AN APPRAISAL OF THE CHARACTERISTICS OF TRAVEL TIMES ON URBAN TRANSIT SYSTEMS

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A B S T R A C T

Several factors such as relative travel time, relative cost, and regularity and convenience of service affect people's choice of travel mode. These factors are important considerations in the planning of transportation improvements. In view of the increasing public interest in transit improvements, there is a need for detailed information on the factors influencing transit usage. This thesis describes an appraisal of the travel time characteristics of urban transit services and the relationship of these characteristics to transit patronage.

This thesis focuses on the waiting times and transfer times at transit interchange points. It involves a qualitative appraisal of the factors affecting choice of travel mode, and a field survey to estimate waiting times compared to interarrival times of the transit system.

The survey was conducted in July 1971 at six locations on Montreal Island. It involved a count of the number of passengers arriving at the transit station by two minutes time intervals. A mean waiting time was then calculated and compared with interarrival time.

The results obtained were considered satisfactory when checked back, but surveys should be conducted in other cities to develop a general formula for different types of cities and transit systems.

ACKNOWLEDGEMENTS

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The help of the Sir George Williams library Staff and the personnel of the Montreal Urban Community Transportation Commission, in providing references and data for this study, is acknowledged with gratitude.

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LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER 1

BACKGROUND

1-1. MASS TRANSIT

Different modes of transportation are used by people every day in the pursuit of their daily activities. In almost every community, there has been a trend away from mass transportation and towards the private automobile. This trend now is being reversed due to increasing interest in expanding mass transit systems and public opposition to urban freeway construction e.g. the Metro extensions on Montreal Island viz a viz the public opposition to the Trans-Canada highway construction.

The proportion of the population using mass transportation increases as the size of the city or metropolitan community increases, because of high density residential areas, traffic congestion and more expensive off-street parking facilities.(2)

In order to divert traffic from private cars, mass transportation must compete in terms of travel time , cost, comfort and convenience. Otherwise the potential motorist may not be influenced into leaving his car at home or at least at a suburban transit station.

One of the major problems in forecasting future transportation patterns is to determine how people will travel from their origin to their destination, particularly when they have a choice in transportation modes. With consideration being given to the installation of new rapid transit systems, improved bus services and increased commuter train utilization for many of the major metropolitan areas, the problem of accurately predicting the usage of these facilities is important in the planning process.(5)

1-2. DEVELOPING A MODAL SPLIT MODEL

1-2-1. Concept of Modal Split Relationships

The total number of people moving during a certain period of time from an Origin zone (O) to a Destination zone (D), may be thought of as the total market existing between the O and D in question. The various modes of travel available for moving from O to D are competing for a share of this market, and each will win a portion of it, depending on its competitive position with others. The comparative advantages and disadvantages of each of the two major types of travel mode (Public transit and Private automobile) are measured by the time, cost, and convenience criteria. The other criteria, such as economic status and trip purpose, may be thought of as market characteristics which affect user reaction to the first three criteria.

To isolate the effect of the five determinants on market reaction (i.e., relative usage of transit and auto), it is necessary first to calculate the relative values of travel time, cost, and service in order to describe the relative competitive position of public transit and the private automobile between every O-D pair under consideration. It is also necessary to determine the average economic status (income category) of traveler proceeding from O to D. Next the percentage of travelers proceeding from O to D using public transit and private automobile is determined for each trip purpose and is related to each of the other four determinant factors. (4)

1-2-2. Factors Determining Choice of Travel Mode

The five basic factors considered in the study described in reference 4 are as follows:

1. Relative travel time via public transit and private automobile.
2. Relative travel cost via public transit and private automobile.
3. Regularity and convenience of service.

4. Economic status of trip makers (income per worker).
5. Trip purpose.

These five factors were selected on the basis of multiple regression analysis as having more independent significance than any others studied, to explain peoples' propensity to use public transit.

Among the factors considered originally were: trip length, population density, employment density, transit seat capacity, and orientation of the trip with regard to the central business district (CBD). However, they were found to be linearly dependent on at least one of the four determinants, time, cost service and income. Consequently, the degree of orientation of the trip with regard to the CBD is not included. Previous modal split studies (1) have shown that difference in transit usage of people traveling to CBD and non-CBD areas is adequately explained by differences in the five factors.

Usually there are more than two modes of travel available to most trip makers in urban areas. However, it is believed at this stage of development work, that the division of these travel modes into the two main types, public transit and private automobile, is sufficient to account for the basic differences in the properties of the main types.

Public transit is characterized by fixed routes and schedules, while private automobiles may be used flexibly whenever desired by the traveler.

Relative usage of alternative submodes within each of the main types (bus, metro, commuter train within the public transit mode; private automobile or taxi within the motor vehicle mode) can be shown to depend on similar determinant factors. (4)

(a). Relative Travel Time

The relative travel time is expressed as a ratio: door-to-door travel time via public transit divided by door-to-door travel time via private automobile. Figure (1) shows how the percentage of trips made to work by transit varies with time ratio. (4)

(b). Relative Travel Cost

Relative travel cost is also defined as a ratio: the out-of-pocket travel cost via public transit divided by the out-of-pocket travel cost via private automobile (figure 2). Travel cost in this ratio is defined as the total fare paid during the trip. Automobile travel cost is defined as operating cost (gasoline, oil, lubrication), one half parking cost and tolls if any. Automobile depreciation, licensing and insurance costs are not included, on the assumption that most automobile drivers

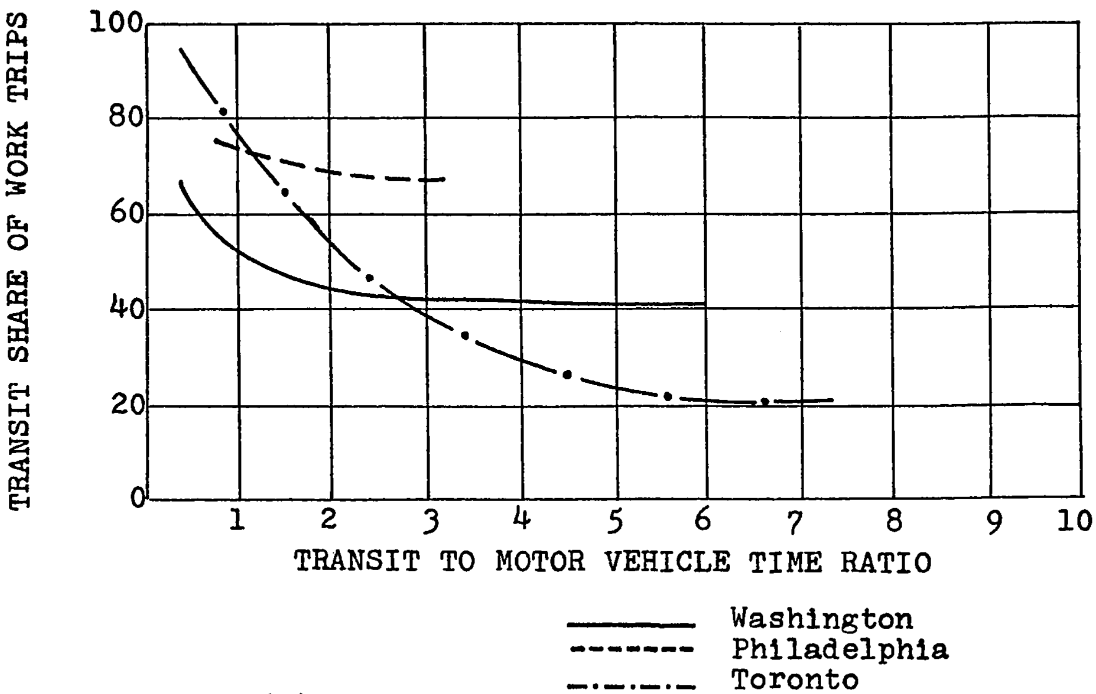

FIGURE (1). Travel time ratio diversion curve for work trips in peak periods (No. of trips in 1,000's)

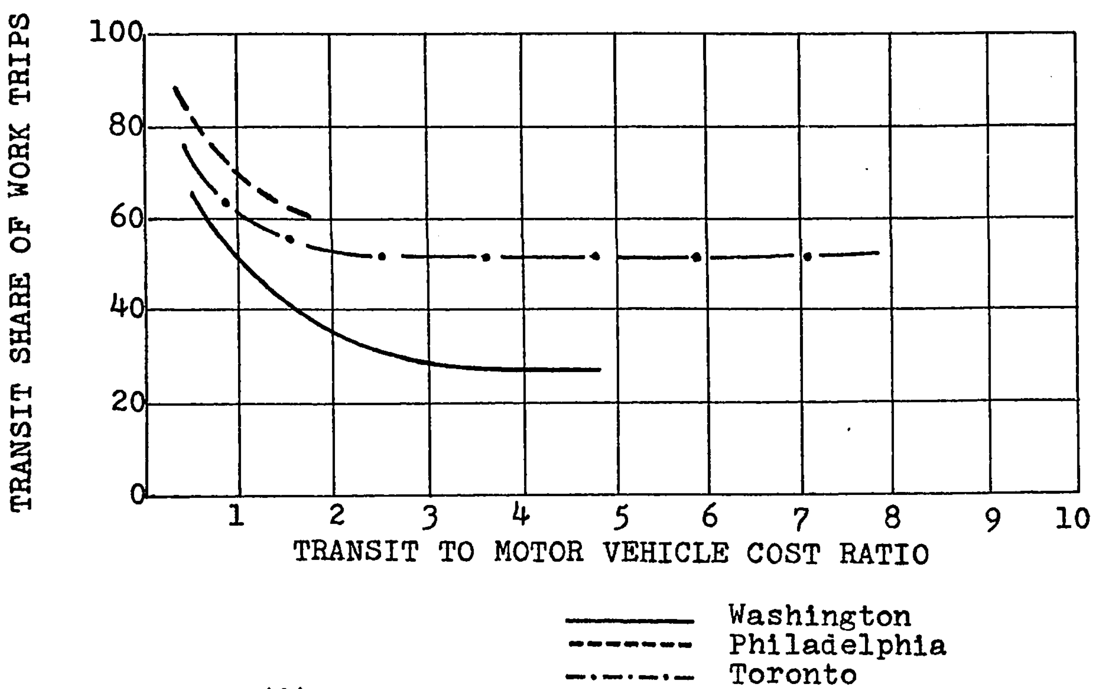

FIGURE (2). Cost ratio diversion curve for work trips in peak periods (No. of trips in 1,000's) do not consider these costs in connection with each trip made. The travel cost via private automobile is divided evenly among all occupants of an automobile based on the principle of cost sharing which usually exists in car pool arrangements. (4)

(c). Regularity and Convenience of Service

The private vehicle offers a more luxurious and convenient mode of travel than does public transportation, particularly by eliminating lengthy waiting periods and walking times. However, waiting periods and walking times are important considerations when using transit because they reflect the level of service offered on the public transportation facility. People tend to measure the regularity and convenience of public transportation service in terms of the time spent in addition to traveling, such as walking from the trip origin to the station, waiting time at the station, transfer time between route changes, and walking time from the station to the trip destination. The following steps were taken to calculate these measurements:

(i). Waiting Times

The waiting time at a station was estimated equal to one-half the scheduled headway time of the public transportation facility in a zone as recorded by the Toronto Transit Commission for rush hour service on October 4, 1955. (6)

(ii). Transfer Times

It is reported that approximately 90% of subway passengers make at least one transfer, approximately 50% of all transit passengers make one transfer, and 10% of this number make two or more transfers. Despite the introduction of a small error, each Origin - Destination transit movement is recorded with one transfer. This transfer time is set equal to one-half the scheduled headway time of the public transportation facility in the destination zone. (6)

(iii). Walking Times

Although walking times were not reported in the surveys, there was sufficient information available, such as the number of miles of transit track, the average spacing between stations, and the number of acres of developed land in a zone, to make possible the computation of average walking times to and from transit stations. A few assumptions concerning first the location of transit lines with respect to the zone boundaries and secondly, people's walking behavior, were necessary for the estimation of these average walking times.

Because transit routes follow the rectangular road layout of the city, it was assumed that approximately one-half of the transit routes servicing a zone, run north-south and the other half east-west. Also, one can assume that people tend to walk to the nearest transit station located on a transit route that runs parallel to their desired direction of travel.

If the north-south and east-west transit lines are evenly distributed throughout the same developed area, then the following formulas may be used to compute representative walking distances, and walking times, which people may experience in each zone.

The average distance walked in miles,

$$D = \frac{1}{3}\sqrt{d^2 + w^2} + \frac{d^2}{6w} \cdot \ln\left[\frac{\sqrt{d^2 + w^2} + w}{d}\right] + \frac{w^2}{6d} \cdot \ln\left[\frac{\sqrt{d^2 + w^2} + d}{w}\right]$$

in which

$d = \frac{1}{2}$ x stop spacing, miles,

$w = \frac{A_D}{L_T} \times \frac{1}{640}$, miles,

A_D= number of acres of developed land,

= total land - vacant land - open space,

L_T= number of miles of transit track.

The average walking time in minutes,

$T = \frac{60}{3} \times D$ (walking speed of 3 mph)

The level of O-D transit service is measured by the sum of the walking plus waiting time in the origin zone, a transfer time and the walking time in the destination zone.

Observations were grouped and plotted on graph paper. A curve was drawn through the grouped observations to show the relationship between transit usage and the changing levels of O-D transit service (see figure 3). (6)

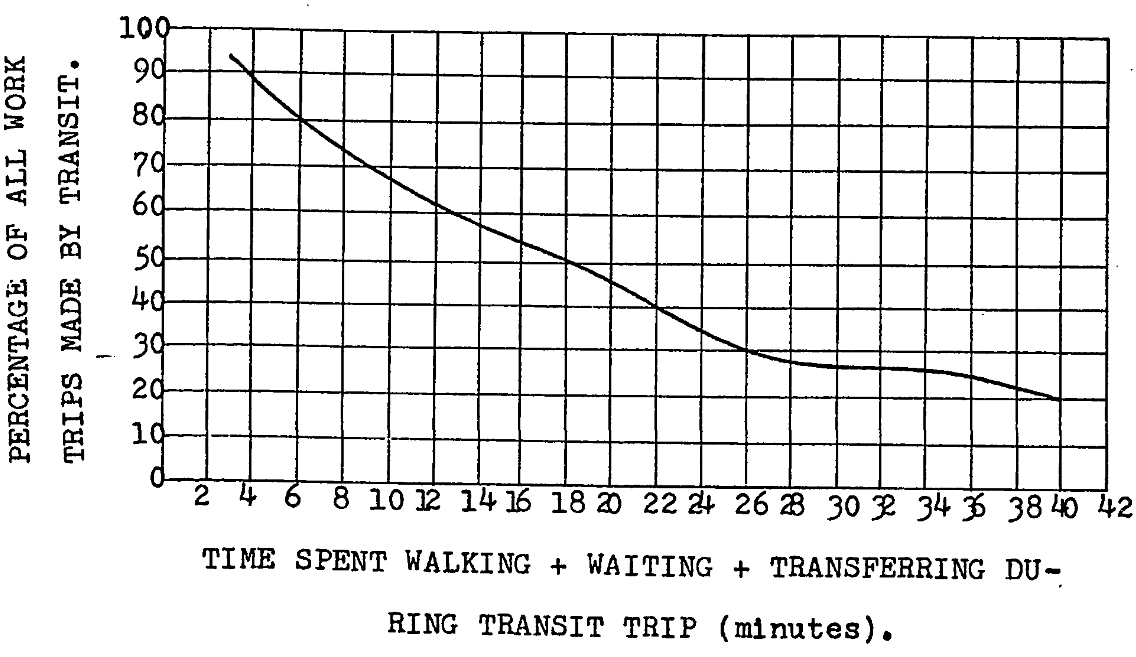

FIGURE (3). Transit share of work trips related to total walking and waiting times.

(d). Economic Status of Trip Makers

It might be expected that increases in income would increase the elasticity of demand for transit. In the first place, prosperous people expect good service for their money and will tend to avoid a transit system which does not provide good service. Augmenting this is the fact that those with high income can afford the capital outlay necessary for private automobile ownership. The overall effect of trip maker's income (per worker) on relative transit usage is shown in figure (4). (4)

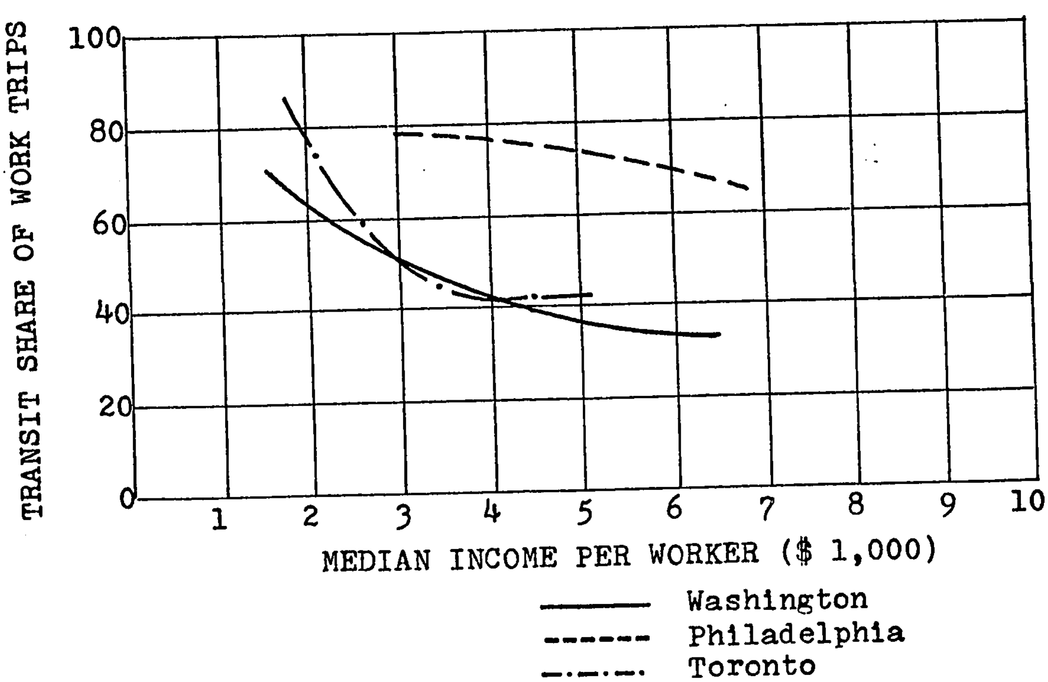

FIGURE (4). Income diversion curve for work trips in peak periods (No. of trips in 1,000's) (e). Trip Purposes

For many trip purposes such as selling to widely separated clients or shopping for week's groceries, the use of an automobile is all but mandatory. For trips, such as work trips of office staff, the choice is open and will depend on other factors. For other trips, such as many school trips, transit is the only choice because of travelers' inability to drive or own an automobile. It is logical to expect, therefore, that modal split relationships based on the four determinant factors described previously will vary somewhat, depending on trip purposes. (4)

1-3. NUMERICAL EXAMPLE

To illustrate the process of determining the modal split, the following numerical example is performed. The data needed for the computation of this example was collected during the summer 1971 at peak-hour in city Saint - Laurent (Zone A), where all transit modes are available. The rider had different alternatives to travel from Origin (Zone A) to Destination (Zone B). These alternatives are shown in figure (5).

The following sequence of steps were considered in the determination of modal split:

Alternative I : A-9-10-11-12-B

Alternative II : A-3-4-5-6-B

Alternative III : A-3-7-8-B

Alternative IV : A-1-2-B.

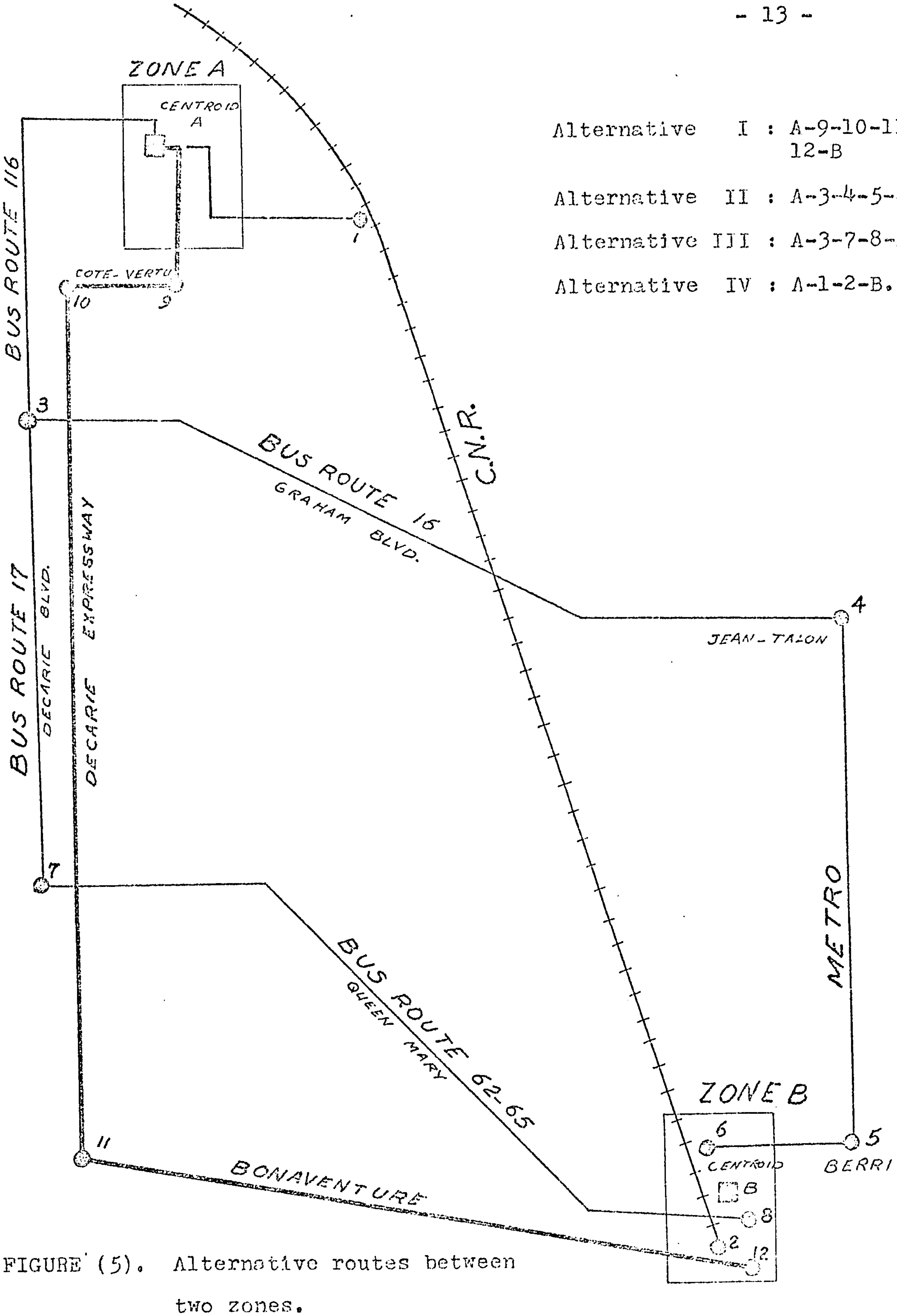

FIGURE (5). Alternative routes between two zones.

a. The study area was divided into traffic zones.
b. A centroid position was selected for each zone.
c. A model was developed for the existing system.
d. Each centroid was connected to the model.
e. Trip time (travel + waiting + walking + transfer times) was assigned to each branch of the model.
f. The minimum trip time between each two centroids was calculated for each mode of transportation.
g. The modal split was finally calculated for the transit routes with a minimum trip time.

In this example, only the trip time was taken into consideration because it is more related to the performance of the system than the other factors discussed previously. The walking time was estimated on the basis of an average walking speed of 3 mph. The interarrival time of transit facility was taken from bus and train schedules. The waiting and transfer times were considered equal to one-half the scheduled headway time as in reference (6).

Calculation of Trip Time

(a). Alternative I. Travel by Car

	Time in minutes
Travel time from centroid (A) to point 9	1
Travel time from point 9 to point 10	3
Travel time from point 10 to point 11	10
Travel time from point 11 to point 12	4
Travel time from point 12 to centroid (B)	2
Trip time =	20 minutes

(b). Alternative II. Travel by Bus and Metro

	Time in minutes
Waiting time at centroid (A) (interarrival time=16)	8
Travel time from centroid (A) to point 3	5
Transfer time at point 3 (interarrival time=16)	8
Travel time from point 3 to point 4	15
Transfer time at point 4 (interarrival time=2)	1
Travel time from point 4 to point 5	6
Transfer time at point 5 (interarrival time=2)	1
Travel time from point 5 to point 6	3
Walking time from point 6 to centroid (B)	2
Trip time =	49 minutes

(c). Alternative III. Travel by Bus only

	Time in minutes
Waiting time at centroid (A) (interarrival time=16)	8
Travel time from centroid (A) to point 3	5
Waiting time at point 3 (interarrival time=2)	1
Travel time from point 3 to point 7	12
Transfer time at point 7 (interarrival time=2)	1
Travel time from point 7 to point 8	10
Walking time from point 8 to centroid (B)	2
Trip time =	39 minutes

(d). Alternative IV. Travel by Train

	Time in minutes
Walking time from centroid (A) to point 1	10
Waiting time at point 1 (interarrival time=32)	16
Travel time from point 1 to point 2	12
Walking time from point 2 to centroid (B)	3
Trip time =	41 minutes

To estimate the modal split, the curves presented in figure (6) and figure (7) are used. These curves show the percentage of the population using transit inside the city and in suburban areas. (7) If the trips are to and from downtown, more people are attracted in using transit system to eliminate traffic congestion during peak hours and parking expenses. In the downtown area where trip length is short and parking facilities limited, more people tend to use transit.

In this example, alternative III offers the minimum transit trip time, but travel by this route is almost twice the time by car.

$$\text{Time Ratio} = \frac{\text{Travel time via transit system}}{\text{Travel time via automobile}}$$

$$= \frac{39}{20}$$

$$= 1.95$$

Therefore from the curve (A) in figure (7), the percent of total person trips using transit = 27%. The percentage of the population using automobiles = 73%.

Assuming that the daily volume = 1,000 passengers, then 270 passengers could be expected to use bus (AlternativeIII) and 730 passengers to use car. Some of the 270 passengers using bus might use alternative IV due to the small difference between III and IV. Relatively few passengers will use alternative II.

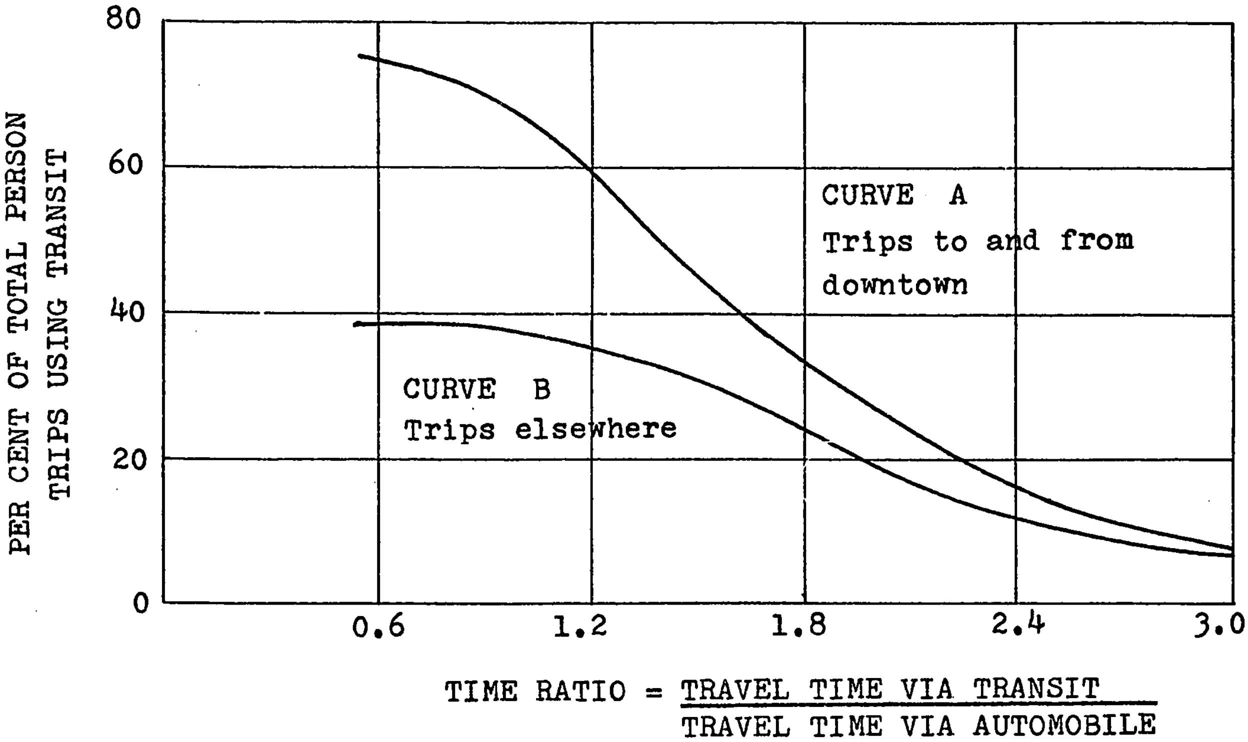

FIGURE (6). Transit usage inside the city.

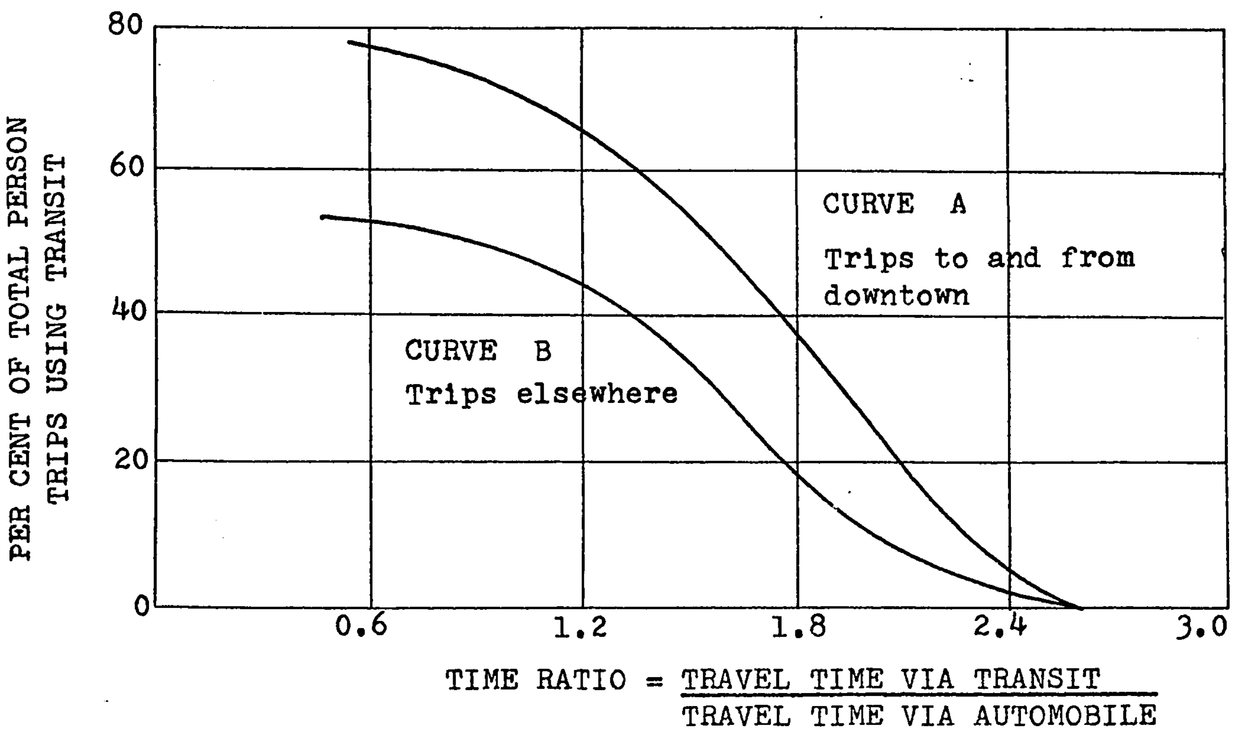

FIGURE (7). Transit usage suburban area.

CHAPTER II

WAITING TIME SURVEY

2-1. PURPOSE AND SCOPE

The total time spent by passengers to travel from O to D is an essential part of the input data needed for estimating the modal split. This total time, or trip time, is the sum of walking, waiting, traveling and transfering times.

As part of this thesis, an investigation was made of the characteristics of trip times, particularly waiting times at transit stations. A field survey was carried out from June to August 1971, at six different locations on Montreal Island during peak and off-peak hours, to measure the time spent by passengers waiting for various transit modes.

To date, waiting time as discussed in Chapter I has usually been taken equal to one-half the scheduled headway time of public transportation facility. It was found from the survey that waiting time varies for different transit modes and depends on several factors such as public knowledge of schedules, frequency and reliability of service, and trip purpose.

A numerical factor was then calculated, from which an average waiting time can be estimated if the interarrival time of the transit facility is known. One factor was calculated for each aspect of transit system. These factors are presented in table (2).

2-2. DESCRIPTION OF STUDY AREAS

Montreal Island is a good site for this type of survey because of the variety of transit modes available (scheduled and unscheduled buses, commuter trains and subway). Figure (8) shows the different transit modes in Montreal Island.

In choosing the survey locations, arrange of conditions were considered. Four basic conditions were:

(a) High frequency of service with printed schedules

(b) Low frequency of service with printed schedules

(c) High frequency of service with no schedules

(d) Low frequency of service with no schedules.

In addition, information on peak and off-peak travel characteristics was required.

The survey stations were selected to include the three types of transit - bus, train and metro. In general, due to Montreal route patterns, the stations were oriented to central city travel.

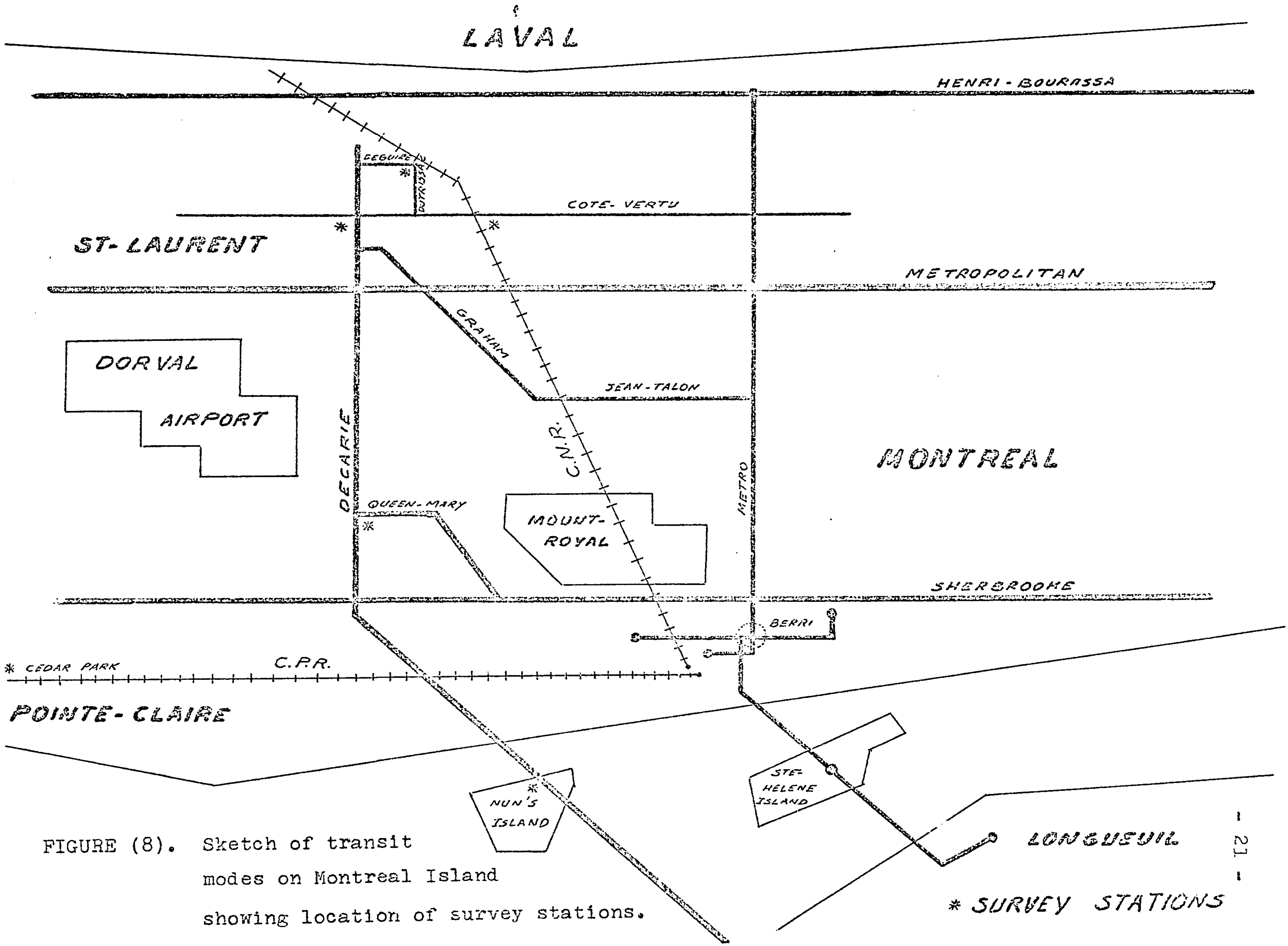

FIGURE (8). Sketch of transit modes on Montreal Island showing location of survey stations.

2-2-1. Survey Routes and their Characteristics

Each of the selected stations was offering certain aspects needed for the survey. Table (1) shows these locations and their characteristics.

Table (1). Survey locations and characteristics.

STATION LOCATION	TRANSIT MODE AND ROUTE No.	CHARACTERISTICS
1- CEDAR PARK (west island)	CP TRAINS	- Direct line to Downtown - No other transit mode available in this area - Low frequency of service - Printed schedules available - Average interarrival time at peak hours = 32 minutes.
2- COTE VERTU (St-Laurent)	CN TRAINS	- Direct line to Downtown - Low frequency of service - Printed schedules available - Average interarrival time at off-peak hour = 40 minutes.

Continued......

3- NUNS' ISLAND	12 BUS	- Direct line to Downtown - No other transit mode available in this area - High frequency of service - Printed schedules available - Average interarrival time at peak = 9 minutes and off-peak = 15 minutes.
4-DEGUIRE-DUTRISAC	116 BUS	- Indirect line to Downtown - No printed schedules available - Low frequency of service - Average interarrival time at peak = 15 minutes and off-peak = 20 minutes.
5- DECARIE-COTE VERTU	17 BUS	- Indirect line to Downtown - No printed schedules available - High frequency of service - Average interarrival time at peak = 2 minutes and off-peak = 9 minutes.

Continued......

6- QUEEN MARY-DECARIE	65 BUS	- Direct line to Downtown - No printed schedules available - High frequency of service - Average interarrival time at peak = 2 minutes and off-peak = 4 minutes - Used to check obtained results.

These survey locations are shown on Figure (8).

2-3. DESIGN OF SURVEY

2-3-1. Work Schedule

The field survey extended over an 18 day period starting July 1, 1971. Surveys were conducted for two days at each station location. The counting started at 6.30 a.m. and finished at 9.30 a.m. This period of time enabled the covering of the peak-hour period and showed the increase in the number of passengers arriving at station. For off-peak hour, the counting was done from 2 p.m. to 4 p.m.

2-3-2. Type of Survey

For the purpose of this study only one type of survey was performed at the stations. Since the waiting time differs from one station to another depending on the frequency of service, the ratio of waiting time to interarrival time was taken as a basis for comparison. Therefore, two essential factors had to be determined:

a) Interarrival time of transit system,

b) Number of passengers waiting during a certain time interval.

The interarrival time was divided into two minute intervals and the number of passengers arriving during any interval was recorded. In case of train stations where interarrival time is large, the interval was taken as 5 minutes. A mean waiting time was then calculated and compared with the mean interarrival time for each transit facility.

2-3-3. Data Collection Method

A special form was prepared to facilitate counting. It is shown in figure (9). The route name, direction, time, weather and special remarks were specified on the form. The arrival time of transit at station was recorded and the stop watch set to work. The number of passengers arriving during any interval was counted and marked in appropriate column.

2-4. CHECKING OBTAINED RESULTS

One survey was performed on a high frequency, no printed schedules available line (65 bus route) to check validity of the obtained results. As shown in table (2) the ratio R for the 65 bus route almost coincides with the 17 bus route which has the same characteristics. The results obtained were considered satisfactory though several other surveys should be carried out to determine whether waiting time characteristics are different from those presented herein.

ROUTE No. 12
DIRECTION NORTH
TIME 7.05 – 8.50 a.m.

DATE 14-7-71
WEATHER CLOUDY

BUS No.	BUS ARRIVAL TIME AT STATION	No. OF PASSENGERS ARRIVING DURING INTERVAL									TOTAL	INTER-ARRIVAL TIME	REMARKS
		0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18			
	7h15	0	1	2	2	0	6	3	2	0	16	15	Bus empty
	7h30	0	0	4	4	6	4	7	3	0	28	15	Light rain
	7h45	3	10	5	13	12					43	10	Light rain

FIGURE (9). Typical form for survey counts.

CHAPTER III

DATA ANALYSIS

3-1. STATISTICAL COMPUTATIONS

The information collected in the surveys was summarized in the form of frequency distribution tables, an example of which is presented in figure (10). Simple statistical procedures were used to describe the series of results obtained from the survey. The statistical analysis is described below.

3-1-1. Waiting Time Arithmetic Mean (m)

The arithmetic mean is a measure of central tendency and gives an average waiting time for the total number of passengers arriving at a station. It is computed from the frequency distribution tables using the following equations:

Arithmetic mean (m) $= A + C \frac{d_i f_i}{N}$

Where $d_i = \frac{X_i - A}{C}$

X_i = mid point

C = class interval

A = assumed mean

$N = f_i$

= total number of variates.(10)

ROUTE No. 12 DATE 14.7.71

DIRECTION NORTH WEATHER Cloudy

TIME 7.05 to 8.50 a.m.

BUS No.	WAITING TIME BOUNDARIES	MID-POINTS X_i	NUMBER OF PASSENGERS f_i	DISTRIBUTIVE %	CUMULATIVE %	$X_i f_i$	d_i	$d_i f_i$	$d_i^2 f_i$	$x_i = X_i - m$ x_i	$x_i f_i$	x_i^2	$x_i^2 f_i$
1	0-2	1	2	12.50	12.50	2	-2	-4	8	4.87	9.74	23.72	47.44
	2-4	3	3	18.75	31.25	9	-1	-3	3	2.87	8.61	8.24	24.72
	4-6	5	6	37.50	68.75	30	0	0	0	0.87	5.22	0.76	4.26
	6-8	7	0	0.00	68.75	0	1	0	0	1.13	0.00	1.28	0.00
	8-10	9	2	12.50	81.25	18	2	4	8	3.13	6.26	9.80	19.60
	10-12	11	2	12.50	93.75	22	3	6	18	5.13	10.26	26.32	52.64
	12-14	13	1	6.25	100.00	13	4	4	16	7.13	7.13	50.84	50.84
	14-16	15	0	0.00	100.00	0	5	0	0	9.13	0.00	83.36	0.00
T O T A L			16	100.00		94		+7	53		47.22		199.50
2	0-2	1	3	10.73	10.73	3	-3	-9	27	4.93	14.79	24.30	72.90
	2-4	3	7	25.00	35.73	21	-2	-14	28	2.93	20.51	8.58	60.16
	4-6	5	4	14.28	50.01	20	-1	-4	4	0.93	3.72	0.86	3.44
	6-8	7	5	21.43	71.44	42	0	0	0	1.07	6.42	1.15	6.90
	8-10	9	4	14.28	85.72	36	1	4	4	3.07	12.28	9.42	37.68
	10-12	11	4	14.28	100.00	44	2	8	16	5.07	20.28	25.70	102.80
	12-14	13	0	0.00	100.00	0	3	0	0	7.07	0.00	49.98	0.00
	14-16	15	0	0.00	100.00	0	4	0	0	9.07	0.00	82.26	0.00
T O T A L			28	100.00		166		-15	79		78.00		283.78

FIGURE (10). Typical form for calculations.

3-1-2. Histogram, Frequency Curves, Mode and Pace

For the analysis of waiting time, histograms and frequency curves were drawn. From these curves shown in figure (11), the modal average is determined. The modal average (m_d) is the time waited by most of the passengers at a station. It is determined by the location of the peak on the frequency distribution curves.

The pace is also determined from the frequency curves. The pace (p) is the range of waiting time which include the greatest number of passengers for some nominal increment of time (2 minutes). It falls where the upper and lower limits intercept equal frequencies.

3-1-3. Cumulative Frequency Curves, Median and Percentile

Figure (12) shows the cumulative frequency curves. These curves were useful in the determination of the median and the percent of passengers waiting for a period of time above or below a given interval. The median (M_d) is the time waited by 50% of the passengers. It is determined for each transit mode and shown on the curves.

Ther 85 percentile was also determined and it shows the time waited by 15% of the passengers. Such percentile values

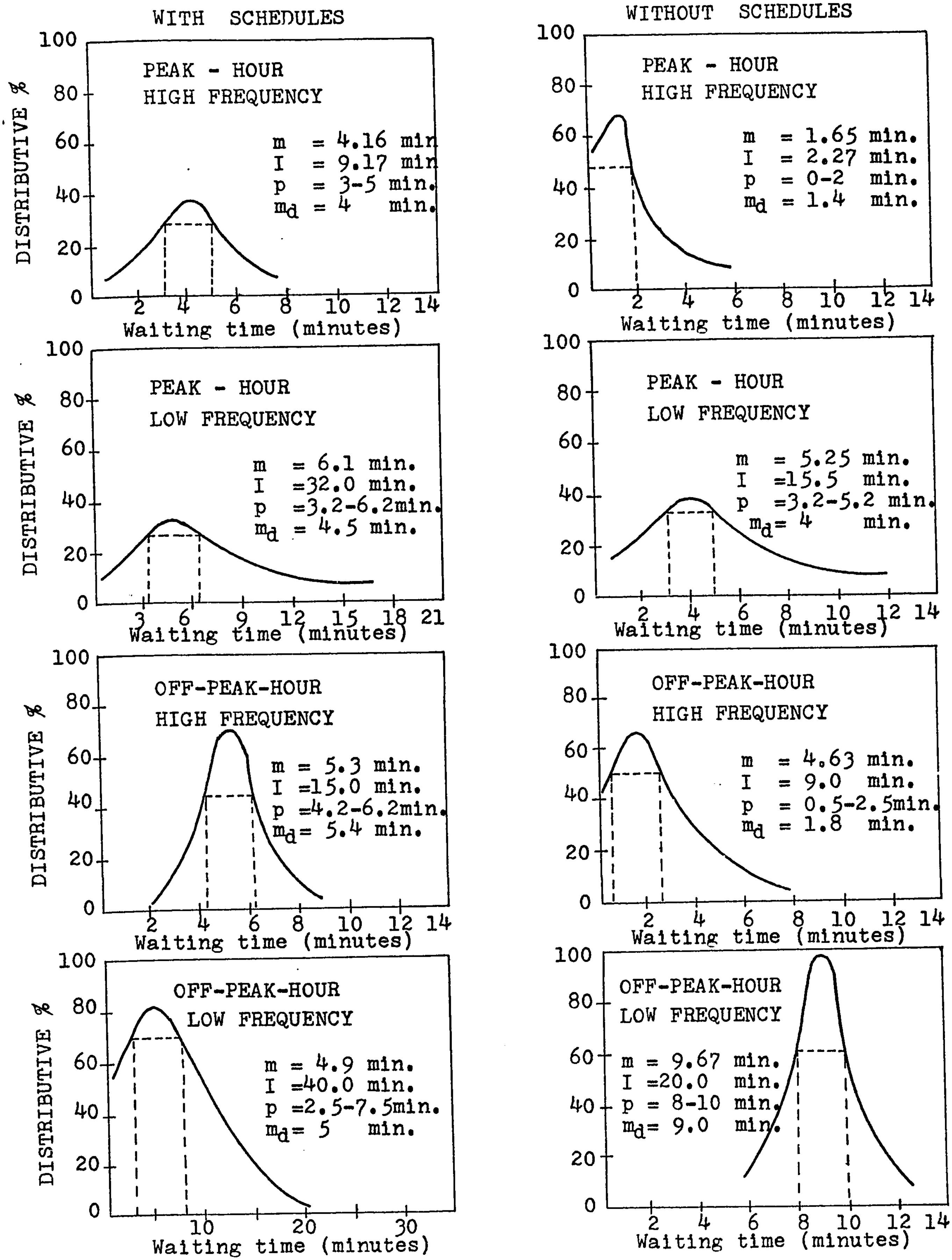

FIGURE (11). Typical frequency distributions for peak and off-peak hours, and scheduled and unscheduled transit services.

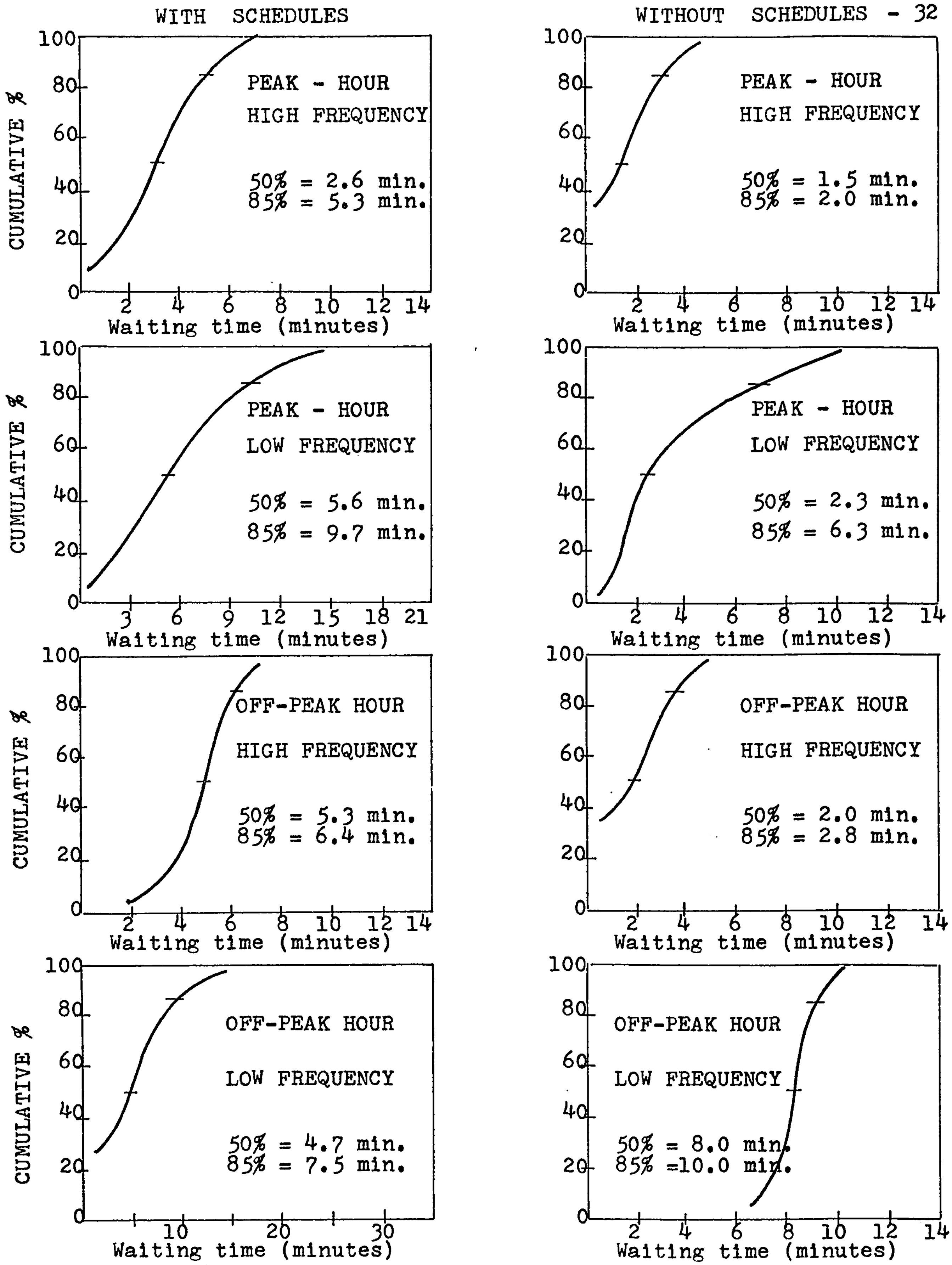

FIGURE (12). Typical cumulative frequency distributions for peak and off-peak hours, and for scheduled and unscheduled transit modes.

are of special significance in determining interarrival time of transit facility and in the calculation of waiting times for the computation of modal split because these values give the probable waiting time for most of the passengers (85% of them).

3-2. SUMMARY OF RESULTS OBTAINED

The following table (2) summarizes the results obtained from the survey. After the calculation of the mean waiting time (m), and the mean interarrival time (I) for each transit mode, it was noticed that the waiting time changes from one station to another according to the frequency of service. The ratio of mean waiting time to mean interarrival time (R) was taken as basis for comparison.

$$R = \frac{\text{Mean waiting time in minutes}}{\text{Mean interarrival time in minutes}}$$

The modal average (m_d), which represents the time waited by most of the passengers, was taken from the frequency curves (figure 11). The pace (p) was also determined from figure (11). It represents the range of time waited by most of the passengers.

From figure (12), the values of the median (M_d) and 85 percentile (85%) were taken. These values represent the time waited by 50% and 15% of the passengers respectively.

3-3. FACTORS INFLUENCING WAITING TIME

3-3-1. Public Knowledge of Schedules

It can be seen from table (2) that the value of the ratio (R) is smaller for cases where printed schedules are available. The Minimum (R) value, 0.1, occured on a low frequency route with printed schedules at off-peak hour. The average waiting time in that case was 4.90 minutes with a range of 2.5 to 7.5 minutes. Only 15% of the passengers waited for 7.50 minutes and 50% of them waited for 4.70 minutes. Although the interarrival time in that case was large (40 minutes), the waiting time was small. People knowing, from the printed schedules, that interarrival time is high tend to arrive at station just before arrival of transit facility.

On transit routes with no printed schedules availabe, it was noticed that people also kept waiting time to a minimum. For example, the case of low frequency of service with no printed schedules availalle at peak-hour, the (R) value was 0.30. The range of waiting time was reasonable (3.2 to 5.2) if compared with the interarrival time of 15.50 minutes. Only 15% of the passengers waited for 6.30 minutes and 50% waited for 2.30 minutes. In this case, it was assumed that the schedule of the transit facility was known by the public through experience.

These findings indicate that public knowledge of schedules through printed information or through experience can minimize waiting time especially on low frequency routes.

3-3-2. Frequency of Service

The maximum (R) value (0.70) occurred on a high frequency route with no printed schedules at peak-hour. The waiting time of 1.65 minutes, is the smallest. The range of waiting time varies from 0 to 2 minutes, 50% of the passengers waited for 1.50 minutes and 15% waited for 2 minutes. The interarrival time in this case is very small (2.27 minutes). Due to this high frequency of service, people arrive at station at random knowing that waiting time is going to be a minimum.

On routes where the frequency of service is low, for example the case of low frequency of service with printed schedules at peak-hour, the public is more concerned about waiting times. In this case, the waiting time is 6.10 minutes, the (R)value 0.20, the interarrival time is 32 minutes and the range of waiting time varies from 3.2 to 6.2 minutes. When service is infrequent, people tend to arrive at station just on time for transit, making allowances for walking times and traffic delays.

Table (2). Summary of survey results.

	TRANSIT MODE WITH PRINTED SCHEDULES AVAILABLE				TRANSIT MODE WITH NO PRINTED SCHEDULES AVAILABLE			
	High Frequency of Service		Low Frequency of Service		High Frequency of Service		Low Frequency of Service	
	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
m	4.16	5.30	6.10	4.90	1.65	4.63	5.25	9.67
I	9.17	15.00	32.00	40.00	2.27	9.00	15.50	20.00
R	0.50	0.40	0.20	0.10	0.70	0.50	0.30	0.50
m_d	4.00	5.40	4.50	5.00	1.40	1.80	4.00	9.00
p	3-5	4.2-6.2	3.2-6.2	2.5-7.5	0-2	0.5-2.5	3.2-5.2	8-10
M_d	2.60	5.30	5.60	4.70	1.50	2.00	2.30	8.00
85%	5.30	6.40	9.70	7.50	2.00	2.80	6.30	10.00

Where:

m = Mean waiting time in minutes

I = Mean interarrival time in minutes

R = Ratio $\frac{m}{I}$

m_d = Modal average in minutes

p = Pace (range in minutes)

M_d = Median in minutes.

3-3-3. Trip Purpose

Exception made for the case of low frequency of service with printed schedules available, the waiting time at stations increased due to lower frequency of service at off-peak hours. In the case of low frequency of service with schedules, and where the interarrival time is very large, (sometimes the train stops on signal only), people arrive at the station just in time to board.

People appear to be less concerned about waiting times at off-peak hours, because the purpose of travel is usually not related to work. This aspect was observed at stations during off-peak where most of the passengers were aged people standing at station talking and enjoying the weather. It was also observed that regular commuters appear to be more adept at minimizing waiting time than occasional travelers (shoppers).

3-3-4. Reliability of Service

This factor was difficult to investigate for transit routes without printed schedules. In other cases where printed information was available, the service was found to be reliable, transit arriving at station within two minutes of the scheduled time.

Most of the passengers were arriving at the station earlier than scheduled transit, making allowances for walking time, delays that can occur on their way to the station and in some cases just to enjoy the weather.

3-4. NUMERICAL EXAMPLE

The purpose of performing this example is to compare the survey findings with the previous rule taking the waiting time as equal to one-half the headway time of transit facility as discussed in chapter (I).

The example uses the same figures as in example 1-3. The modal split in that case is calculated by using the values of ration (R) obtained in table (2) to estimate the waiting times.

Calculation of Trip Time

(a). Alternative I. Travel by Car.

Trip time (same as in example 1-3) = 20 minutes (b). Alternative II. Travel by Bus and Metro

	Time in minutes
Waiting time at centroid (A) (Low frequency, peak-hour) 0.3 x 16	4.8
Travel time from centroid (A) to point 3	5.0
Transfer time at point 3 (0.3 x 16)	4.8
Travel time from point 3 to point 4	15.0
Transfer time at point 4 (0.7 x 2)	1.4
Travel time from point 4 to point 5	6.0
Transfer time at point 5 (0.7 x 2)	1.4
Travel time from point 5 to point 6	3.0
Walking time from point 6 to centroid (B)	2.0
Trip time =	43.4 minutes

(c). Alternative III. Travel by Bus only

	Time in minutes
Waiting time at centroid (A) (0.3 x 16)	4.8
Travel time from centroid (A) to point 3	5.0
Transfer time at point 3 (high frequency) (0.7 x 2)	1.4
Travel time from point 3 to point 7	12.0
Waiting time at point 7 (0.7 x 2)	1.4
Travel time from point 7 to point 8	10.0
Walking time from point 8 to centroid (B)	2.0
Trip time =	36.6 minutes

(d). Alternative IV. Travel by Train

	Time in minutes
Walking time from centroid (A) to point 1	10
Waiting time at point 1 (low frequency, peak-hour) (0.2 x 32)	6
Travel time from point 1 to point 2	12
Walking time from point 2 to centroid (B)	3
Trip time =	31 minutes

In this example, alternative IV offers the minimum trip time. Alternative III is the second best and differs slightly from the one computed in example 1-3.

$$\text{Time ratio for IV} = \frac{\text{Travel time via transit system}}{\text{Travel time via automobile}}$$

$$= \frac{31}{20} = 1.55$$

Therefore, from the curve (A) in figure (7), the percent of total person trips using transit = 52%. The percentage of the population using the car = 48%.

Assuming that the daily volume = 1000 passengers, then 520 passengers could be expected to use the train (Alternative IV) and 480 passengers to use the car.

Comparing this example with the one performed in 1-3, we notice that the shortest route has changed (Best route is by bus in 1-3 and is by train in 3-4). Also the modal split differs (27% in 1-3 and 52% in 3-4). The resulting difference of 25%, between the computed modal splits in the two examples, is only due to different waiting times taken to calculate the trip time.

We can conclude then, that the higher the interarrival time of transit facility the greater the discrepancy resulting in the calculation of the modal split by the two methods.

C H A P T E R IV

CONCLUSIONS

The modal split, constructed by the study of factors influencing people's choice of travel mode, forms a reliable framework of reference necessary in predicting travel movements and capacities for specific transportation planning purposes.

One of the factors influencing choice of travel mode is the trip time. It is taken equal to the sum of the walking, waiting, transfering and traveling times. The waiting times, as found from this study, are influenced by factors such as public knowledge of schedules, frequency of service, reliability of service and trip purpose. In turn, these waiting times influence the value of the trip time and consequently, the resulting modal split is changed.

Waiting times used for the estimation of trip times can induce a large error in the resulting modal split if not accurately estimated. Based on the calculations performed in examples 1-3 and 3-4, there was a difference of 25% in the computed modal split due to waiting time differences between the two examples. In addition, it was found that, the higher the interarrival time of the transit facility, the higher the error resulting in the computed modal split.

The approach used in this study could be useful in urban transportation studies for the estimation of waiting times at stations for different transit modes, but several other surveys should be carried out. It may be found that quite different results are obtained in other cities depending on service characteristics.

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