined as follows:

1. Effect of Standees

While this research has indicated that standees increase boarding and alighting times, many additional questions were raised by the collection and analysis of data. It was observed that standees did not always have a consistent effect upon the alighting and boarding passengers. In some cases, the standees would cluster in the front of the bus;

in others they would cluster in the rear of the bus. It was also observed that in many cases passengers would move to the door before the bus had stopped, thereby mitigating the effect of standees.

The research on standees should determine when the effect of standees becomes significant. It is realized that the collection of data will be difficult and will require a large number of observations. It will also be important to determine the service standards of the systems under study and the legal restriction on the number of standees. One approach may be to relate the density of standees with changes in passenger service time requirements.

2. Passenger Service Characteristics for Alighting with a Pay-Leave Method of Fare Collection

This area was not investigated in this dissertation because of the difficulty in obtaining sufficient data for analysis. Similar surveys could be conducted as described herein, except that enumerators should be posted inside the vehicle. A specific item to be considered is the number of passengers that pay their fare before the bus stops. This effect should result in the same passenger service time as any other alighting passenger under another method of fare collection. It would also be interesting to know the number of stops where more than one passenger alights.

3. Effect of Aisle Width

The effect of aisle width was difficult to quantify because of its interaction with other elements. It was generally concluded that restricted or narrower aisles increase passenger service time. Additional research should be done in comparable areas with the same methods of fare collection to quantify the effect of aisle width. Of particular interest would be a comparison of other areas with the transit buses operated by the Montreal Urban Community Transit Commission, which have wider aisles.

4. Amount of Fare

Although this research has concentrated on the type of fare used and the method of fare collection, no comparison was made of the amount of fare. It was observed in some areas that odd-penny fares were being used. Specifically in Los Angeles, California, change makers provided passengers with their odd-penny exact fares for boarding. The effects of odd-penny, two-coin, and three-coin fares should be investigated. It seems that many systems have eliminated odd-penny fares. If so, the research should concentrate on the differences in passenger service time produced by two-, three- and four-coin fares.

5. Climate and Weather

The results of this dissertation indicated that climate and weather may have an effect upon passenger service time by changing the mix of passengers. Additional research of passenger service time should be conducted under a full range of weather conditions, including drizzle, light rain, heavy rain, snow, and ice conditions. It is anticipated that the results of such additional research will indicate an increase in the variability and amount of time required for passenger service with increased severity of weather. It also would be interesting to research the effects of snow and ice conditions and make comparisons between cities of different climates, such as Minneapolis, Minnesota, and Newark, New Jersey.

6. Additional Modeling Using GPSS

This dissertation has shown the usefulness of GPSS in evaluating the effects of method of fare collection upon queue length and average waiting time under varying rates of passenger arrivals. These results indicated the maximum number of passengers that could board a vehicle under varying passenger flows and service time distributions. Additional GPSS models could be developed to simulate a series of situations which could be used to develop guidelines to assist the terminal designer and street transit system operator in evaluating their existing or proposed systems. These models could be used to evaluate many situations, such as using both front and rear doors for boarding, using the front door for boarding and rear door for alighting, using double stream doors, and using different methods of fare collection.

APPENDICES

APPENDIX A1

Survey Procedures

SURVEY PROCEDURES

Two types of surveys were conducted to measure passenger service time and obtain headway information. The human observer with the stop watch was used to collect data on service time for groups of passengers. Photographic studies were used to obtain information on service time for individual passengers.

For the human observer surveys, passenger service times were recorded to the nearest tenth of a second the moment the vehicle stopped and the doors opened until the last passenger alighted or boarded the vehicle. The number of passengers boarding and alighting by each door were recorded during this same interval. Stragglers boarding the vehicle after the initial queue were not counted in the passenger service time and passenger volume measurements. Stalling time (time while the bus was stopped and did not perform passenger service even though it could proceed) was not recorded and unusual conditions were noted. A copy of the survey form is shown in Figure A-1.

In some cases, two observers were used for vehicles with two doors. Each observer had two stop watches and was only required to view one door. Man No. 1, viewed the front door and had watches "A" and "B"; Man No. 2, observed the rear door and had watches "C" and "D". Both started their watches when the front door opened. Man No. 1 stopped watch "A" at the completion of passenger service time through the front door and stopped watch "B" at the completion of passenger service time

PASSENGER SERVICE TIME FIELD SURVEY AND COMPUTER INPUT SHEET

Type of Vehicle ______________ ☐
Time of Day ______________ ☐
Day of Week ______________ ☐
Date ______ ☐ ☐ ☐ ☐ ☐ ☐
Location of Survey:

Temperature ______________ ☐ ☐
Moisture ______________ ☐
Wind ______________ ☐
Light ______________ ☐

Loading Area ______________ ☐
Location of Loading Area ______________ ☐
Surveyed By ______________ ☐ ☐

Type of Service	Method of Fare Collection	Type of Fare	Congestion		Vehicle Manufacturer	Model Number or I. D. Number	Rear Door				Front Door			
							Passengers		Dead Time	Dead & Service Time	Passengers		Service Time	Service & Dead Time
			Inside	Outside			Alighting	Boarding			Alighting	Boarding		

Figure A - 1 PASSENGER SERVICE TIME FIELD SURVEY AND COMPUTER INPUT SHEET through the rear door. In some cases, these times were the same. Man No. 2, stopped watch "C" when the rear door opened and stopped watch "D" upon the completion of passenger service time through the rear door. Figure A-2 illustrates two common cases of these times.

Human observer surveys were taken in the following locations:

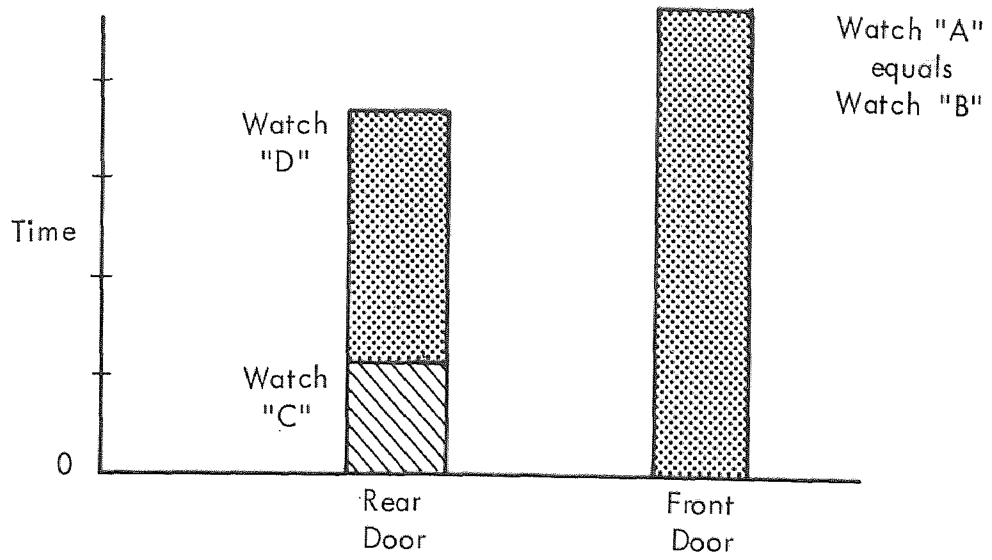
- Chicago, Illinois
- Clifton, New Jersey
- Detroit, Michigan
- Irvington, New Jersey
- Los Angeles, California
- Louisville, Kentucky
- Montreal, Canada
- Morristown, New Jersey
- Newark Airport, New Jersey
- Newark, New Jersey
- New Brunswick, New Jersey
- New York City
- Paterson, New Jersey
- Port Authority Bus Terminal, New York City
- San Diego, California
- San Francisco, California
- Wilmington, North Carolina

All data was collected between the period of May, 1968 and July, 1975.

Photographic studies, at a nominal speed of 18 frames per second, were taken of persons boarding and alighting from buses in Montreal, Canada; San Diego, California; and New Brunswick, New Jersey. Information on these observations is contained in Table A-1.

The camera utilized in this study was a Minolta Autopack D10 Super 8 mm. movie camera equipped with a Rokkor F 1.8 zoom lens which can vary

CASE I. FRONT DOOR CRITICAL



CASE II. REAR DOOR CRITICAL

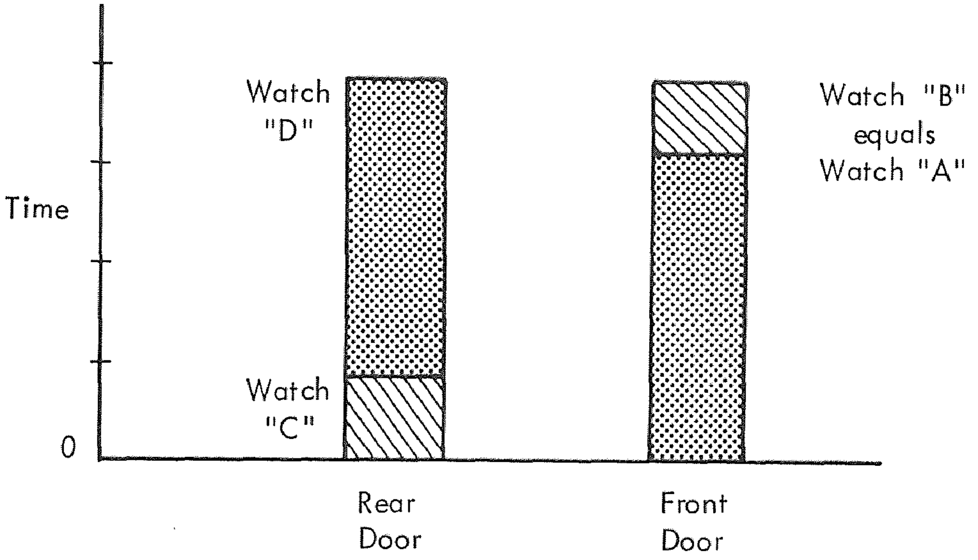


Figure A-2 PASSENGER SERVICE TIME MEASUREMENTS OF VEHICLES WITH TWO DOORS

focal lengths from 7 to 70 mm. (See Figure A-3.) Also utilized was an electronic Intervalometer with settings ranging from 0.5 to 60 seconds. The camera drive and Intervalometer are each powered by a five-penlight battery (5 x 1.5 volts) pack; the apparatus takes standard 50 foot cartridges of super 8 mm. film. The photographic components for this study offered advantages in terms of availability and ease of securing film and its processing and also its portability, i.e., lightweight (four pounds) and small size (23 by eight by nine inches).

TABLE A-1

Information on Photographic Surveys

	Location		
Item	Montreal	San Diego	New Brunswick
Service	Local	Local	Suburban
Day of Week	Wed., Thurs.	Wed., Fri.	Mon., Tues.
Date	7/17-18/74	12/4/74, 12/6/74	4/29/74, 6/18/74
Method of Fare Collection	Pay Enter Cash & Change	Pay Enter Exact Fare	Pay Enter Cash & Change
Type of Fare	Flat, Mixed	Flat, Mixed	Multiple Zone, Cash
Number of Buses Observed	30	25	23
Number of Passengers Observed	412	233	411
Men	125	127	326
Women	286	105	83
Children	1	1	2

Figure A-3

MINOLTA AUTOPACK D 10 SUPER 8 mm CAMERA

APPENDIX A2

Data Reduction Procedures

DATA REDUCTION PROCEDURES

All data from the human observer surveys were coded according to the information shown in Table A-2 using the basic survey form (see Figure A-1). This information was then keypunched and processed on an IBM 1130 computer. Regression equations were developed with the number of passengers being the independent variable and time the dependent variable. For observations of either boarding or alighting, a simple linear regression model was used. Where observations included both alighting and boarding passengers, a multiple step-wise regression equation was used. In both cases plots of residuals versus observed values were reviewed to determine if the model had been appropriately structured, if the residuals were normally distributed and if extreme values were present.

Data recorded by the photographic studies was summarized utilizing a Kodak Ektographic MFS-8 projector (Figure A-4). This super 8 apparatus offered the flexibility of manual or remote control operation in the forward or reverse direction at either 6, 18, or 54 frames per second. Single frames were accommodated as well.

The number of frames for each person to pass through the portal of the bus were recorded. Passengers were classified as to men, women and children, and included the type and number of items carried. Copies of the coding form and key are shown in Figure A-5 and Table A-3 respectively. The information was keypunched and then tabulated by use of an IBM 1130 computer.

TABLE A-2

Passenger Service Time

Data Processing Code

A. Type of Vehicle
  1. Bus
  2. Trolley Bus
  3. Trolley

B. Time of Day
  1. A.M. 7 A.M. - 9 A.M.
  2. Mid 9 A.M. - 4 P.M.
  3. P.M. 4 P.M. - 6 P.M.
  4. Night 6 P.M. - 7 A.M.

C. Day of Week
  1. Sunday
  2. Monday
  3. Tuesday
  4. Wednesday
  5. Thrusday
  6. Friday
  7. Saturday

D. Date
  Month, Day, Year
  i.e., 12 28 74

E. Temperature
  Degrees Fahrenheit

F. Moisture
  1. None
  2. Drizzle
  3. Rain
  4. Snow

G. Wind
  1. Strong
  2. Light
  3. None

H. Light
  1. Natural
  2. Artificial
  3. Poor
  4. None

I. Loading Area
  1. Ground Level
  2. Platform
  3. Curb

J. Location of Loading Area
  1. Unprotected
  2. Partially Enclosed
  3. Enclosed Terminal

Table A-2 (cont'd)

Passenger Service Time

Data Processing Code

K. Type of Service

1. Local
2. Suburban
3. Intercity
4. Airport
5. Shopper
6. Campus
7. Dial-A-Ride
8. Charter

L. Method of Fare Collection

1. None
2. Pay Enter, Cash and Change
3. Pay Enter, Exact Fare
4. Pay Enter, Pass or Other
5. Pay Leave, Cash and Change
6. Pay Leave, Exact Fare
7. Pay Leave, Pass or Other
8. Outside Vehicle
9. Inside Vehicle

M. Type of Fare

1. None
2. Cash
3. Ticket
4. Pass
5. Credit Card

N. Congestion

Inside

1. much
2. some
3. none

Outside

1. much
2. some
3. none

O. Vehicle Manufacturer

Indicate Name

P. Model Number or I.D.

Indicate Number
to Identify Vehicle

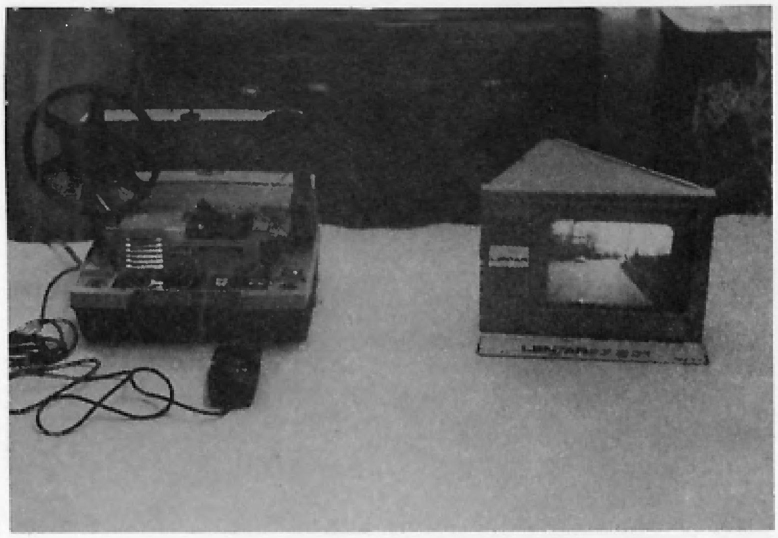


Figure A-4

KODAK EKTOGRAPHIC MFS - 8 PROJECTOR AND VIEWING SCREEN

Day of Week________

Temp________ Wind________

Roll #________

Bus________

Fare________

Time________ Date________

# of Pass.		# of Frames
Off	On	

TIME CALCULATIONS

	Stopwatch Sec.	# of Frames	Time By Frames	Ave. Time Per Pass.
Alighting				
Boarding				
Total				

DISTRIBUTIONS

Interval	Alighting		Boarding	
Sec. (Frames)	Tallied	fi	Tallied	fi
0 -0.49 (0-8)				
0.5-0.99 (9-17)				
1.0-1.49 (18-26)				
1.5-1.99 (27-35)				
2.0-2.49 (36-44)				
2.5-2.99 (45-53)				
3.0-3.49 (54-62)				
3.5-3.99 (63-70)				
4.0-4.49 (71-79)				
4.5-4.99 (80-88)				
5.0-5.49 (89-97)				
5.5-5.99 (98-106)				
6.0-6.49 (107-115)				
6.5-6.99 (116-124)				
7.0-7.49 (125-132)				
7.5-7.99 (133-141)				
8.0-8.49 (142-150)				
8.5-8.99 (151-159)				
9.0-9.49 (160-168)				
9.5-9.99 (169-177)				
10.0-10.49 (178-186)				
10.5-10.99 (187-195)				
11.0-11.49 (196-204)				
11.5-11.99 (205-213)				
12.0-12.49 (214-221)				
12.5-12.99 (222-230)				

Figure A - 5 PHOTOGRAPHIC STUDY SUMMARY FORM

TABLE A-3

Code for Time Lapse Photography

Col. 1 - 2 (Location)

01	New Brunswick
02	Newark
03	Montreal
04	Detroit
05	San Diego

Col. 3 - 6 (Roll & Bus #)

i.e. Roll 6 Bus #1
0601

Col. 7 (Day of Week)

1	Sunday
2	Monday
3	Tuesday
4	Wednesday
5	Thursday
6	Friday
7	Saturday

Col. 8 - 13 (Date)

	Month,	Day,	Year
i.e.	12	28	74

Col. 14 - 15 (Temperature)

Degrees Fahrenheit

Col. 16 (Wind)

1	Strong
2	Light
3	None

Col. 17 (Type of Fare)

1	None
2	Cash
3	Ticket
4	Pass
5	Credit Card
6	Mixed
7	Unknown

Col. 18 (Method of Collection)

1	None
2	Pay enter, cash & change
3	Pay enter, exact fare
4	Pay enter, pass or other
5	Pay leave, cash & change
6	Pay leave, exact fare
7	Pay leave, pass or other

Col. 19 (Service)

1	Local
2	Suburban
3	Intercity
4	Airport
5	Shopper
6	Campus
7	Dial-A-Ride
8	Charter

Col. 20 (Time)

1	A.M.	7 A.M. - 9 A.M.
2	Mid.	9 A.M. - 4 P.M.
3	P.M.	4 P.M. - 6 P.M.
4	Night	6 P.M. - 7 A.M.

Col. 21 (Moisture)

1	None
2	Drizzle
3	Rain
4	Snow

Col. 22 (Door)

1	Front, single
2	Front, double
3	Back, single
4	Back, double
5	Front, Wide Single

Col. 24 - 25 (Passenger Number)

i.e.	1	First
	2	Second

Col. 29 (Type of Passenger)

1	Man
2	Woman
3	Child

Col. 33-34 (Items Carried)

01	None
02	Briefcase or bag
03	Jacket or coat
04	Newspaper
05	Package
06	Umbrella
07	B&J
08	B&N
09	B&P
10	J&N
11	J&P
12	N&P
13	B&B
14	B, B & B
15	U&N

Col. 35 (# of Items Carried)

0	None
1	One
2	Two

Col. 37-39 (Time Alighting)

000 Number of frames

Col. 44-46 (Time Boarding)

000 Number of frames

APPENDIX A3

Passenger Service Time Equations

PASSENGER SERVICE TIME EQUATIONS

Many of the equations used to analyze the factor affecting PVI are contained in Tables A-4 to A-7. Certain definitions are needed to explain the abbreviations and symbols used as follows:

A = Number of Passengers Alighting
ALF = Number of Passengers Alighting through Front Door
ALR = Number of Passengers Alighting through Rear Door
AM = Morning Peak Traffic Period, 7 A.M. - 9 A.M.
B = Number of Passengers Boarding
BDF = Number of Passengers Boarding through Front Door
BDR = Number of Passengers Boarding through Rear Door
GMC = General Motors Corporation
n = Number of Observations
PEC = Passengers with Exact Fare
PM = Afternoon Peak Traffic Period, 4 P.M. - 6 P.M.
PRC = Passengers Requiring Change
R^2 = Coefficient of Determination
S_E = Standard Error of Estimate
T = Passenger Service Time in Seconds
$\bar{T}$ = Mean Response

TABLE A-4

Passengers Service Time Equations

Alighting Only

Location	Date	Day	Type of Fare	Service	Time	Vehicle	Door	n	R^2	S_E	$\frac{S_E}{T}$	Equation	Acceptable Range
San Diego, California	12-4-74 12-6-74	Wednesday Friday	Mixed Exact Fare	Local	P.M.	GMC Bus	Front Single	11	.95	1.57	.27	$T = 0.1968 + 1.4545\,ALF$	$1 \le ALF \le 14$
New Brunswick, New Jersey	4-29-74 6-18-74	Monday Friday	Cash, Cash & Change	Suburban	P.M.	GMC Bus	Front Single	21	.91	5.73	.15	$T = 0.9563 + 1.9453\,ALF$	$1 \le ALF \le 30$
Louiville, Kentucky (6)	5-16-68 to 5-29-68	Monday to Friday	Mixed, Cash & Change	Local	All	GMC Bus	Both Single	121	.76	3.06	.34	$T = 1.8437 + 1.1122\,A$	$1 \le A \le 20$
	6-23-69 to 6-27-69	Monday to Friday	Mixed Exact Fare	Local	All	GMC Bus	Both Single	147	.77	2.73	-	$T = 2.2345 + 1.0792\,A$	$1 \le A \le 26$
Newark, New Jersey (34)	10-15-69 10-16-69 10-22,24-69 10-27-69	Monday to Friday	Mixed Exact Fare	Local	A.M. P.M.	GMC Bus	Both Single	64	.76	1.55	.22	$T = 3.3548 + 1.0816\,A$	$1 \le A \le 11$
Louisville, Kentucky (6)	5-16-68 to 5-29-68	Monday to Friday	Mixed, Cash & Change	Local	A.M.	GMC Bus	Both Single	27	.81	2.24	-	$T = 1.8203 + 0.9187\,A$	$1 \le A \le 20$
					Mid	"	"	71	.79	3.09	-	$T = 1.6067 + 1.2141\,A$	$1 \le A \le 19$
					P.M.	"	"	23	.66	3.15	-	$T = 2.0938 + 1.1725\,A$	$1 \le A \le 17$
Washington, D.C. (10)	6-26-67 to 9-9-67	-	Mixed, Cash & Change	Local	Peak with Standees	Bus	-	44	.98	-	-	$T = 3.945 + 0.943\,A$	$1 \le A \le 10$
					Peak–No Standees	"	-	213	.98	-	-	$T = 3.589 + 0.936\,A$	$1 \le A \le 25$
					Off-Peak–No Standees	"	-	205	.96	-	-	$T = 3.963 + 1.155\,A$	$1 \le A \le 19$
Newark, New Jersey (35)	2-25-74 2-27-74 3-13-74 3- 4-74	Monday Wednesday	Cash, Cash & Change	Local	A.M.	Trolley	Front Double	70	.76	2.76	.21	$T = 2.8236 + 0.8929\,ALF$	$3 \le ALF \le 29$
							Rear Double	87	.91	1.94	.12	$T = 2.2079 + 0.8384\,ALR$	$2 \le ALR \le 36$
							Either Double	157	.85	2.41	.16	$T = 3.0155 + 0.8202\,A$	$2 \le A \le 36$
							Both Double	70	.77	2.70	.16	$T = 4.3224 + 0.4573\,A$	$6 \le A \le 54$

TABLE A-5

Passengers Service Time Equations

Boarding Only-Cash and Change

Location	Date	Day	Type of Fare	Service	Time	Vehicle	Door	n	R^2	S_E	$\frac{S_E}{\bar{T}}$	Equation	Acceptance Range
Montreal, Canada	7-17-74 7-18-74	Wednesday Thursday	Mixed	Local	P.M.	GMC Bus	Front Single	18	.98	2.54	.09	$T = -4.4992 + 2.3724\ BDF$	$6 \le BDF \le 26$
Montreal, Canada	7-17-74 7-18-74	Wednesday Thursday	Mixed	Local	P.M.	Can. Car Bus	Front Single	12	.97	2.64	.09	$T = -3.3720 + 2.3359\ BDF$	$7 \le BDF \le 25$
Louisville, Kentucky (6)	5-16-68 to 5-29-68	Monday to Friday	Mixed	Local	All	GMC Bus	Front Single	41	.94	2.91	.25	$T = -0.0855 + 2.5855\ BDF$	$1 \le BDF \le 16$
Newark, New Jersey (6)	10-15, 16-69 10-22 to 24-69 10-27-69	Monday to Friday	Mixed	Local	A.M. & P.M.	GMC Bus	Front Single	157	.87	13.87	.32	$T = 3.1599 + 3.3272\ BDF$	$1 \le BDF \le 48$
Louisville, Kentucky (6)	5-16-68 to 5-29-68	Monday to Friday	Mixed	Local	Mid P.M.	GMC Bus	Front Single	26 12	.94 .94	2.72 2.72	- -	$T = 0.2396 + 2.5288\ BDF$ $T = -0.6494 + 2.7169\ BDF$	$1 \le BDF \le 14$ $2 \le BDF \le 16$
Irvington, New Jersey	2-27-74 3-28-74	Wednesday Thursday	Mixed	Suburban	A.M. & P.M.	GMC Bus	Front Single	13	.97	7.43	.20	$T = -18.5125 + 7.4099\ BDF$	$3 \le BDF \le 19$
Washington, D.C. (10)	6-26-67 to 9-9-67	-	Mixed	-	Peak with Standees	Bus	-	42	.99	-	-	$T = 0.845 + 3.926\ B$	$1 \le B \le 8$
					Peak—No Standees	"	-	191	.97	-	-	$T = 3.376 + 2.676\ B$	$1 \le B \le 25$
					Off-Peak No Standees	"	-	194	.98	-	-	$T = 1.948 + 3.220\ B$	$1 \le B \le 25$
Newark, New Jersey (35)	3-13-74	Thursday	Cash	Local	Mid	Trolley	Front Double	23	.90	7.52	.22	$T = 9.208 + 3.862\ BDF$	$1 \le BDF \le 25$
								23	.90	5.03	.14	$T = 6.913 + 1.232\ PEC + 7.466\ PRC$	$0 \le PRC \le 10$ $0 \le PEC \le 15$
	3-25-74	Monday	None	Local	A.M. Peak	Trolley	Both Double	12	.89	2.32	.23	$T = 1.5458 + 0.6983\ B$	$4 \le B \le 38$
	3-04-74	Monday					Front Double	12	.92	0.95	.22	$T = 0.4541 + 1.3242\ BDF$	$1 \le BDF \le 9$
							Rear Double	51	.93	1.30	.17	$T = 1.6429 + 0.9213\ BDR$	$2 \le BDR \le 29$

Table A-5 (cont'd)

Passengers Service Time Equations

Boarding Only-Cash and Change

Location	Date	Day	Type of Fare	Service	Time	Vehicles	Door	n	R^2	S_E	$\frac{S_E}{\bar{T}}$	Equation	Acceptance Range
Port Authority Bus Terminal, New York City	2-24-74	Sunday	Cash	Suburban	P.M.	GMC Bus	Front Single	13	.93	39.44	.21	$T = -6.6033 + 8.0890\ BDF$	$2 \leq BDF \leq 49$
	2-22-74 2-28-74	Friday Tuesday	Cash	Suburban	P.M.	GMC Bus	Front Single	25	.92	27.96	.19	$T = 2.1188 + 6.9679\ BDF$	$6 \leq BDF \leq 56$
	4-16-73 5-9-73 2-22-73	Monday Wednesday Friday	Pay Leave	Suburban	P.M.	GMC Bus	Front Single	31	.93	21.31	.27	$T = -36.3732 + 4.5576\ BDF$	$11 \leq BDF \leq 63$
Newark, New Jersey	4-5-73	Thursday	Cash	Suburban	P.M.	GMC Bus	Front Single	27	.99	13.24	.18	$T = -13.4606 + 6.6332\ BDF$	$1 \leq BDF \leq 52$

TABLE A-6

Passengers Service Time Equations

Boarding Only-Exact Fare

Location	Date	Day	Type of Fare	Service	Time	Vehicle	Door	n	R^2	S_E	$\frac{S_E}{\bar{T}}$	Equation	Acceptable Range
San Diego, California	12-4-74 12-6-74	Wednesday Friday	Mixed	Local	P.M.	GMC Bus	Front Single	23	.92	5.12	.21	$T = 0.6997 + 2.1308\ BDF$	$1 \leq BDF \leq 33$
Detroit, Michigan (Curbside)	9-16-74 9-17-74	Monday Tuesday	Mixed	Local	P.M.	GMC Bus	Front Single	20	.94	4.19	.17	$T = -0.8533 + 2.2300\ BDF$	$1 \leq BDF \leq 28$
Detroit, Michigan (Terminal)	9-16-74 9-17-74	Monday Tuesday	Mixed	Local	P.M.	GMC Bus	Front Single	19	.89	10.10	.18	$T = 3.6986 + 2.1889\ BDF$	$1 \leq BDF \leq 49$
Detroit, Michigan	9-16-74 9-17-74	Monday Tuesday	Mixed	Express	P.M.	GMC Bus	Front Single	26	.93	4.59	.20	$T = -3.3313 + 2.6054\ BDF$	$2 \leq BDF \leq 25$
Louisville, Kentucky (6)	6-23-69 to 6-27-69	Monday to Friday	Mixed	Local	All	GMC Bus	Front Single	31	.94	2.70	-	$T = 0.5863 + 1.9957\ BDF$	$1 \leq BDF \leq 25$
Newark, New Jersey (34)	10-15-69 10-16-69 10-22-69 to 10-24-69 10-27-69	Monday to Friday	Mixed	Local	All	GMC Bus	Front Single	110	.95	5.70	.24	$T = 2.3179 + 2.6736\ BDF$	$1 \leq BDF \leq 38$
Irvington, New Jersey	2-27-74 3-28-74	Wednesday Thursday	Mixed	Local	A.M. & P.M.	GMC Bus	Front Single	12	.94	3.38	.18	$T = -1.8147 + 2.7570\ BDF$	$2 \leq BDF \leq 14$
Washington, D.C. (10)	6-27-70 to 7-5-70	-	Mixed	-	Peak	Bus	-	153	.97	-	-	$T = 4.740 + 2.604\ B$	$1 \leq B \leq 25$
					Off Peak	Bus	-	248	.98	-	-	$T = 4.342 + 2.853\ B$	$1 \leq B \leq 25$

TABLE A-7

Passenger Service Time Equations

Simultaneous Boarding and Alighting

Location	Date	Day	Type of Fare	Service	Time	Vehicle	Door	n	R^2	S_E	$\frac{S_E}{\bar{T}}$	Equation	Acceptance Range
Louisville, Kentucky (6)	5-16-68 to 5-29-68	Monday to Friday	Mixed, Cash & Change	Local	All	GMC Bus	Both Single	297	.88	5.78	.26	$T = 1.7701 + 0.9727A + 2.2756BDF - 0.0234(A \cdot BDF)$	$1 \leq A \leq 24$ $1 \leq BDF \leq 36$
	6-23-69 to 6-27-69	Monday to Friday	Mixed Exact Fare	Local	All	GMC Bus	Both Single	359	.83	6.55	-	$T = 1.6043 + 0.9588A + 2.1543BDF - 0.0202(A \cdot BDF)$	$1 \leq A \leq 30$ $1 \leq BDF \leq 33$
	5-16-68 to 5-29-68	Monday to Friday	Mixed, Cash & Change	Local	A.M.	GMC Bus	Both Single	43	.79	3.85	-	$T = 3.5985 + 1.0089A - 0.0913(A \cdot B) + 0.4653(B)^2 - 0.0215(B)^3$	$1 \leq A \leq 22$ $1 \leq B \leq 17$
					Mid			191	.88	6.38	-	$T = 1.1762 + 1.3822A - 2.3041B - 0.0828(A \cdot B) + 0.0013(B)^3$	$1 \leq A \leq 21$ $1 \leq B \leq 30$
					P.M.			63	.96	4.16	-	$T = 0.4757 + 1.0987A + 2.2614B - 0.0423(A \cdot B)$	$1 \leq A \leq 24$ $1 \leq B \leq 36$
Irvington, New Jersey	2-27-74 3-28-74	Wednesday Thursday	Mixed, Cash & Change	Local	A.M. & P.M.	GMC Bus	Both Single	11	.93	11.10	.23	$T = 1.5601 + 1.2288ALF + 4.504BDF$	$1 \leq ALF \leq 20$ $1 \leq BDF \leq 23$
	2-27-74 3-28-74	Wednesday Thursday	Mixed Exact Fare	Local	A.M. & P.M.	GMC Bus	Both Single	11	.96	8.37	.21	$T = 6.0043 + 3.2503(BDF + ALF)$	$3 \leq (BDF + ALF) \leq 33$
Washington, D.C. (10)	6-26-67 to 9-9-67	-	Mixed, Cash & Change	-	Peak with Standees	Bus	-	224	.99	-	-	$T = 3.602 + 0.873A + 3.340B - 0.0298(A \cdot B)$	-
					Peak—No Standees			849	.96	-	-	$T = 3.439 + 0.911A + 2.901B - 0.0324(A \cdot B)$	-
					Off Peak with Standees			1160	.96	-	-	$T = 3.456 + 1.094A + 3.084B - 0.0554(A \cdot B)$	-
					No Standees			1114	.96	-	-	$T = 3.512 + 1.088A + 3.078B - 0.0523(A \cdot B)$	-
Newark, New Jersey (35)	3-13-74	Wednesday	Cash	Local	A.M.	Trolley	Front	15	.80	2.93	.17	$T = 3.2364 + 1.2564(ALF + BDF)$	$4 \leq (ALF + BDF) \leq 20$
	2-27-74	Wednesday	Cash & Change	Local	A.M.	Trolley	Both	18	.80	2.66	.13	$T = 3.1066 + 0.5789(B + A)$	$11 \leq (A + B) \leq 47$
San Diego, California	12-4-74 12-6-74	Wednesday Friday	Mixed Exact Fare	Local	P.M.	GMC Bus	Front	10	.78	7.54	.26	$T = -3.9599 + 2.4184(ALF + BDF)$	$5 \leq (A + B) \leq 21$

APPENDIX A4

Physical Characteristics of Street Transit Vehicles

TABLE A-8

Light Transit Bus Specifications

Item	Dimensions			
Manufacturer	Flexible Co.	Twin Coach	Twin Coach	GMC*
Model Number	21' Transit Coach (Flexette)	TC-25-B	TC-31-B	TDH-3302
Number of Seats	19-23	25-30	31-35	33
Width	90"	96"	96"	95.75"
Height (non air-cond.)	105"	112"	112"	118.75" (a)
Overall Length	225.25"	302"	338"	350.62"
Wheelbase	137"	133"	169"	164.5"
Body Overhang				
Front	35"	70"	70"	-
Rear	83.25"	87"	97"	-
Headroom	75"	75.5"	75.5"	78.5"
Floor Height From Ground	30"	30"	30"	33.65" - 34.51"
Step Height From Ground				
Entrance	14"	14"	14"	13.62"
Exit	14"	14"	14"	15.25"
Door Opening				
Entrance	24" x 75.5"	29" x 79"	29" x 79"	30" x 79.88"
Exit	24" x 75.5"	26" x 79"	26" x 79"	26.5" x 77"
Turning Radius				
Wheels	258"			350"
Body	300"	312"	357"	396"
Engine	Gasoline	Gasoline Diesel, LPG or LNG	Gasoline Diesel LPG or LNG	Diesel

(a) - Height with Air-Conditioning = 121"
LPG - Liquified Petroleum Gas
LNG - Liquified Natural Gas
*GMC - General Motors Corp.

TABLE A-9

Transit Bus Specifications

Item	Dimensions				
Manufacturer	Flexible Co.	GMC*	Flexible Co.	GMC*	GMC*
Model Number	35' Transit Coach	T6H-4523	40' Transit Coach	T6H-5307 T8H-5307	T6H-5308 T6H-5308
Number of Seats	45	45	49 - 53	53	53
Width	96" - 102"	95.75"	96" - 102"	101.75"	95.75"
Height (non air-cond.)	117.75"	120.25"	117.75"	120.25"	120.25"
Overall Length	420"	420"	480"	480"	480"
Wheelbase	225"	235"	285"	284.75"	284.75"
Body Overhang					
Front	86.75"	-	86.75"	-	-
Rear	108.25"	-	108.25"	-	-
Headroom	78"	78.25"	78"	78.5"	78.5"
Floor Height From Ground	33.79"	32.54" - 34.34"	33.79"	32.76" - 34.92"	32.76" - 34.92"
Step Height From Ground					
Entrance	14.25"	13.5"	14.25"	13.5"	13.5"
Exit	15.75"	15.69"	15.75"	15.69"	15.69"
Door Opening					
Entrance	32.5" x na	30" x 79.88"	32.5" x na	30" x 79.88"	30" x 79.88"
Exit	26.5" x na	26.5" x 77"	26.5" x na	26.5" x 77"	26.5" x 77"
Turning Radius					
Wheels	354" - 359"	386"	432" - 436"	447"	445"
Body	410" - 414"	445"	489" - 492"	507"	505"
Enginee	Diesel	Diesel	Diesel	Diesel	Diesel

*GMC - General Motors Corp.

na - Not Available

TABLE A-10

Intercity Bus Specifications

Item	Dimensions				
Manufacturer	General Motors Corporation		Eagle Bus Sales	Motor Coach Industries	
Model Number	P8M-4108	P8M-4905	05	MC8	MC5B
Number of Seats	41	49	46		
Width	95.76"	95.76"	96"	96"	96"
Height (with air-cond.)	131.58"	131.58"	133.5"	130"	120"
Overall Length	420"	479.11"	480"	479.5"	422.25"
Wheelbase	259.5"	318.54"	285.5"	285"	261"
Body Overhang					
Front			85.5"	70.25"	70.25"
Rear			109"	124.25"	91"
Headroom	75.75"	75.75"	75.5"	75.5" - 78.5"	75.5"
Floor Height From Ground	37.56"	37.56"	36.75"	-	-
Step Height From Ground					
Entrance	15.42"	15.42"	16.12"	-	-
Exit	-	-	-	-	-
Door Opening					
Entrance	25" x na	25" x na	25.25" x 77.5"	-	-
Exit	-	-	-	-	-
Turning Radius					
Wheels	474"	540"	492"	580"	447"
Body	522"	588"	534"	616"	489"
Engine	Diesel	Diesel	Diesel	Diesel	Diesel
Underfloor Baggage Space					
2 Axles	-	403 cu.ft.	-	-	212 cu.ft.
3 Axles	290 cu.ft.	290 cu.ft.	330 cu.ft.	300 cu.ft.	-

na - Not Available

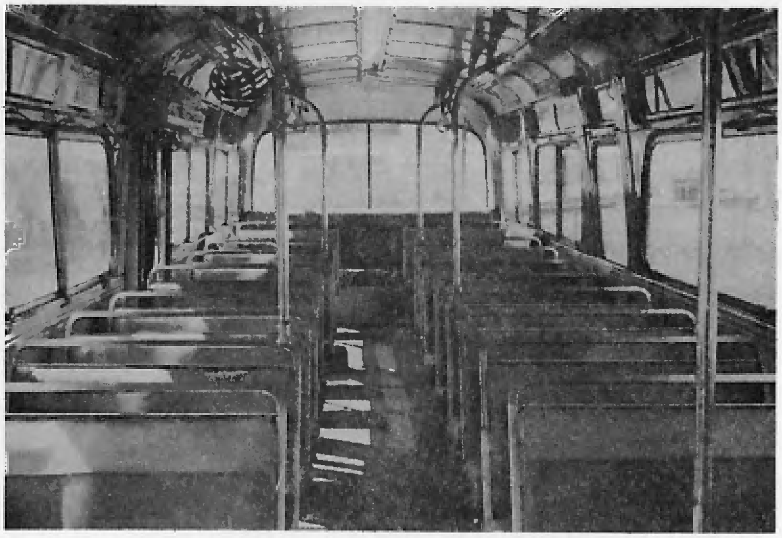
TABLE A-11

Trolley and Trolley Bus Specifications

Item	Dimensions		
Manufacturer	Flyer Industries Ltd.	St. Louis Car Co. (Double End)	St. Louis Car Co. (Single End)
Model Number	E700A (Trolley Bus)	D P.A.Y.E. (Trolley) 1006 - 1015 (1948)	PCC P.A.Y.E. (Trolley) 1016 - 1040 (1952)
Number of Seats	49	60	59
Width	102"	108"	107.38"
Height	128"	131"	135.75"
Overall Length	486.25"	605"	557.50"
Wheelbase	284.75"	275"	273"
Body Overhang			
Front	87.25"	129"	113.25"
Rear	113.75"	129"	96.25"
Headroom	81"		
Floor Height From Ground	34.5"	33"	33"
Step Height From Ground			
Entrance	14"	15"	15"
Exit	14"	15"	15"
Door Opening			
Entrance	31" x 79.5"	26" x 77"*	27" x 79"
Exit	26" x 78.75"*	26" x 77"*	28" x 79"
Turning Radius			
Wheels	409"	-	-
Body	471"	-	-
Engine	Electric	Electric	Electric

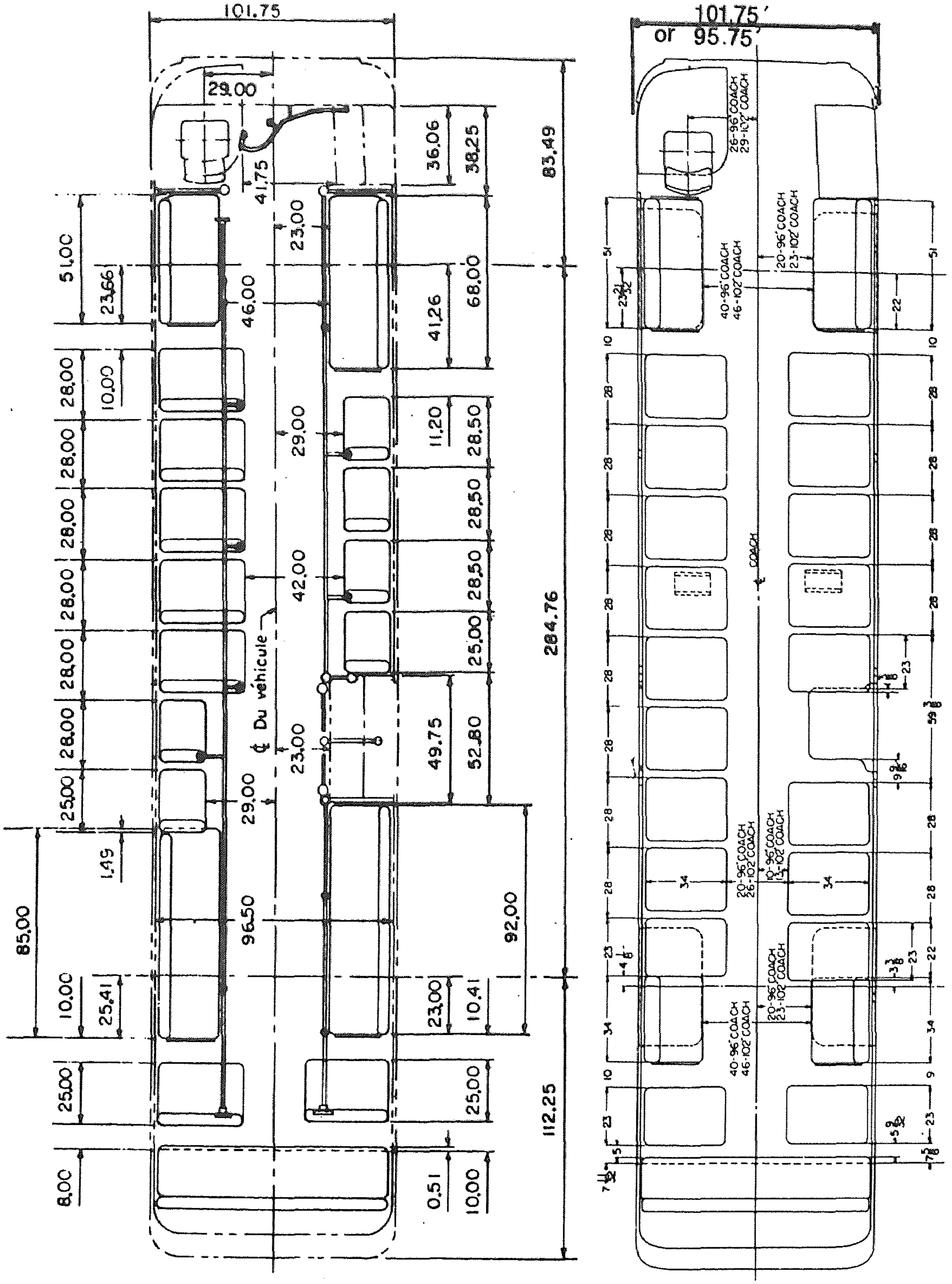
*Has double doors each with indicated dimensions.

a. Suburban Coach.



b. Local Transit Coach.

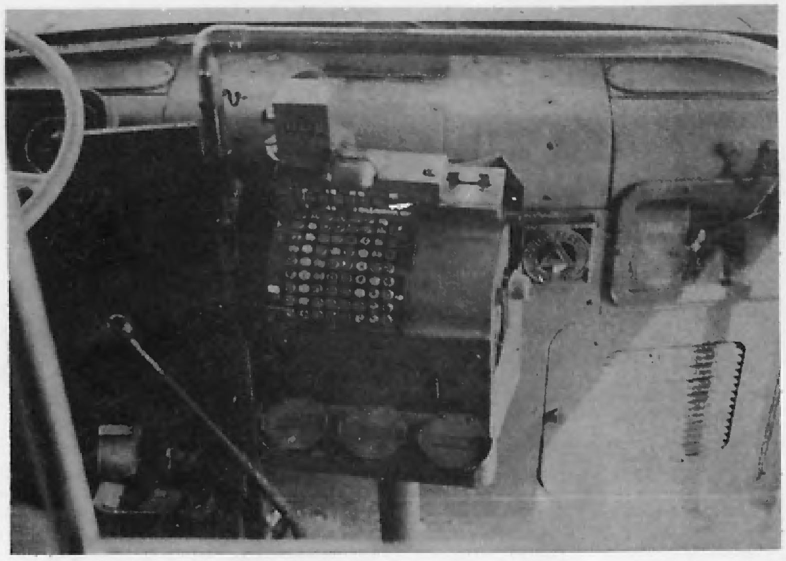
Figure A - 6 AISLE WIDTHS OF BUSES



Wider Aisle (Used in Montreal) Standard Aisle

Figure A -7 SEATING CONFIGURATIONS

GENERAL MOTORS CORPORATION BUSES



a. Fare Register.

b. Fare Box.

Figure A - 8 FARE COLLECTION EQUIPMENT

TRANSPORT OF NEW JERSEY BUSES

APPENDIX A5

Selected Photographs of Street Transit Terminals and Vehicles

a. Curbside Terminal, Newark, New Jersey.

b. Suburban Terminal, Maplewood, New Jersey.

c. Downtown Terminal, Detroit, Michigan.

d. Downtown Terminal, Detroit, Michigan.

Figure A - 9 STREET TRANSIT TERMINALS

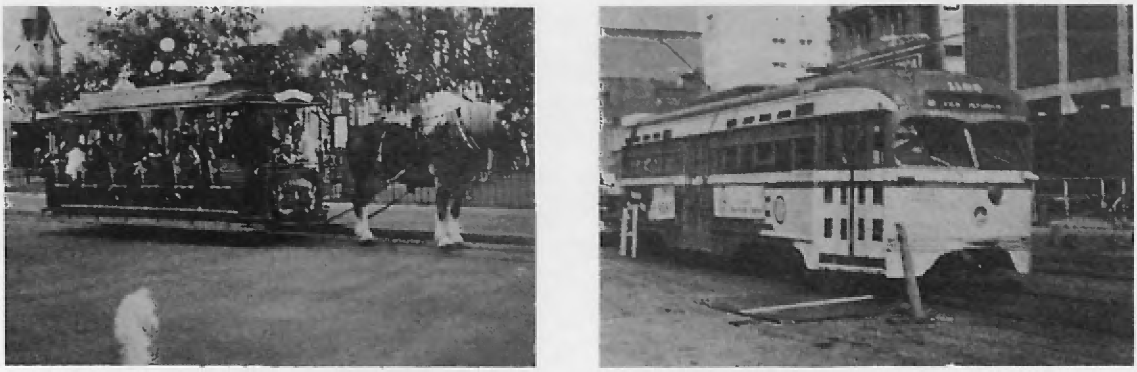
e. Trolley Terminal,
Newark, New Jersey.

f. Port Authority Bus
Terminal, New York City.

g. Port Authority Bus
Terminal, New York City.

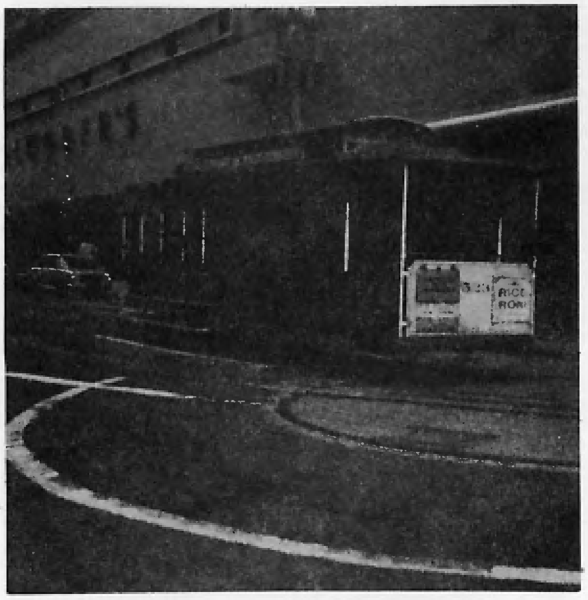
h. Curbside Trolley Terminal,
San Francisco, California.

Figure A - 9 STREET TRANSIT TERMINALS (cont'd)



a. Horsecar, Disney World, Florida.

b. Trolley, San Francisco, California.



c. Cable Car, San Francisco, California.

Figure A - 10 STREET TRANSIT VEHICLES

d. Trolley Bus, San Francisco, California.

e. Passenger Bus, Wilmington, North Carolina.

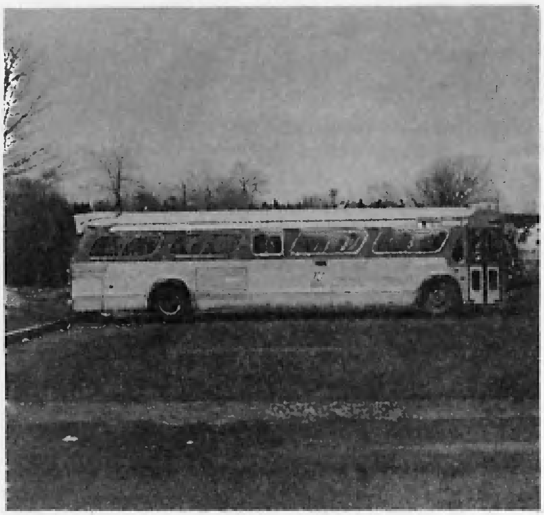
f. Shopper Shuttle, Detroit, Michigan.

Figure A - 10 STREET TRANSIT VEHICLES (cont'd)

g. 53-Passenger Transit Bus, Newark, New Jersey.

h. Ten-Passenger Jitney, Atlantic City, New Jersey.

i. 77-Passenger Articulated Bus, San Francisco, California.



j. Suburban Bus, Newark, New Jersey.

Figure A - 10 STREET TRANSIT VEHICLES (cont'd)

APPENDIX A6

GPSS Program Listings and Tables

```
BLOCK                                                                                   STATEMENT
NUMBER   *LOC    OPERATION  A,B,C,D,E,F,G,H,I            COMMENTS                        NUMBER
         *  W KRAFT  MONTREAL BOARDING  GMC (TYPE 1)                                         1
         *                                                                                   2
         *       FUNCTION DEFINITION                                                         3
         *                                                                                   4
          DOORB FUNCTION    RN1,C9                                                           5
         0.0,1.25/.137,1.50/.365,1.75/.569,2/.723,2.25/.828,2.5/.895,2.75                    6
         .937,3/1,6                                                                          7
         *                                                                                   8
         *       MODEL SEGMENT 1                                                             9
         *                                                                                  10
                 SIMULATE                                                                   11
1         HERE   GENERATE    ,,,6                                                           12
2                QUEUE       DORQ             ENTER THE LINE                                13
3                SEIZE       DOR              CAPTURE THE DOOR                              14
4                DEPART      DORQ             LEAVE THE LINE                                15
5                ADVANCE     100,FN$DOORB      PASS THRU DOOR                               16
6                RELEASE     DOR              FREE THE DOOR                                 17
7                TERMINATE                     ENTER THE BUS                                18
         *                                                                                  19
         *       MODEL SEGMENT 2                                                            20
         *                                                                                  21
8                GENERATE    15000            TIMER ARRIVES AT TIME 15000                   22
9                TERMINATE   1                SHUT OFF RUN                                  23
         *                                                                                  24
         *       CONTROL CARDS                                                              25
         *                                                                                  26
                 START       1                                                              27
1         HERE   GENERATE    ,,,6                                                           28
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                 CLEAR                                                                      29
                 START       1                                                              30
1         HERE   GENERATE    ,,,6                                                           31
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                 CLEAR                                                                      32
                 START       1                                                              33
1         HERE   GENERATE    ,,,7             PASSENGERS  ARRIVE                            34
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                 CLEAR                                                                      35
                 START       1                                                              36
1         HERE   GENERATE    ,,,7                                                           37
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                 CLEAR                                                                      38
                 START       1                                                              39
1         HERE   GENERATE    ,,,8                                                           40
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                 CLEAR                                                                      41
                 START       1                                                              42
1         HERE   GENERATE    ,,,8                                                           43
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                 CLEAR                                                                      44
                 START       1                                                              45
1         HERE   GENERATE    ,,,9                                                           46
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                 CLEAR                                                                      47
                 START       1                                                              48
```

Figure A - 11 PARTIAL PROGRAM LISTING OF SIMULATION MODEL FOR VALIDATION TESTS

```
BLOCK                                                                                  STATEMENT
NUMBER  *LOC    OPERATION  A.B.C.D.E.F.G.H.I             COMMENTS                      NUMBER
        *       W KRAFT   BOARDING SIMULATION   RUN   1       7-28-75                      1
                SIMULATE                                                                   2
        *                                                                                  3
        *       NON-STANDARD RANDOM NUMBER SEQUENCE INITIALIZATIONS FOR 1ST RUN            4
        *                                                                                  5
                RMULT        511.39.7                                                      6
        *                                                                                  7
        *       FUNCTION DEFINITION                                                        8
        *                                                                                  9
         XPDIS FUNCTION   RN1.C24                                                         10
        0.0/.1..104/.2..222/.3..355/.4..509/.5..69/.6..915/.7.1.2/.75.1.38               11
        .8.1.6/.84.1.83/.88.2.12/.9.2.3/.92.2.52/.94.2.81/.95.2.99/.96.3.2                12
        .97.3.5/.98.3.9/.99.4.6/.995.5.3/.998.6.2/.999.7/.9998.8                          13
         DOORN FUNCTION   RN2.C16                                                         14
        0.3.53/.125.4/.24.4.5/.341.5/.428.5.5/.503.6/.569.6.5/.626.7                      15
        .675.7.5/.718.8/.787.9/.84.10/.88.11/.932.13/.97.16/1.21                          16
         DOORS FUNCTION   RN3.C17                                                         17
        0.4.25/.057.4.5/.162.5/.255.5.5/.338.6/.411.6.5/.476.7/.535.7.5                   18
        .586.8/.632.8.5/.673.9/.742.10/.839.12/.899.14/.937.16/.975.20                    19
        1.23.5                                                                            20
        *                                                                                 21
        *       TABLE DEFINITION                                                          22
        *                                                                                 23
         INQUE QTABLE      LINE.3000.3000.2C   TIME SPENT WAITING AT STOP                 24
        *                                                                                 25
        *                                                                                 26
        *       MODEL SEGMENT 1                                                           27
        *                                                                                 28
1        HERE   GENERATE   1200.FN$XPDIS.27000..1.1   PASS. ARRIVE AT 30C PER HR          29
2               QUEUE      LINE                ENTER THE LINE                             30
3               GATE LS    BUS                 WAIT UNTIL GATE IS OPEN                    31
4               DEPART     LINE                LEAVE THE LINE                             32
5               TEST L     X$NOWON.50.STAN     ARE STANDEES ON BUS                        33
        *                                      IF NO. GO STAN AND USE DOORS               34
6               LOGICR     BUS                 IF YES. CLOSE GATE ON NEST PASS            35
7        GETON  ADVANCE    100.FN$DOORN        PASS THRU DOOR                             36
8               TRANSFER   .OUT                CONTINUE TO ENTER                          37
9        STAN   LOGIC R    BUS                 CLOSE GATE ON NEXT PASS.                   38
10       GET    ADVANCE    100.FN$DOORS        PASS THRU DOOR                             39
11       OUT    SAVEVALUE  NOWON+.1            UPDATE NUMBER ON BUS                       40
12              TEST E     W$NAMA.0.QUIT       IS BUS READY TO DEPART                     41
13              TEST E     W$NAMB.0.QUIT       IS BUS READY TO DEPART                     42
14              LOGICS     BUS                 OPEN GATE FOR NEST PASSENGER               43
15       QUIT   TERMINATE                      ENTER THE BUS                              44
        *                                                                                 45
        *       MODEL SEGMENT 2                                                           46
        *                                                                                 47
16              GENERATE   30000               BUS ARRIVES EVERY 5 MIN                    48
17              SAVEVALUE  NOWON.0             SET NUMBER ON BUS EQUAL TO ZERO            49
18              LOGICS     BUS                 OPEN BUS DOOR                              50
19              ADVANCE    27000               BUS LOADS FOR 4 MIN 30 SEC                 51
20       NAMA   TEST E     W$GETON.0           LET LAST PERSON ON                         52
21       NAMB   TEST E     W$GET.0             LET LAST PERSON ON                         53
22              LOGICR     BUS                 CLOSE BUS DOOR                             54
23              TERMINATE  1                   BUS DEPARTS                                55



        *                                                                                 56
        *       CONTROL CARDS                                                             57
        *                                                                                 58
                START      12                  START THE RUN                              59
1        HERE   GENERATE   900.FN$XPDIS.27000..1.1   PASS. ARRIVE AT 40C PER HR           60
MULTIPLE DEFINITION OF SYMBOL IN ABOVE STATEMENT
                RMULT      511.39.7            RESTORE RANDOM SEQUENCE                    61
                CLEAR                                                                     62
                START      12                  START THE RUN                              63
```

Figure A - 12 PARTIAL PROGRAM LISTING FOR EXAMPLE 5 - SIMULATION MODEL OF A TERMINAL LOADING PLATFORM

TABLE A-12

Simulated Service Times For Passengers Boarding Canadian Car Buses in Montreal, Canada

Number of Passengers	Simulated Passenger Service Time in Seconds	
7	18.45	11.88
8	19.81	15.00
9	18.91	22.00
10	20.50	21.25
11	23.88	28.54
12	25.40	21.16
13	24.91	25.35
14	31.84	31.84
15	30.34	31.97
16	39.29	35.54
17	33.39	36.28
18	39.70	36.98
19	40.00	37.41
20	43.55	41.64
21	46.20	47.01
22	45.51	52.26
23	51.06	45.51
24	48.46	45.95
25	53.42	54.06

TABLE A-13

Simulated Service Times

For Passengers Boarding General Motors Corporation

Buses in Montreal, Canada

Number of Passengers	Simulated Passenger Service Time in Seconds		
6	11.65	12.84,	11.94
7	16.93	12.28	
8	16.47	16.26	
9	16.54	20.30	
10	22.15	21.03	
11	25.59	21.74	
12	20.24	23.70	
13	25.08	30.20	
14	25.46	25.46	
15	32.21	34.05	
16	31.53	37.95	
17	34.64	33.17	
18	33.66	37.84	
19	39.57	38.61	
20	39.00	37.69	
21	48.33	43.80	
22	55.38	43.85	
23	46.99	43.17	
24	50.93	57.11	
25	49.64	51.11	
26	51.09	50.71	

TABLE A-14

Simulated Service Times
For Passengers Alighting From
Buses in New Brunswick, New Jersey

Number of Passengers	Simulated Passenger Service Time in Seconds		
1	0.96	2.50	3.10
2	3.56	2.89	
3	8.18	5.87	
4	6.58	6.39	
5	10.54	6.44	
6	13.69	13.33	
7	16.26	13.18	
8	11.95	15.98	
9	19.37	17.47	
10	23.17	20.17	
11	18.38	18.49	
12	23.99	25.33	
13	25.73	26.09	
14	33.80	33.80	
15	25.64	38.81	
16	36.32	31.37	
17	26.10	32.03	
18	34.22	37.80	
19	43.64	32.48	
20	42.37	30.72	
21	42.68	43.48	
22	44.54	46.46	
23	37.91	42.99	
24	44.61	48.09	
25	57.71	50.69	
26	57.87	61.46	
27	67.07	49.59	
28	58.27	49.64	
29	53.39	69.06	
30	68.68	69.93	

TABLE A-15

Simulated Service Times For Passengers Alighting From Buses in San Diego, California

Number of Passengers	Simulated Passenger Service Time in Seconds		
1	0.75	2.50	1.36
2	5.75	2.87	
3	3.14	4.24	
4	5.76	7.97	
5	5.82	6.74	
6	10.09	9.77	
7	11.05	9.64	
8	11.92	11.03	
9	13.57	16.62	
10	15.93	12.35	
11	13.66	16.01	
12	17.80	18.51	
13	17.98	19.64	
14	23.47	20.78	

TABLE A-16

Simulated Service Times
For Passengers Boarding
Buses in San Diego, California

Number of Passengers	Simulated Passenger Service Time in Seconds		
1	0.75	3.32	1.97
2	8.76	4.17	
3	4.11	6.17	
4	8.59	12.77	
5	8.01	9.70	
6	15.67		
7	16.87	16.67	
8	14.81	18.52	
9	21.08	20.34	
10	29.68	16.79	
11	20.93	20.82	
12	24.01	28.55	
13	26.12	28.88	
14	35.48	35.48	
15	34.28	33.43	
16	35.46	35.10	
17	37.57	35.92	
18	40.07	37.00	
19	44.02	38.22	
20	46.23	49.22	
21	42.29	51.48	
22	54.59	44.51	
23	48.20	45.99	
24	49.33	52.13	
25	53.25	59.91	
26	60.70	66.17	
27	55.76	53.27	
28	56.04	51.67	
29	52.29	68.64	
30	67.12	68.82	
31	67.88	72.52	
32	72.72	62.40	
33	72.18	69.23	

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