accomplished by modifying the values of the independent variables which describe the level of service provided by the transportation system.

Finally, these approaches make it easy to compare several alternative transportation modes in a single model such as in the multinominal logit mode choice models described in the next section.

2.4 Classification of Modal Split Models

As indicated earlier, modal split models can be developed using the conventional aggregate approach (zonal level) or the disaggregate behavioural approach (individual or household level). Each of these two approaches may be further classified into several categories as illustrated in Figure 2.3. Several statistical techniques are available for use in association with each category and these are also indicated in the figure.

The second approach is described as being behavioural because it is founded in two disciplines dealing with behaviour, the economics of consumer behaviour, and the psychology of choice behaviour. The approach is based on the identification of the decision variables which enter into the travel-choice situations such as travel time, travel cost, quality of service, etc.

The behavioural approach may be classified into two major categories:
1. The econometric approach which apply the economic theory of consumer behaviour, and
2. The disaggregate stochastic (probabilistic) approach which apply the theory of psychological behaviour of the consumer.
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MODAL SHIFTS AND FINANCIAL EFFICIENCY IN URBAN TRANSPORTATION: A CASE STUDY OF THE REGIONAL MUNICIPALITY OF OTTAWA-CARLETON

by

HANNA N. HANNA

B.Sc. (Civil Engineering, Hons.)

A Thesis submitted to the Faculty of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Engineering

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ABSTRACT

The objective of this research was to develop and implement a methodological framework for studying urban travel modal shifts and financial efficiency. Two interactive steps were involved. Firstly, a policy responsive demand model was developed for estimating modal shifts. Secondly, a methodology was required for estimating public transportation expenditures, revenues and deficits. A case study of O. C. Transpo, Regional Municipality of Ottawa-Carleton was implemented.

The input data used in the model development was the 1977 Telephone Survey. A randomly selected sample of 1000 P.M. peak hour records was used in calibrating four sets of binary choice logit models disaggregated by trip purpose and geographic location. These models were developed using stepwise least square regression technique.

Three combination measures of modal impedances were tested, namely: impedance differences, impedance ratios and relative impedance ratios. The relative impedance ratios model applications were performed on both area-wide and zonal levels.

The financial efficiency measures of O. C. Transpo, using 1977 data, were estimated in terms of unit cost per passenger and revenue/cost ratio for various transportation policies such as fare, gasoline prices and parking charges.
ACKNOWLEDGEMENTS

The research reported in this thesis was carried out under the supervision of Professor A. M. Khan, whose encouragement and assistance were greatly appreciated.

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CHAPTER I
INTRODUCTION

1.1 Problem Definition

The urban transportation system has some severe problems particularly in the industrialized countries. These problems stem from the fact that a high percentage of the urban area travellers use the private automobile as their predominant travelling mode. This high usage of automobiles is a result of many factors including the high disposable income level of the population, weather conditions and the advantages of the automobile in providing a door-to-door service as well as its 24 hour availability. Whatever the reasons, this situation causes many problems which severely influence both the individual and the society as a whole.

The major urban transportation problems are manifested in a number of ways including:

1. Financial problems of public transportation systems. For example, in 1977, about 60% of operating costs of O. C. Transpo were covered by fare box revenue (1).*

2. Congestion phenomenon which is accompanied with excessive delays particularly during the peak hours and which contribute to higher accident rates for both vehicular and pedestrian traffic.

3. Increase in the amount of energy consumed in the transportation sector. Statistics show (2) that in the U.S.A., for example, transportation related activities account for close to 42% of the total energy consumed. Of this about 25% is directly consumed as fuel.

* References are provided at the end of the thesis.
4. Harmful and undesirable environmental impacts such as air pollution, noise, etc.

For a more comprehensive description of urban transportation problems, the reader should refer to reference (3).

Various studies have been devoted to solve these problems on a separate basis because they exhibit different characteristics. Nevertheless, these problems are interrelated, for example, the financial efficiency of the public transport system may be improved if higher ridership is achieved in conjunction with other urban transportation policies such as fare, automobile out-of-pocket cost, etc. Thus, the changes in the motorists' behaviour (particularly in shifting the travellers to the public mode) have become a necessity and a matter of general policy for various communities in order to increase the usage of the transit system. This in turn, will improve the financial efficiency of that system and resolve to some extent the urban transportation problems (i.e. congestion, pollution and energy consumption).

Consequently, this thesis develops a tool which can be used to identify the pricing and level of service measures which effectively simulate the trip makers' behaviour. Obviously, pricing measures (such as increased automobile out-of-pocket cost) would cause people to adjust their travel behaviour in favour of public transit system particularly when such system provides efficient and high quality of service.
1.2 Study Objectives

The objectives of this research are: (a) to develop a framework for investigating the financial efficiency impacts of modal shifts from the operator point of view; (b) to develop a disaggregate, binary choice modal split model for the Ottawa-Hull area for estimating modal travel demand for various urban transportation strategies, and (c) to provide a methodology for evaluating the public transit expenditures, revenues and deficits for the various demand levels obtained in applying the modal split model developed in (b).

An essential component of this framework is the development of a modal split demand model. Four models classified by trip purpose (work and non work) and geographic destination (CBD and Non CBD) were developed and calibrated using the least square regression technique. These models are capable of:

1. estimating transit ridership in a disaggregate fashion according to trip purpose and geographic location for various level of service operating strategies,
2. identifying the effects and sensitivity of mode choice to various urban transportation policies such as transit fare, travel time and frequency, and
3. reflecting changes in socio-economic characteristics of the urban area such as age, sex, income and car ownership.
In the second step of this research, the subsystems of the public transport which influence its operation in an urbanized area are identified. The components of expenditures (operating and capital), revenues and subsidies are determined for financial evaluation and investigation of the financial efficiency of the system from the operator point of view.

1.3 Thesis Organization

Chapter 2 describes the position of modal split models in the urban transportation planning process and a brief description of the historical development of urban transportation models. This chapter also presents a classification of modal split models and their corresponding calibration techniques available.

Chapter 3 outlines the theory of binary choice logit models used in developing and calibrating modal split models. The general methodology, study results together with some sensitivity analysis and comparison with other studies are presented.

Model applications in transit planning are described in Chapter 4. Two levels of analysis are attempted namely: area-wide and zonal levels. The framework employed at the zonal level requires the building of transit and road networks, developing total transit trip table and transit network assignment.

Chapter 5 presents the evaluation of the public transit system for various transportation policies. Expenditures, revenues, subsidy and system deficit are defined. Efficiency indicators for the public transit system are summarized from the operator and user points of view.
Chapter 6 summarizes the model calibration results, applications and evaluation of the public transit system. It provides research conclusions concerning the model development and applications. Finally, some recommendations for future research are advanced to enhance the overall research methodology and conclusions.
CHAPTER II
THE FRAMEWORK FOR THE INVESTIGATION
OF MODAL SHIFTS AND FINANCIAL EFFICIENCY

2.1 The Research Framework

The general framework of this research consists of three major activities. These activities will be presented separately in detail in chapters 3, 4 and 5. Major features of this framework are shown in Figure 2.1 and described briefly below.

Development and calibration of four different sets of binary choice logit model for the study area is the first activity. Variables reflecting the trip characteristics, the trip maker characteristics and the attributes of the transportation system are included in the model formulation. Impedances describing the road and transit networks are established on the basis of modal travel times and travel costs. Three combination measures of modal impedances are tested, namely: impedance differences, impedance ratios and relative impedance ratios. Defined as the impedance differences divided by the average impedance value. The four sets of models disaggregated by trip purpose (work, non-work)* and geographic destination (CBD, non-CBD)* are:
1. work, core oriented travel,
2. work, non-core oriented travel,
3. non-work, core oriented travel, and
4. non-work, non-core oriented travel.

The study of the sensitivity of the travel demand shift changes due to various transportation policies using the relative impedance ratios model is the second

* See Appendix A.1
FIGURE 2.1

THE RESEARCH FRAMEWORK
activity within the framework. The applications of the model in this regard considered the following:

1. improving the public transit level of service such as reducing: the number of transfers, total transit travel time and average fare, and
2. increasing the automobile out-of-pocket cost.

Two levels of analysis are considered in this study. Firstly, area-wide analysis which is based on a courseley estimated average value of the independent variables specified in the generalized travel functions. In this analysis, the total travel demand associated with the corresponding four modal split models is assumed to be constant. Secondly, zonal analysis which considers the interzonal probability of the mode choice and the PM peak hour person trips in estimating the total transit ridership at the base year conditions. This level of analysis required the following:

1. building transit and road networks for the study area,
2. developing total transit trip table, and
3. assigning the transit trip table to the transit network.

The third activity in this framework is the evaluation of the public transit system economic efficiency by identifying the components of expenditures (operating and capital) and revenues of the system. Revenues are based on the fare box revenues which are equal to average fare* times the annual ridership. The subsidy of the system is established as percentage of the operating costs for a given population level.

Consequently, the deficit of the system is estimated as well as the efficiency of the system from the operator point of view in terms of unit cost per passenger. The evaluation of the public transit system is based on O. C. Transpo data for 1977.

* See Appendix A.1
2.2 The Context of This Research Within Urban Transportation Planning Process

The urban transportation planning process has been defined as the process of guiding the changing transportation system environment in order to prepare a scheme to provide an urban area with a determined level of mobility (4). The process is orderly, structural and goal oriented. A composite structure of the transportation/land use planning process is shown in Figure 2.2.

In a typical urban transportation planning study, the process involves the following main activities:
1. formulation of goals and objectives,
2. inventory of the existing land-use and transport systems,
3. development of land-use allocation and travel demand models,
4. formulation of alternative transport land-use plans,
5. forecasting, testing, and evaluation of the alternative plans,
6. selection and implementation of the preferred alternative,
7. development of staging priorities, and
8. monitoring the impacts and the continuous update of the study and the plan.

Each of the above activities may be further subdivided into numerous elements. However, only the third and fifth activities are of direct concern to this research. They involve the use of mathematical models which are described in the next section.
FIGURE 2.2
THE URBAN TRANSPORTATION/LAND USE PLANNING PROCESS

Source: Reference (4)
2.3 Model Building in The Urban Transportation Planning Process

Most urban transportation planning studies have relied heavily on mathematical models. These models serve three basic functions:

1. improve the planner's comprehension and understanding of the complex transportation system and its environment,
2. provide the planner with a tool to test the various land use and transportation concepts and their interaction, and
3. provide data and information that are essential for developing programs, priorities and projects.

Transportation models are build to replicate in abstract terms the existing travel patterns and to provide a simple and effective tool for estimating future travel demand.

The history of transportation planning models is relatively brief. Their development dates from the late 1940's. However, three separate periods in their development may be identified. These are described below.

2.3.1 First Period Models

Transportation models built during the late 1940's and early 1950's were mainly of the factoring or trends type. Existing travel conditions would be examined and extrapolated to the design year. While such models have been abandoned for long range planning, they are still applied in practice for short range planning and in small urban areas experiencing little growth.
The major short-comings of these models are firstly their inability to take into account the impact of dramatic changes in land use and secondly their inability to reflect changes in travel patterns resulting from changes in transportation supply and services (4).

2.3.2 Second Period Models

Transportation models development from the mid 1950's to the late 1960's was rather extensive. The early models were refined and structured through a series of transportation studies. From these efforts evolved the so-called urban transportation planning system models. These second period models (also referred to as second generation models) were adopted by most subsequent urban transportation planning studies. In addition to their structural appeal, the availability of computer packages specifically tailored for these models enhanced their continued use and improvement.

Four essential components of second generation models can be easily identified:
1. Trip Generation,
2. Trip Distribution,
3. Modal Split, and
4. Trip Assignment.

Reference (5) provides an excellent description of these second generation models.
Generally, in spite of the widespread application of these second generation models, they suffer from a number of limitations. Firstly, extensive data is needed in the model development which are both costly and time consuming. Secondly, these approaches which are based on aggregate level are insensitive to changes associated with the transportation system policies (6). Finally, in terms of data processing, models based on this approach are expensive to execute which may be rendered impractical to evaluate more than few variables.

2.3.3 Third Period Models

The above limitations in consequence caused the transportation planners to search for other more effective techniques. These techniques, which appeared in the late 1960's and early 1970's were based on the individual travel behaviour instead of the conventional aggregate existing approaches. The main advantage of these approaches stems from the fact that they are based on the individual behaviour. Thus, expensive large scale origin destination surveys may be minimized and this in turn may reduce the time allocated to the transportation study.

Furthermore, because of their individualistic basis, these types of models are transferable to other urban areas (6). In addition, these models are policy sensitive in the sense that they can be used for testing a variety of urban transportation policies. This may be
accomplished by modifying the values of the independent variables which describe the level of service provided by the transportation system.

Finally, these approaches make it easy to compare several alternative transportation modes in a single model such as in the multinominal logit mode choice models described in the next section.

2.4 Classification of Modal Split Models

As indicated earlier, modal split models can be developed using the conventional aggregate approach (zonal level) or the disaggregate behavioural approach (individual or household level). Each of these two approaches may be further classified into several categories as illustrated in Figure 2.3. Several statistical techniques are available for use in association with each category and these are also indicated in the figure.

The second approach is described as being behavioural because it is founded in two disciplines dealing with behaviour, the economics of consumer behaviour, and the psychology of choice behaviour. The approach is based on the identification of the decision variables which enter into the travel-choice situations such as travel time, travel cost, quality of service, etc.

The behavioural approach may be classified into two major categories:
1. The econometric approach which apply the economic theory of consumer behaviour, and
2. The disaggregate stochastic (probabilistic) approach which apply the theory of psychological behaviour of the consumer.
modal split models

conventional aggregate models (zonal)

diversion curves (strat-analysis)

least square regression

linear

non-linear

direct demand models

least square non-linear regression

least square non-linear regression

behavioral models (individual or household)

econometric

abstract

least square regression

least square regression

disaggregate

diversion curves (strat-analysis)

probabilistic

logit

probit

discriminant

least square regression

maximum likelihood method

figure 2.3
classification of model split models and their associated statistical techniques

source: reference (7)
2.4.1 Econometric Approach

In this approach, travel is treated as an economic commodity subject to the economics laws of supply and demand. The demand for travel is viewed as dependent on the socio-economic characteristics of the consumer; the available modes and their level of service; and the cost at which they are supplied. These factors are essential to include in the econometric model because the theory of consumer behaviour of economics states that the consumer always attempts to maximize his satisfaction and minimize his cost. This satisfaction varies from group of consumers to another based on the socio-economic indicators.

The econometric models include the Direct Demand Models which combine the trip generation, trip distribution and modal split processes, and the Abstract Mode Models which are not-mode specific. These latter type of models are mode attribute-specific. They differ from Direct Demand Models in that they consider only the "best" mode on each attribute as a basis for comparison. Reference (8) provides an excellent description of these two types of models.

2.4.2 Disaggregate Stochastic (Probabilistic) Approach

This approach is termed disaggregate because the basic unit of observation for the modal calibration is the individual traveller and not the traffic zone as in the conventional aggregate approach. The models developed using
this approach are probabilistic in the sense that they assign a probability to each possible outcome of a particular travel decision for a specific traveller. There are three mathematical techniques which can be used to develop this type of behavioural models. These techniques are:

1. Discriminant Analysis,
2. Probit Analysis, and
3. Logit Analysis.

The Discriminant Analysis technique has been used by the transportation planners to decide on the amount of travel demand by each transportation mode, and it is based upon the assumption that there exists in a population two or more distinct subgroups that can be distinguished by means of discriminating functions. These subgroups are assumed to be normally distributed with respect to that function (9).

Empirical tests of discriminant analysis when compared with estimates from probit and logit analyses have indicated that the relative coefficient values are markedly different and the goodness-of-fit statistics are significantly inferior for this technique than the other two techniques (9). Therefore, the discriminant analysis technique does not appear to be appropriate for building behavioural-choice models.
The word probit means probability unit. Through mathematical transformation, the probability measurement is changed from percentage to probits and sigmoid to a straight line in order to facilitate mathematical operation (10). This procedure has a major limitation which is the difficulty of estimating probabilities for population individuals. It involves a two-stage procedure. In the first stage, the value of the linear function is estimated for the specific set of attribute values of alternative k, relative to some other alternative j. Then, in the second stage, the integral of the normal curve must be evaluated. This requires either using a table of the area under the normal curve or a computer program that evaluates the integral by a stepped approximation process. Research has shown that in comparison with the logit model, the probit model was found to perform almost identically (11).

However, the more complex formulation of the probit model and its inavailability in multiple-choice situations (i.e. it is restricted to binary choice situations only), makes it inferior to the logit model.

The logit model is simply a statement of a modal structure without the specification of any distributional assumptions. This type of model may be specified as either a binary choice or multiple choice. Because of the limitations of the other two techniques described earlier, the logit model has been chosen in this research for the development of modal split models for the
study area in a binary choice format. The logit model formulation and structure will be discussed in more detail in the next chapter.

2.5 A Review of the Modal Split Model Calibration Techniques

Generally, there are three basic common techniques which can be used in developing and calibrating the modal split models (see Figure 2.3). The calibration of these statistical techniques means estimating the unknown coefficients in the generalized travel function. These techniques are: The Diversion Curves, Maximum Likelihood, and Least Square Regression. Each of these techniques is described briefly below.

2.5.1 Diversion Curves

This technique is the simplest and less accurate procedure in modal split models calibration. It can be used in two different ways. In the first way, a mathematical formulation approximating the observed plotted curve is used as the basis of providing a mathematical model. In the second way, the graphical representation directly through a cross-classification table for the transportation system attributes can be obtained. The resulting curves are generally S-shaped. This technique has the following problems:

a. statistical measures of goodness-of-fit are largely unavailable, and
b. problems of extrapolation are unexplored.
2.5.2 Maximum Likelihood Method

This technique searches for the coefficient which, when multiplied by appropriate values of alternative characteristics, generate probabilities which are most likely to produce the observed distribution of choices for the sample (11).

Maximum Likelihood method is extremely complex and difficult technique to perform. Therefore a number of computer programs have been developed which do maximum likelihood estimation specifically for logit models as it is provided in the Urban Transportation Planning System (UTPS) Package (6). This program consists of "UMODEL" which provides a binary calibration file format of the dependent variables which correspond to modes and independent variables in the generalized travel function. This file is used as an input to "ULOGIT" which gives the modal split model equations and various statistical measures for how well the statistical model fit the observed data.

2.5.3 Least Square Regression

This statistical technique can be used to estimate the unknown coefficients in the generalized travel function. This technique is based on the following assumptions:
1. the sum of squared residuals (SS_{res}) is minimum.

This can be written as:

\[ \sum (Y - Y')^2 = SS_{res} = \text{Minimum} \quad \text{Eq}(2.1) \]

where:

\( Y, Y' \) are observed and estimated values of the dependent variable.
The resulting line in linear least square regression is called the least-square line or the line of the best fit.

2. The regression of the dependent variable and the independent variables is linear. This may be accomplished using scattergram analysis and Pearson correlation analysis (12). In probabilistic models, log transformations may achieve such linearity; and

3. The deviation of the dependent variable values about the regression line must be independent of each other and normally distributed.

The advantage of this technique is its capability in eliminating the problems of the non-quantifiable variables such as trip purpose, geographic location, socio-economic characteristics or transit quality of service. This can be achieved by stratifying the sample records by these variables. However, such stratification may increase the complexity of the model and the statistical reliability of the individual sub-models can be satisfactorily achieved if the sample used is relatively large.

This technique in linear stepwise manner is used in this research for developing and calibrating the binary choice logit modal split models for the study area. This selection is based on the fact that Least Square Regression (L.S.R.) can be used to calibrate a logit model. The stratification analysis developed in this research (see Section 3.3) has proved that it is possible to observe the probabilities of choice and consequently the dependent variable G(X) can be evaluated for observed choice data. This means, in turn, that this research has overcome the second objection as described in reference (9) concerning the calibration of a logit model by L.S.R. technique.
CHAPTER III
MODAL SPLIT MODEL DEVELOPMENT AND CALIBRATION

3.1 Introduction

This chapter presents the methodology employed in the development and calibration of the binary choice logit model for the Ottawa-Hull area. The binary choice calibration involves two basic modes, namely the private automobile and public transit.

The selection of the binary choice format was based on the following considerations:

1. Studies have shown that trips made by auto and transit in the study area represent approximately 88% of the total travel in the P.M. peak hour (13).

2. The binary choice logit model permits the analyst to use the relative level of service variables of the competing modes instead of the absolute values required by the multinomial model. This, in turn allows the planners to assess the direct impact of changing the attributes of any of the competing modes on mode choice. This point will be elaborated upon in the next section.

3. Since the sum of all the probabilities of an individual selecting a particular mode from the entire set of the available modes k has to equal one, in the case of binary choice models the probability of choosing the other mode is simple to obtain. In the case of multinomial models, on the other hand, it is necessary to normalize all the probabilities for each individual to derive the absolute mode choice. This is a time consuming exercise.
4. Difficulties are associated with the size of the sample records used in the calibration based on the least square regression technique. These difficulties stem from the fact that this statistical technique requires the stratification of sample records by the various dimensions necessitated by the type of models desired. This point will be further discussed in the section 3.3.

3.2 Theory of Binary Choice: Logit Models

The earliest development of the behavioural demand modelling approach were founded on the basis that the individuals make travel choices by comparing the level of service provided by the alternative transportation modes. Subsequently, these models were modified by adding the individual socio-economic characteristics.

Furthermore, the decision making of individuals involves the use of probabilities of choice and these probabilities must conform to the basic rules of probability given in equations 3.1 and 3.2.

\[ 0 \leq p_{ik} \leq 1 \quad \text{for all } i \text{ and } k \quad \text{... Eq. (3.1)} \]

\[ \sum_{k=1}^{n} p_{ik} = 1 \quad \text{for all } i \quad \text{... Eq. (3.2)} \]

where:

- \( p_{ik} \) is the probability of individual \( i \) choosing alternative \( k \)
- \( n \) defines the entire set of available alternatives.
The logit formulation may be specified as either a binary choice (Equation 3.3) or a multiple choice (Equation 3.4).

\[
P_k^i = \frac{e^{G(X_{jk})}}{1 + e^{G(X_{jk})}} \quad \ldots \text{Eq. (3.3)}
\]

\[
P_k^i = \frac{e^{G(X_k)}}{\sum_j e^{G(X_j)}} \quad \ldots \text{Eq. (3.4)}
\]

where:

\(G(X_{jk})\) defines the generalized linear travel function. It should be noted that the term \(X_{jk}\) in the binary case is assumed to represent the relative measures of attributes of mode \(k\) against mode \(j\). In the multiple choice model however, the term \(X_k\) represents absolute attribute measures. The form of a binary logit curve is shown in Figure 3.1.

In the binary logit model, the application of the probability rule (Equation 3.2) will lead to either of the two probabilities given in Equations 3.5 and 3.6.

\[
P_a^i = \frac{e^{[f(X_a, S_i)]}}{e^{[f(X_a, S_i)]} + e^{[f(X_b, S_i)]}} \quad \ldots \text{Eq. (3.5)}
\]

\[
P_b^i = \frac{e^{[f(X_b, S_i)]}}{e^{[f(X_a, S_i)]} + e^{[f(X_b, S_i)]}} \quad \ldots \text{Eq. (3.6)}
\]
FIGURE 3.1
FORM OF THE BINARY LOGIT CURVE

Source: Reference (9)
where:

\( p_a^i, p_b^i \) are the probability of an individual \( i \) selecting mode a and b respectively.

\( X_a, X_b \) are respectively the attributes of alternative mode a and b respectively.

\( S_i \) defines the socio-economic characteristics of individual \( i \).

Dividing equations 3.5 and 3.6 by \( e^{f(X_b, S_i)} \) yields

\[
p_a^i = \frac{e^{f(X_a, S_i)}}{1 + e^{f(X_a, S_i)}} \quad \text{... Eq. (3.7)}
\]

\[
p_b^i = \frac{1}{1 + e^{f(X_a, S_i)}} \quad \text{... Eq. (3.8)}
\]

These two last equations are referred to as the standard binary choice logit model (14). As will be demonstrated later, the standard binary choice logit model should be redefined in the more general formulations given by equations 3.9 and 3.10.

\[
p_a^i = \frac{e^{f(X_a, S_i)}}{1 + e^{f(X_a, S_i)}} \quad \text{... Eq. (3.9)}
\]

and

\[
p_b^i = \frac{1}{1 + e^{f(X_a, S_i)}} \quad \text{... Eq. (3.10)}
\]
3.3 Model Calibration Methodology

The general framework for the methodology employed in the development and calibration of the binary choice modal split models for the study area is shown in Figure 3.2. The basic output desired in applying this methodology was to derive different sets of modal split models by trip purpose disaggregated by geographic destination.

The methodology was applied to travel occurring during the P.M. peak hour in the Ottawa-Hull area. Trips made during this period were stratified by two trip purposes, work (which accounts for about 60% of the total P.M. peak hour travel) and non-work. Furthermore because of the unique attributes of the downtown areas of Ottawa and Hull (characterized by high employment concentration and excellent level of transit service), it was believed necessary that separate models for the CBD can be derived. In effect, four basic models were derived for the study area to describe the P.M. peak hour mode choice process.

The methodology was geared to establishing a logit type disaggregate behavioural model for explaining and predicting the choice between the auto and the public transit modes. The sequence of steps carried out to apply this methodology is given below:

1. Survey data were obtained from the 1.4% telephone survey carried out in the Fall of 1977 by the Regional Municipality of Ottawa-Carleton (15,16). A computer file was developed based on the data obtained from this survey which contained information on households, individuals and trips.
FIGURE 3.2

SEQUENCE OF STEPS CARRIED OUT IN
THE MODEL DEVELOPMENT AND CALIBRATION
2. The P.M. peak hour records from this survey were extracted and from there, a random sample was selected for use in the model calibration process. It was believed that between 300 to 400 records were adequate to construct each of the four modal split models desired.

3. Since the calibration procedure requires information about all modes available to an individual making a particular trip, and since these information were not available on the telephone survey records, it was necessary to supplement the selected sample records with these information from other sources. For this reason, the transportation system variables (particularly travel time) were developed from the 300 zone system road network used in the TRANS* programme (17). For transit related variables, it was considered necessary to estimate such variables as the transit travel time, waiting time, number of transfers, and walking distance from trip origin and destination to appropriate transit stops based on the actual address of origin and destination of the particular trip.

4. Additional variables were generated from the original and supplemental variables. These generated variables, in general, described some measures of road and transit impedances. For example, comparison of level of service provided by the auto and transit system were described in terms of travel time differences and ratios, travel cost differences and ratios and the relative impedance ratios defined as the impedance difference divided by the average impedance value.

* TRANS - Transportation Model Development Programme
5. Since the least square regression technique utilizes the independent variables in a linear form and relates them to the dependent variable, collinearity between the independent variables was checked and avoided wherever possible.

6. The general formulation of the binary choice logit model with the linear generalized travel function is given as:

\[
P_a = \frac{e^{G(X)}}{1 + e^{G(X)}}
\]

where:

- \(P_a\) = the probability of individual selecting the automobile as the travel mode,
- \(G(X)\) = a linear function of the independent variables for which the parameters are to be estimated.

The function \(G(X)\) can be expressed as follows:

\[
G(X) = \text{Constant} + a_1 \text{MTIME} + a_2 \text{MCOST} + \sum_{i=1}^{P} a_i I_i
\]

where:

- \(\text{MTIME}\) = a variable describing an impedance measure of travel time by the two modes,
- \(\text{MCOST}\) = a variable describing an impedance measure of travel cost of the two modes, and
- \(I_i\) = a variable describing the individual socio-economic characteristics such as age, sex, income and total number of vehicles owned by the individual or his household.
7. The logit formulation (using the least square regression technique employed in this research) calls for the stratification of the survey records by trip purpose \( p \) (work and non-work), geographic destination \( g \) (CBD and Non-CBD), travel mode \( m \) (auto and transit), transportation system variables \( X \) (such as travel time and travel cost), and socio-economic variables \( S_j \) (such as sex, age and income). Thus, in addition to the six main dimensions (2 modes, 2 trip purposes and 2 geographic destinations), data would be disaggregated by the other two dimensions namely, the socio-economic attributes and the transportation system variables. However, because of the sample size limitations, the socio-economic dimension was not used directly in the stratification analysis. Furthermore, only two variables per stratification represented the transportation system variable dimension. These two variables were described in terms of the travel time and travel cost of the two competing modes as shown in Figure 3.3. Each of these two variables was broken into a number of elements depending on the distribution of sample observations. These elements in turn used to select the associated socio-economic attributes of the individuals. It should be noted that when a zero value is assigned to a particular stratification element, the other records in the corresponding element in the other stratification for a specific model are lost. Thus, the fewer the number of stratifications; the better the distribution of the survey records and the more reliable the model derived. From this stratification of the sample records, the observed probability of choosing the auto as the travel mode was calculated and in turn, the dependent variable \( G(X) \) was obtained by taking the natural logarithm of the logit model.
FIGURE 3.3

STRATIFICATION OF SAMPLE RECORDS
8. For each cell in the stratification analysis, the transportation system impedances and the associated socio-economic characteristics of the trip maker for all records in that cell were listed together with the associated variables G(X) calculated in Step 7.

9. Stepwise regression analyses were then carried out using the dependent variable against the independent variables listed in Step 8.

10. Once the G(X) function was developed, it was substituted in the equation given in Step 6 above and the probability of choosing the auto mode was calculated. This estimated probability was then compared with the observed probability and then the predictive power of the derived models was determined. The same process was repeated for developing the other sets of models by trip purpose and geographic destination. The calibration procedure is shown in Figure 3.4. Finally, sensitivity analysis was performed in order to test and predict the impact of various transportation policies on mode choice.

3.4 Data Base

The primary source of data used in this research was the 1977 origin-destination telephone survey carried out by the Regional Municipality of Ottawa-Carleton (15, 16). A sample of 1.4% of all household residing in the Ottawa-Hull area were initially contacted by mail and subsequently interviewed by telephone. The survey collected information on household, individuals and their trips over a 24 hour period. An edited file containing 29 variables for some 22,000 individual trip records was used. Since the desired binary choice models were to be applied to P.M. peak hour conditions, the following criteria were established
FIGURE 3.4

MODEL CALIBRATION PROCEDURE
upon which a sample of the original survey records were selected for inclusion in the model development:
1. each survey record contained complete information about the individual and his trip,
2. the trip was made during the P.M. peak hour as defined by the trip-in-motion concept (4),
3. the trip was made either by the auto or the transit modes; and
4. availability of bus service, i.e. an actual mode choice is available.

About 3,000 records were selected that satisfied the above criteria. In order to cut on the time consuming exercise of adding supplementary variables to these records, it was believed that about 1000 records were adequate for calibrating the desired modal split models.

As indicated in the previous section, the attributes of each of the two competing modes had to be added to each trip record. Thus, the following supplementary variables were added manually to the selected survey sample records:
1. walk time,
2. regular bus running time,
3. express bus running time,
4. number of transfers,
5. wait time to board the first transit vehicle,
6. wait time to board the second transit vehicle, and
7. auto travel time.

Furthermore, in order to test different measures of the attributes of the two competing modes as well as different specification of socio-economic attributes, additional variables were generated from the original and the supplementary variables (see Appendix A.1). The final computer file contained 53 variables. A list and description of these variables is given in Appendix A.2.
The flow chart summarizes the process of development of the final sample records used in calibrating the modal split models is given in Appendix A.3.

The distribution of the final sample records by trip purpose, geographic destinations and various modal attribute measures is given in Table 3.1.

3.5 Study Results

A listing and definition of variables used in developing the binary choice logit models are given in Table 3.2. The model impedances for the four desired models were described in terms of three combinations of travel time and travel cost for the competing transportation modes. These combinations were:

1. Impedance Differences i.e. \( TTDAT = HWYTT - TRSTT \), and \( TCDAT = GHWYC - TCOST \)
2. Impedance Ratios i.e. \( TTRAT = HWYTT/TRSTT \), and \( TCRAT = GHWYC/TCOST \)
3. Relative impedance ratios defined as the impedance difference divided by the average impedance value i.e. \( TDAAT = (HWYTT - TRSTT)/[(HWYTT+TRSTT)/2] \), and \( CDAAT = (GHWYC - TCOST)/[(GHWYC+TCOST)/2] \)

The study results of the impedance difference model and impedance ratios models are given in Table 3.3 and 3.4 respectively. The stepwise linear regression technique employed generates different order of appearance of the independent variables in the derived models.

Although this order is not indicated in Table 3.3 and 3.4, tables 3.5, 3.6, 3.7 and 3.8 show for each type of the relative impedance ratio models the sequence of independent variables as they entered the regression equations.
TABLE 3.1

DISTRIBUTION OF SAMPLE RECORDS USED IN CALIBRATING THE VARIOUS MODELS

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Impedance Differences</th>
<th>Impedance Ratios</th>
<th>Relative Impedance Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work, CBD</td>
<td>284</td>
<td>293</td>
<td>286</td>
</tr>
<tr>
<td>Work, Non-CBD</td>
<td>336</td>
<td>358</td>
<td>340</td>
</tr>
<tr>
<td>Non-Work, CBD</td>
<td>78</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Non-Work, Non-CBD</td>
<td>221</td>
<td>222</td>
<td>234</td>
</tr>
<tr>
<td>Total Number of Records</td>
<td>919</td>
<td>965</td>
<td>952</td>
</tr>
</tbody>
</table>
TABLE 3.2
A LIST AND DEFINITION OF VARIABLES USED IN
THE DEVELOPMENT AND CALIBRATION OF THE MODAL SPLIT MODELS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
<td></td>
</tr>
<tr>
<td>INSEX</td>
<td>Individual Sex: 0=Female, 1=Male</td>
</tr>
<tr>
<td>INAGE</td>
<td>Individual age in years</td>
</tr>
<tr>
<td>TPVPHH</td>
<td>Total vehicles per household</td>
</tr>
<tr>
<td>XNTOR</td>
<td>Number of transfers</td>
</tr>
<tr>
<td>INCOME</td>
<td>Individual Income: 1=High, 2=Medium, 3=Low</td>
</tr>
<tr>
<td>HWYTT</td>
<td>Auto travel time</td>
</tr>
<tr>
<td>TRSTT</td>
<td>Transit travel time</td>
</tr>
<tr>
<td>GHWYC</td>
<td>Auto travel cost</td>
</tr>
<tr>
<td>TCOST</td>
<td>Transit travel cost (average fare)</td>
</tr>
<tr>
<td>TTDAT</td>
<td>Travel time difference*</td>
</tr>
<tr>
<td>TCDAT</td>
<td>Travel time difference*</td>
</tr>
<tr>
<td>TTRAT</td>
<td>Travel time ratio**</td>
</tr>
<tr>
<td>TCRAT</td>
<td>Travel cost ratio**</td>
</tr>
<tr>
<td>TDAAT</td>
<td>Travel time difference* divided by average total value</td>
</tr>
<tr>
<td>CDAAT</td>
<td>Travel cost difference* divided by average total value</td>
</tr>
<tr>
<td>Dependent Variable</td>
<td></td>
</tr>
<tr>
<td>Pα</td>
<td>Probability of auto choice</td>
</tr>
<tr>
<td>G(X)</td>
<td>Generalized linear travel function</td>
</tr>
</tbody>
</table>

* Auto - Transit
** Auto by Transit
### Table 3.3

**Impedance Differences Model**

<table>
<thead>
<tr>
<th>Independent Variables</th>
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<th>Non-Work</th>
</tr>
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<tbody>
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</tr>
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</tr>
<tr>
<td>TCDAT</td>
<td>-0.0016*</td>
<td>0.0149*</td>
</tr>
<tr>
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<td>-0.0657</td>
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<td>CONSTANT</td>
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**Evaluative Measures**

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</tr>
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<tbody>
<tr>
<td>Multiple R</td>
<td>0.23</td>
<td>0.59</td>
</tr>
<tr>
<td>R Square</td>
<td>0.06</td>
<td>0.34</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.733</td>
<td>1.038</td>
</tr>
<tr>
<td>F-Test</td>
<td>2.69</td>
<td>25.80</td>
</tr>
</tbody>
</table>

* Indicates that the variable is significant at 0.01 level.
** Indicates that the variable is significant at 0.05 level.

All other variables are not significant at 0.05 level.
TABLE 3.4
IMPEDEANCE RATIOS MODEL

<table>
<thead>
<tr>
<th>INDEPENDENT VARIABLE</th>
<th>ESTIMATED MODEL COEFFICIENTS</th>
<th>WORK</th>
<th>NON-WORK</th>
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<tbody>
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<td>NON-CBD</td>
<td>CBD</td>
<td>NON-CBD</td>
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<td>TTRAT</td>
<td>0.4804*</td>
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<td>-</td>
<td>1.2836*</td>
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<tr>
<td>TCRAT</td>
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<td>-0.0353</td>
<td>0.0598</td>
<td>-0.2519*</td>
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<td>0.0409</td>
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<td>0.0006</td>
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EVALUATIVE MEASURES

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<td>MULTIPLE R</td>
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<tr>
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<td>0.03</td>
<td>0.03</td>
<td>0.27</td>
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</tr>
<tr>
<td>STANDARD ERROR</td>
<td>0.704</td>
<td>0.337</td>
<td>0.595</td>
<td>0.398</td>
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<tr>
<td>F-TEST</td>
<td>21.90</td>
<td>1.48</td>
<td>0.49</td>
<td>13.08</td>
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</tbody>
</table>

* Indicates that the variable is significant at 0.01 level. All other variables are not significant at 0.05 level.
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<thead>
<tr>
<th>INDEPENDENT VARIABLES IN THE EQUATION</th>
<th>REGRESSION STATISTICS</th>
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<td>CDAAT</td>
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<tr>
<td>-1.8246</td>
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</tr>
<tr>
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</tr>
<tr>
<td>-1.8635</td>
<td>0.0512</td>
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</table>

- Regression Coefficient is significant at 0.01 level
- Standard error of the regression coefficient.
- Indicates the variable is not significant at 0.05 level.
**TABLE 3.6**

**ESTIMATED COEFFICIENTS FOR THE WORK, NON-CBD MODEL**

<table>
<thead>
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<th>INDEPENDENT VARIABLES IN THE EQUATION</th>
<th>REGRESSION STATISTICS</th>
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<td>TDAAT</td>
<td>CDAAT</td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>0.4363</td>
<td>0.0493</td>
</tr>
<tr>
<td>0.5489</td>
<td>0.2277</td>
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<td>0.2335</td>
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<tr>
<td>0.5808</td>
<td>0.2460</td>
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<tr>
<td>0.5802</td>
<td>0.2439</td>
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<tr>
<td>0.5832</td>
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<tr>
<td>0.5830</td>
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* Regression coefficient is significant at 0.01 level.

( ) Standard error of the regression coefficient.

c Indicates that the variable is not significant at 0.05 level.
## TABLE 3.7

**ESTIMATED COEFFICIENTS FOR THE NON-WORK, CBD MODEL**

<table>
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<td>CDAAT</td>
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</tr>
<tr>
<td>XNOTR</td>
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<td>INAGE</td>
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<td>IDAAT</td>
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<td>TVPHH</td>
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<tr>
<td>INCOME</td>
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</tr>
<tr>
<td>0.3676</td>
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<tr>
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<td>2.8</td>
</tr>
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</table>

* Regression coefficient is significant at 0.01 level.

( ) Standard error of the regression coefficient.

c Indicates that the variable is not significant at 0.05 level.
### Table 3.8

**Estimated Coefficients for the Non-Work, Non-CBD Model**

<table>
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<tr>
<th>The Independent Variables in the Equation</th>
<th>Regression Statistics</th>
</tr>
</thead>
<tbody>
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<td>Constant</td>
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<td><strong>TDAAT</strong></td>
<td><strong>CDAAT</strong></td>
</tr>
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<td>(0.1549)</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
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<td>-0.9063</td>
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<tr>
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<td>(0.1731)</td>
</tr>
<tr>
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</tr>
<tr>
<td>1.4853</td>
<td>-0.8882</td>
</tr>
<tr>
<td>(0.1389)</td>
<td>(0.1770)</td>
</tr>
</tbody>
</table>

* Regression coefficient is significant at 0.01 level.
( ) Standard error of the regression coefficient.
* Indicates that the variable is not significant at 0.05 level.
Examination of Table 3.3 indicates that the binary choice simulated by the impedance differences model is poor and sometimes inconsistent particular for the CBD, work and non-work models. The work, non-CBD model produces fair results in terms of statistical criteria as manifested by the F-test and the coefficient of determination R.

The impedance differences model makes the assumption that the mode choice decision is strictly based on the absolute values of the difference in times and costs. In this respect, the model implies that the choice between travel times of 10 and 20 minutes for example is equivalent to a choice between 40 and 50 minutes when all the other variables are kept constant. However, the traveller's perception of the difference may not be so. For this reason, the impedance ratios model given in Table 3.4 was developed where this assumption is eliminated.

The work, CBD and non-work, non-CBD models in Table 3.4 produce fair results in terms of statistical significant of the transportation system variables, while the other two models are rather poor particularly the non-work, CBD model where no significant variables appeared.

The relative impedance ratios model results are shown in detail in Tables 3.5 through 3.8 for each of the four model disaggregation. Note that the order of appearance of the independent variables differs from one model disaggregation to another because of the stepwise regression technique employed. In general, the model based on the relative impedance ratios produced significantly better results than the impedance differences and ratios based models. Only the non-work, CBD model produced poor and inconsistent results. However, travel described by this model category represents 2.4% of the overall peak hour travel.
The observed and estimated mode choice logistic curves for the relative impedance ratio models are shown in Figures 3.5 through 3.8. Table 3.9 summarizes and compares the results of statistical tests performed for each of the four sets of models developed. Additionally, each model's predictive power measured in terms of maximum and average error* were developed. It is believed that the models based on relative impedance ratios are better predictive tools for simulating and forecasting mode choice.

3.6 Sensitivity Analysis

The sensitivity of the travel mode choice behaviour to changes in the explanatory variables may be described by means of the associated elasticities. The elasticity \((\varepsilon_{m,k})\) is a dimensionless number defined as the relative percentage change in the probability of the specified choice that results from a one percent change in any explanatory variable \((18)\). Mathematically, the elasticity of the probability of using mode \(m\) \((P_m)\) with respect to a given variable \(X_k\) is stated as follows:

\[
\varepsilon_{m,k} = \frac{\partial P_m / P_m}{\partial X_k / X_k}
\]

Elasticities were computed for the relative impedance ratios model at the mean values of the transportation system variables (travel time and travel cost) as shown in Table 3.10. Of the four models examined, the first model (work, CBD) was found to be the most sensitive to changes in the transit fare and automobile out-of-pocket cost. The fourth model (non-work, non-CBD) was elastic (i.e. \(\varepsilon_{m,k} > 1\)) with respect to changes in transit total travel time and it was sensitive to changes in the automobile total travel time.

* Average error is defined as \(\sum \) observed probability of mode choice minus \(\sum \) predicted probability of mode choice divided by the total number of records.
FIGURE 3.5
WORK, CBD MODEL

FIGURE 3.6
WORK, NON-CBD MODEL
FIGURE 3.7

NON-WORK, CBD MODEL

FIGURE 3.8

NON-WORK, NON-CBD MODEL
## TABLE 3.9
MODAL SPLIT MODELS RANKED BY PERFORMANCE AND RELIABILITY

<table>
<thead>
<tr>
<th></th>
<th>IMPEDANCE DIFFERENCES</th>
<th>IMPEDANCE RATIOS</th>
<th>RELATIVE IMPEDANCE RATIOS</th>
</tr>
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<tr>
<td></td>
<td>WORK CBD</td>
<td>NON-CBD CBD</td>
<td>NON-CBD CBD</td>
</tr>
<tr>
<td>Multiple R</td>
<td>0.23</td>
<td>0.59</td>
<td>0.31</td>
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<tr>
<td>R Square</td>
<td>0.055</td>
<td>0.341</td>
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<td>Standard Error</td>
<td>0.733</td>
<td>1.038</td>
<td>0.483</td>
</tr>
<tr>
<td>F Ratio</td>
<td>2.69</td>
<td>25.80</td>
<td>1.26</td>
</tr>
<tr>
<td>Max. Error</td>
<td>43.5</td>
<td>57.0</td>
<td>41.0</td>
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<tr>
<td>Average Error</td>
<td>12.1</td>
<td>15.3</td>
<td>12.4</td>
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</table>
TABLE 3.10
AGGREGATE ELASTICITIES OF MODE CHOICE

<table>
<thead>
<tr>
<th></th>
<th>Work (CBD)</th>
<th>Work (NON-CBD)</th>
<th>Non-Work (CBD)</th>
<th>Non-Work (NON-CBD)</th>
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</thead>
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<td>0.932</td>
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<td>-0.979</td>
<td>0.735</td>
<td>-0.027</td>
<td>0.076</td>
</tr>
<tr>
<td>Transit PTP Time</td>
<td>0.026</td>
<td>-0.023</td>
<td>0.069</td>
<td>-0.451</td>
</tr>
<tr>
<td>Auto PTP Time</td>
<td>-0.023</td>
<td>0.021</td>
<td>0.058</td>
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</tbody>
</table>

* For relative impedance ratios model.
## TABLE 3.11

### COMPARISON WITH OTHER STUDIES

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<td>Time diff.</td>
<td></td>
<td>Time diff.</td>
<td>Log cost ratio</td>
<td>Time ratio</td>
<td>Overall travel</td>
<td>Cost diff.</td>
<td>In-vehicle travel</td>
<td>Auto travel time</td>
<td>Relative time ratio</td>
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<td></td>
<td>Cost diff.</td>
<td></td>
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<td>Overall travel</td>
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<td>Auto cost</td>
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<td>II. Socio-Economic variables alone or combined with system variables</td>
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<td>Car ownership X time diff.</td>
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<td>Income X time diff.</td>
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<td>Income X cost diff.</td>
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<td>Car availability Sex</td>
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<tr>
<td>Income Car availability</td>
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<tr>
<td>Out of Pocket Cost Income</td>
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<td>Family income</td>
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<tr>
<td>On Veh. time diff.</td>
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<tr>
<td>X part tax wage</td>
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<tr>
<td>Bus walk time X wage</td>
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<td>Bus first wait time X wage</td>
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</table>

Source: Reference (19)
3.7 Comparison with Other Studies

As modal split models developed by different researchers cannot be strictly compared, an attempt is made here to present a general comparison of this research with research performed by others (Table 3.11). It can be appreciated from this table that sample size used ranges from 160 to 2211 records. Such a range is a reflection of and dependent upon the study objectives, calibration technique used, number of desired models, and the time and data availability. An obvious common research result is that of the importance of travel time and travel cost to the trip maker.
CHAPTER IV

MODAL DEMAND SHIFT ANALYSIS

4.1 Introduction

Urban transportation planning in Canada ten years ago was mainly concerned with the development of highly auto oriented transportation plans. The application of the computer tools which were developed for this purpose resulted in the transit component of any plan being usually treated as a relatively minor component.

With the recent trends in most Canadian Cities towards the objective of increasing the transit usage, it is necessary to treat the public transit as a major component of the overall urban transportation planning process. Therefore, the modal split models developed in this research can serve as a tool that may be used to study the effect of different transportation policies on mode choice.

4.2 Model Applications in Transit Planning

Two areas of possible impact on mode choice were tested by the binary choice logit modal split models developed in this research. These were:
1. improving the public transit level of service, and
2. increasing the automobile out-of-pocket cost.

The transit operating strategies which if implemented would achieve significant improvements in the transit level of service and in turn would likely increase the transit ridership were:
   a. reducing the number of transfers,
b. reducing the total transit travel time, and

c. reducing the transit average fare.

Firstly, the number of transfers and the transfers times can be significantly reduced or even eliminated if
direct routes between employment centers and major gen-
erators of activity centers (hospital, schools, shopping
centers, social service activities, etc.) are provided
when sufficient demand exists to economically support
such services. But in the absence of such demand, transit
routes and schedules should be adjusted to make these
routes meet at main centers at fixed intervals. This will
provide multiple destination opportunity and transfers are
guaranteed on a regular basis if they are necessary with
no walking time.

Secondly, reducing the total transit travel time
can be achieved if all the components of a transit
passenger's travel from the actual origin to the actual
destination are being considered. These components are:
a. access time from trip origin to the boarding transit
   stop,

b. waiting time for the transit vehicle,

c. travel time in the transit vehicle,

d. transfer time (waiting and possibly walking) required
   if more than one transit line is used for a single
   trip, and

e. egress time from the boarding off transit stop to
   the point of trip destination.

Obviously reducing these components will improve
transit level of service and significantly increase the
system ridership. For example, the walking time can be
reduced by increasing the density of the existing network
and by providing the roadways and walkways in new devel-
opment areas with a configuration that minimizes walking
distances. In addition the waiting time reduction can be achieved by increasing the service frequency, since the higher the frequency, the more travellers are attracted to the system.

The determination of service headway in operating any public transit system is not an easy matter because it is affected by many other factors which influence the whole operation of that system (20). However, a study carried out in Edmonton (21) showed that with a good scheduled information and service headway of 30 min. or more the waiting time was minimum. While when the frequency of service is 15 min. or less the waiting time tends to equal half the frequency of service.

Finally, since the traffic density increases particularly during peak hour, the transit level of service becomes lower because the operating speed will be reduced, in other words, in-vehicle travel time will be increased. This reduction in speed will mean that, to maintain the same frequency of service, more buses will be required. This in turn, will reduce the productivity of the system at a time when costs are increasing greatly and the travel demand is the highest. Therefore, the level of service improvements which may overcome this situation include:

1. introducing express routes along major corridors, and
2. improving traffic control operations for the road network which may facilitate rapid and safe movement for the transit vehicles in order to minimize interference with the vehicular traffic and subsequently reduce delay times and traffic congestion (22). The traffic control operations which may be implemented include:

a. prohibiting left turns on major roads,
b. removing on-street parking,
c. encouraging one-way street,
d. providing bus bays,
e. encouraging road reconstruction at night,
f. using exclusive transit signals with or without exclusive lanes, and
g. using exclusive right-of-way for the transit vehicles (23).

4.3 Levels of Analysis

The disaggregate modal split models developed for the study area were used to test travel demand sensitivity to the various policies described in Section 4.2. The analysis of these tests was carried out at two levels: area-wide and zonal. Because of the complexity of the zonal level of analysis as a time and cost consuming exercise, it was applied only to the base year conditions. This level of analysis is usually used for detail design and planning for the study area as it will be described in Section 4.3.2. However, the framework developed for this level of analysis can be used for testing the same policies tested at the area-wide level or other alternative policies.

4.3.1 Area-Wide Analysis

The developed disaggregate modal split models were used to predict the aggregate mode choice for various transportation policies to achieve the modal shift in the study area. The naive procedure was used as the aggregation procedure in which the mean values of the independent variables in the generalized travel function were considered. Although this procedure is not the only aggregation procedure (24). However, it was applied because of the time and data availability.
Furthermore, the modal split models were used in a simplified manner by including only those variables which were significant at 0.01. Such simplification of the model structure may increase the specification error $e_s$ as shown in Figure 4.1. However, the measurement error which arises from the fact that the values of the variables considered in developing the models were obtained from a 1.4% telephone survey will decrease as the number of variables decrease.

Thus, the combined effect of the specification and measurement errors plays an important role in determining the number of variable $n$ to be included in the final model formulation in order to produce the minimum error $e_0$.

The variables used in the generalized travel function for the four models employed in this level of analysis and their associated statistical measures are described as follows:

**Model 1**

$G(X) = 0.4494 - 1.8246 \text{ CDAAT}$

$R^2 = 0.58$  Standard Error (S.E.) = 0.43

$F = 386.6$  S.E. of CDAAT = 0.09

Degrees of Freedom = 1,284

**Model 2**

$G(X) = 1.6365 + 0.5621 \text{ TDAAT} - 0.2335 \text{ CDAAT}$

$+ 0.0624 \text{ TVPHH}$

$R^2 = 0.26$  Standard Error (S.E.) = 0.28

$F = 38.8$  S.E. of TDAAT = 0.053

S.E. of CDAAT = 0.048

S.E. of TVPHH = 0.02

Degrees of Freedom = 3,336
FIGURE 4.1

GENERAL RELATIONSHIP BETWEEN COMBINED MEASUREMENT AND SPECIFICATION ERRORS AND THE NUMBER OF VARIABLES

Source: Reference (25)
Correlation Coefficients Matrix

<table>
<thead>
<tr>
<th></th>
<th>TDAAT</th>
<th>CDAAT</th>
<th>TVPHH</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDAAT</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDAAT</td>
<td>0.449</td>
<td>1.000</td>
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</tr>
<tr>
<td>TVPHH</td>
<td>-0.073</td>
<td>0.004</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Model 3

\[ G(X) = -0.7076 + 0.3248 \text{ CDAAT} + 0.0716 \text{ XNTR} \]

\[ R^2 = 0.17 \]  Standard Error (S.E.) = 0.25

\[ F = 9.0 \]  S.E. of CDAAT = 0.11  

S.E. of XNTR = 0.03

Degrees of Freedom = 2, 89

Correlation Coefficients Matrix

<table>
<thead>
<tr>
<th></th>
<th>CDAAT</th>
<th>XNTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDAAT</td>
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<td></td>
</tr>
<tr>
<td>XNTR</td>
<td>0.130</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Model 4

\[ G(X) = 1.3429 + 1.5062 \text{ TDAAT} - 0.7581 \text{ CDAAT} \]

\[ R^2 = 0.35 \]  Standard Error (S.E.) = 0.65

\[ F = 63.0 \]  S.E. of TDAAT = 0.13  

S.E. of CDAAT = 0.16

Degrees of Freedom = 2, 231

Correlation Coefficients Matrix

<table>
<thead>
<tr>
<th></th>
<th>TDAAT</th>
<th>CDAAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDAAT</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>CDAAT</td>
<td>0.434</td>
<td>1.000</td>
</tr>
</tbody>
</table>
The general procedure adopted in applying the above modal split models formulation at the area-wide level of analysis for the various transportation policies as described in Section 4.2 is shown in Figure 4.2.

A computer program was developed (see Appendix B) to apply the above procedure for testing the various pricing (i.e. fare and auto out-of-pocket cost) and level of service (i.e. transit travel time) policies in order to increase the transit ridership. The procedure results are shown in Figures 4.3, 4.4, 4.5 and 4.6. As it was expected, the modal split models behave in a logical way. In other words, increasing auto out-of-pocket cost and decreasing the fare and transit travel time as one would expect would cause the travellers to adjust their behaviour in favour of public transit. These findings are similar to those obtained by other studies for the Regional Municipality of Ottawa-Carleton (13). Statistics have been shown (26) that although O. C. Transpo policy is toward increasing the fare, the transit ridership is increasing as well. This is so, because of the fact that the fare was tested as a variable independent of other variables which affect the traveller's behaviour in mode choice. These variables which are usually non-quantifiable in nature and which were not considered in formulating modal split models play an important role in the choice of public transit. They include:

1. The distinction between captive and non captive riders.
2. Parking Conditions.
FIGURE 4.2

MODAL SHIFT ANALYSIS AT THE AREA-WIDE LEVEL
FIGURE 4.3
ANNUAL RIDERSHIP CHANGES TO
TRANSIT FARE AND AUTO OUT-OF-POCKET COST
FIGURE 4.4

ANNUAL RIDERSHIP CHANGES TO TRANSIT
TRAVEL TIME SAVING AND AUTO OUT-OF-POCKET COST
FIGURE 4.5
ANNUAL RIDERSHIP CHANGES TO TRANSIT
TRAVEL TIME SAVING AND TRANSIT FARE

Annual Ridership in Millions

TC=0.0¢
TC=8¢
TC=16¢
TC=24¢
TC=32¢

Base Year Transit Cost

% Transit Travel Time Savings

10 20 30 40 50
FIGURE 4.6
ANNUAL RIDERSHIP CHANGES TO TRANSIT TRAVEL TIME SAVING AND COMBINATION POLICIES OF TRANSIT FARE AND AUTO OUT-OF-POCKET COST
3. Traffic congestion during peak periods.
4. Convenience of public transit which provides the opportunity for reading and relaxation, and
5. Good service availability.

A survey was carried out in another study (27) to find out the non-quantifiable variables which affect the mode choice process and which cannot be incorporated in the typical modal split models developed in research. It was found that parking conditions and traffic congestion are dominant factors in the minds of those who usually choose public transit, while the automobile convenience is the dominant factor in the mind of those who usually choose the private automobile.

4.3.2 Zonal Analysis

This level of analysis provides the planner with the required information which are necessary for other various studies. These include:

1. determining the deficiencies in the existing system,
2. assisting the development of a future transportation system through an evaluation of the effects of improvements and additions to the existing system,
3. providing the highway engineer with design-hour traffic volumes,
4. analyzing the location of facilities and services required within a transportation corridor, and
5. providing necessary input and feedback to other planning tools.
This level of analysis is based on the inter-zonal probability of the mode choice in evaluating the total transit ridership at the base year conditions. The formulation of the generalized travel function in the four modal split models used in this analysis are given as follows:

**Model 1**

\[
[G(X)]_{ij}^{1,1} = a_1 - a_2 \left( \frac{c_{ij}^{a,1} - c_t}{(c_{ij}^{a,1} + c_t)/2} \right)
\]

**Model 2**

\[
[G(X)]_{ij}^{1,2} = a_3 + a_4 \left( \frac{t_{ij}^a - t_{ij}^t}{(t_{ij}^a + t_{ij}^t)/2} \right) - a_5 \left( \frac{c_{ij}^{a,2} - c_t}{(c_{ij}^{a,2} + c_t)/2} \right)
\]

**Model 3**

\[
[G(X)]_{ij}^{2,1} = -a_6 + a_7 \left( \frac{c_{ij}^{a,1} - c_t}{(c_{ij}^{a,1} + c_t)/2} \right)
\]

**Model 4**

\[
[G(X)]_{ij}^{2,2} = a_8 + a_9 \left( \frac{t_{ij}^a - t_{ij}^t}{(t_{ij}^a + t_{ij}^t)/2} \right) - a_{10} \left( \frac{c_{ij}^{a,2} - c_t}{(c_{ij}^{a,2} + c_t)/2} \right)
\]

where:

- \([G(X)]_{ij}^{P,g}\) = generalized travel function between zone \(i\) and \(j\) for trip purpose \(P\) (\(P = 1\) work and \(P = 2\) non-work) and geographic destination \(g\) (\(g = 1\) CBD and \(g = 2\) non-CBD)
- \(c_{ij}^{a,1}, c_{ij}^{a,2}\) = automobile out-of-pocket cost between zone \(i\) and \(j\) for CBD and non CBD travel respectively,
- \(c_t\) = transit travel cost i.e. average fare,
- \(t_{ij}^a\) = automobile travel time between zone \(i\) and \(j\),
\[ t_{ij}^t = \text{transit travel time between zone } \]
\[ i \text{ and } j, \text{ and} \]

\[ a_1, a_2, \ldots, a_{10} = \text{models estimated coefficients.} \]

Consequently, the probability of choosing transit between zone \( i \) and for trip purpose \( p \) and geographic destination \( g \) is given by:

\[ p_{t,p,g} = 1 - \frac{[G(X)]_{ij}^{p,g}}{1 + e^{[G(X)]_{ij}^{p,g}}} \]

Furthermore, the total transit trips were estimated as follows:

\[ T_{t,ij} = \sum_{p=1}^{2} \sum_{g=1}^{2} p_{t,p,g} \times T_{p,g} \]

The general framework employed at this level of analysis involved:

1. building transit and road networks,
2. developing zonal interchange total transit trip table, and
3. assigning the transit table to the transit network.

4.3.2.1 Building Transit and Road Networks

One of the main objectives in building transit and road networks for the study area was to develop the two basic variables in the modal split models namely: transit travel time \( t_{ij}^t \) and automobile travel time \( t_{ij}^a \) from which the automobile travel cost \( C_{ij}^a \) was estimated.
The 300 zone system of the study area were aggregated to 60 District in order to build simplified networks. Figure 4.7 shows the 60 District system for the study area while the zone ranges aggregation is given in Appendix C.1. Since only the boundaries of these districts were defined by the TRANS team the centroids were located at the center of gravity of activities or at the geographic center for each district wherever applicable.

1. Transit Network

The most heavy corridors in the study area during PM peak hour were considered in building the transit network. These corridors consisted of 16 regular bus service corridors and 8 express bus service corridors. These corridors were defined in terms of transfer points called nodes. The node was defined as any point in the network where people may enter or leave the corridor. Actually, the nodes are the points within the study area where people get on or off the public transportation system. These corridors consisted of a sequence of nodes and each pair of nodes taken in sequence along the corridors defined a link. The first node in the link is called the A-node and the second node is called the B-node. The link can be either two way (e.g., regular bus service corridors or one way (e.g., express bus service corridors).

---

* A complete description of these corridors is available at Systems Planning Branch, Regional Municipality of Ottawa-Carleton.
FIGURE 4.7
THE 60 DISTRICTS SYSTEM (URBAN)
FIGURE 4.7 (Continued)

THE 60 DISTRICTS SYSTEM (RURAL)
In the transit network there are also the so-called non-transit links. These links handle the situations where non transit mode (e.g. walk, auto connector, etc) was required to get on or off the defined corridors. The non-transit links have their A-node as the district centroid, and the B-node, as a node on one of the corridors of the system.

The transit network was constructed by coding the link-line data for each corridor including information such as headways and distances in sheets of the form given in Appendix C.2. The coded link-line data were converted to cards which in turn were used with JCL* control cards to build the transit network. The flow chart developed in building the transit network is given in Appendix C.3. The computer files produced in building the transit network were:
1. transit network description file,
2. transit path or tree file, and
3. transit skim tree or minimum path file which represents the transit travel time $t_{ij}$.

2. Road Network

The road network was built in a similar way as in the transit network except the nodes here were defined as the road intersections instead of transfer points in the transit

* Job Control Language
network. The link information were coded in sheets given in Appendix C.2. Subsequently they were converted into cards which in turn were used with JCL control cards to build the road network.

The flow chart developed in building the road network is given in Appendix C.4. The computer files produced here are similar to those produced in the transit network. These files were:
1. road network description file,
2. road tree file, and
3. road skim tree or minimum path file which represents the automobile travel time table $t_{ij}^a$ from which the automobile out-of-pocket cost tables $c_{ij}^{a,g}$ were estimated.

4.3.2.2 Developing Total Transit Trip Table

Once the zonal variables entering the modal split models were developed (i.e. $t_{ij}^a$, $t_{ij}^t$, and $c_{ij}^{a,g}$), a procedure was prepared to apply these models to develop the total transit trip table $T_{ij}^t$ using the MTC* package (28). This procedure is shown in Appendix C.5. It was found however, that this procedure cannot be implemented because of the nature of the specified variables in the models. These variables are in terms of ratios (usually less than one). They were truncated to zero values since the MTC package was designed for integer values only.

* Ministry of Transportation and Communications of Ontario
Therefore, another procedure was designed to achieve the same purpose as shown in Appendix C.6. This procedure was based on a Fortran computer program designed to develop the total transit person trip table $T_{ij}^t$. Then this table was input to the MTC computer package to be used in the assignment to the transit network.

4.3.2.3 Transit Network Assignment

The transit network assignment may be defined as the process whereby trips are allocated to specific corridors (lines) within the transportation system.

The total transit trip table $T_{ij}^t$ developed in the previous section was assigned to the transit network using the All-Or-Nothing method which has been adopted in the MTC computer package. This table was supplied on TRIP file. The trips for each origin-destination pair on a particular path were added. These origin-destination pairs were provided by the TRANSIT NETWORK DESCRIPTION file which the path between each origin and destination pair was provided in the PATH file. The flow chart of the assignment process is shown in Appendix C.7.

It is important to point out that the assignment using this technique was based on the following assumptions (28):
1. There is only one path (minimum path) between each origin and destination pair, and
2. All trip makers between each origin and destination pair use the same path.
Therefore, as a result of this technique it tends to overestimate traffic volumes on minor facilities. However, there are many other techniques (29) which have been developed for generating multipaths between each origin and destination pair which have been developed for the road assignment. Research is in progress for applying these techniques for the transit assignment as well. Almost all of these techniques generate irrational paths and use more computer time and the results are difficult to understand although they may look more reasonable.

The transit network assignment output is given in the following six reports:
1. The non-transit link volumes report which gives the volumes of the person trips for all non-transit links in the network.
2. The unassigned trips report which gives the unassigned trips by origin zones which represent the intra-zonal trips.
3. The mode-to-mode transfer volumes report which gives the transit mode-to-mode transfers volumes of person trips.
4. The node-to-node volume report which is organized by mode and line. This report is very useful in studies which are based on screenlines or cordon analysis.
5. The passenger loading report which is generated for the transit volumes and it is organized by mode and line. The following items are printed for both directions of travel:
a. The number of trips which enter the line at every node on the line.
<table>
<thead>
<tr>
<th>Corridor Number</th>
<th>Corridor Length (Miles)</th>
<th>Passenger Trips</th>
<th>Miles</th>
<th>Hours</th>
<th>Peak Load</th>
<th>Headway (min.)</th>
<th>Running Time (min.)</th>
<th>Required Vehicle Hours (P.M.)</th>
</tr>
</thead>
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<td><strong>163</strong></td>
<td><strong>45,276</strong></td>
<td><strong>91,057</strong></td>
<td><strong>7,760</strong></td>
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<td>CORRIDOR NO.</td>
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<td>PASSENGER</td>
<td>PEAK LOAD</td>
<td>HEADWAY (MIN.)</td>
<td>RUNNING TIME (MIN.)</td>
<td>REQUIRED VEHICLE HOURS (P.M.)</td>
<td></td>
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<tr>
<td>--------------</td>
<td>-----------------------</td>
<td>-----------</td>
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<td>11.3</td>
<td>9.2</td>
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<tr>
<td>7</td>
<td>18.7</td>
<td>9,575</td>
<td>326</td>
<td>9.5</td>
<td>12.2</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>22.3</td>
<td>12,695</td>
<td>373</td>
<td>13.8</td>
<td>11.9</td>
<td>35</td>
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<tr>
<td>TOTAL</td>
<td>151.1</td>
<td>7,100</td>
<td>62,093</td>
<td>1,995</td>
<td>1,362</td>
<td>79</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
b. The number of trips which leave the line at every node on the line.

c. The total load on the line entering every node on the line.

6. The transit usage summary report which prints a number of items for each corridor for each mode in the network. This report for regular bus corridors is shown in Table 4.1, while for express bus corridors is shown in Table 4.2.
CHAPTER V

REVENUES, EXPENDITURES AND FINANCIAL EFFICIENCY
EVALUATION OF THE PUBLIC TRANSIT SYSTEM

O. C. TRANSPO: A CASE STUDY

5.1. Introduction

This chapter outlines a procedure to be followed in order to evaluate the financial status of a public transit system operating in a given urban area. The two major components of expenditures for the transit system are capital and operating costs. Capital costs involve purchase of vehicles and maintenance facilities (garages). This of course assumes that no additional investment is required in roadways. Operating and maintenance expenses vary considerably based on different variables such as vehicle-miles, vehicle-hours and number of vehicles used in the peak hour. This procedure will enable the planner to evaluate the public transit system for any transportation plan.

The evaluation of the public transit system should consider the different points of view which are supporting the system in order to operate it efficiently and with acceptable level of service to the users. These points of view are those of: the operator, the user, the society as a whole, and finally the government.

Furthermore, this chapter summarizes the public transit efficiency measures for the two most important points of view acting in the system i.e. the operator and the user. Various areas of concern for these two points of view have been considered. However, the financial efficiency has been considered in terms of revenue/
cost ratio for the public transit system and in terms of unit cost from the operator point of view.

5.2 Public Transit Interest Groups

Four major components are involved in the provision and operation of public transit system. These are:

1. The operator who has a direct impact on the system and provides the capital investment for the construction of the transportation system, maintenance facilities and all the requirements for operating the system.

2. The user who represents the second major actor in the public transit system. In fact, the user makes the basic input to the operator and in the meantime he is the first to realize the system's output. In terms of input, he contributes his out-of-pocket cost (i.e., transit fare) which represents the major source of income to the operator. In terms of output, he receives his trip completed with the provided level of service.

3. The society enters into consideration also because of the social significance of the public transit system and because in most cases the society at large is forced to take a specific stand with regard to the transit system that operates in the region under study.

Consequently, it may be satisfied or dissatisfied with what is being asked to provide for, or receive from the system. In fact, the society inputs the public transit system with the basic resources such as land, raw materials, manpower, energy, etc. While the system's output to the society is based on providing the people with the movements which are essential to achieve their economical and social activities.
4. The government which represents the most important actor in the system. This is so, because of the fact that the increased involvement of the government with the operations and the improvements of the public transportation services. In other words, it provides grants, subsidies, loans as well as investment in research projects, policy formulation, and administration of the system. It is clearly apparent that the government has an important role in evaluating the public transit system.

Figure 5.1 shows a schematic presentation of the different components in the urban public transit system and the relationships between them as patterns of flow of inputs and outputs.

5.3 Public Transit System Expenditures and Revenues

5.3.1 Total Expenditures

The total system expenditures consists of two major components namely operating (including maintenance) and capital costs.

5.3.1.1 Operating Expenditures

Generally, the operating expenditures of a public transit system are allocated to three areas; vehicle-hours, vehicle-miles and vehicles (31).

1. Operating Cost Per Vehicle-Hour

Operating employees' wages represent by far the largest single element of cost in most transit properties. Employees engaged in operating vehicles are paid on an hourly basis; hence, the allocation
FIGURE 5.1
THE PUBLIC TRANSIT INTEREST GROUPS

Source: Reference (30)
of wage expense is most properly made on the basis of hours of service on the system. Similarly, supervision of the system operations is directly related to the number of hours of service on the system.

2. Operating Cost Per Vehicle-Mile

Many costs in operating public transit are related directly to the miles in which the system operates. Expenses such as fuel, tires, and equipment maintenance are a direct function of miles operated. Material expenses for vehicle bodies, brakes, engines, chassis, and transmissions are also a function of exposure in terms of miles of service. Consequently, these costs, together with the cost of motor fuel, taxes, and other miscellaneous expenses, are assigned to the category of vehicle-miles in the operating expenditures of the transit system.

3. Operating Cost Per Vehicle

Many individual expense items do not vary as functions of either of the foregoing categories (i.e. vehicle-hours or vehicle-miles). For example, the cost of providing operating and maintenance facilities for vehicles is determined by the number of vehicles required rather than the number of hours or miles of service provided. Various material expenses are also related
<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAR021</td>
<td>Auto Availability</td>
<td>AUTAV</td>
</tr>
<tr>
<td>VAR022</td>
<td>Auto Occupancy</td>
<td>AOCCP</td>
</tr>
<tr>
<td>VAR023</td>
<td>Parking Period</td>
<td>PAKPR</td>
</tr>
<tr>
<td>VAR024</td>
<td>Parking Cost</td>
<td>PAKCS</td>
</tr>
<tr>
<td>VAR025</td>
<td>Income</td>
<td>INCME</td>
</tr>
<tr>
<td>VAR026</td>
<td>Industry</td>
<td>INDUS</td>
</tr>
<tr>
<td>VAR027</td>
<td>CBD or Non-CBD</td>
<td>CBDPL</td>
</tr>
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<td>VAR028</td>
<td>Perceived Travel Time in Mins.</td>
<td>PERTT</td>
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<tr>
<td>VAR029</td>
<td>Recorded Trip Purpose</td>
<td>RECTP</td>
</tr>
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<td>VAR030</td>
<td>Walk Time Min. Times Ten</td>
<td>WALKT</td>
</tr>
<tr>
<td>VAR031</td>
<td>Regular Bus Run Time Times Ten</td>
<td>RGBRT</td>
</tr>
<tr>
<td>VAR032</td>
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<td>Wait One</td>
<td>WAIT1</td>
</tr>
<tr>
<td>VAR035</td>
<td>Wait Two</td>
<td>WAIT2</td>
</tr>
<tr>
<td>VAR036</td>
<td>Auto Travel Time Min. Times Ten</td>
<td>ATIME</td>
</tr>
<tr>
<td>VAR037</td>
<td>Travel Cost by Auto</td>
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</tr>
<tr>
<td>VAR038</td>
<td>Highway PTP Travel Time Times Ten</td>
<td>HWYTT</td>
</tr>
<tr>
<td>VAR039</td>
<td>Transit PTP Travel Time Times Ten</td>
<td>TRSTT</td>
</tr>
<tr>
<td>VAR040</td>
<td>Walk Time Plus Wait 1</td>
<td>WAKW1</td>
</tr>
<tr>
<td>VAR041</td>
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<td>VAR042</td>
<td>Group Highway Cost</td>
<td>GHWYC</td>
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<tr>
<td>VAR043</td>
<td>Travel Cost Difference Auto-Transit</td>
<td>TCDAT</td>
</tr>
<tr>
<td>VAR044</td>
<td>Travel Time Difference A-T</td>
<td>TTDAT</td>
</tr>
</tbody>
</table>
to peak vehicle needs. These expenses include the maintenance of buildings, fixtures, shops and garages, service car equipment, and other miscellaneous shop items. A number of broad overhead expenses will vary with the number of vehicles required to operate the system, including depreciation of equipment, general office costs, and the salaries of general office clerks and officials.

5.3.1.2 Capital Expenditures

Capital expenditures of a transit system essentially comprise vehicles purchase and maintenance facilities (garages). Related street furniture, such as shelters and information signs are a relatively minor part of these costs.

5.3.2 System Operating Revenues

The user perceived cost, (i.e. transit fare) is one of the most important pricing policies in operating a public transit system. It is generally based on the following principles (32):

1. it must be competitive with automobile perceived cost;
2. it must support transit system needs for determined levels of operational and financial performance of the system, and
3. it must represent a fair economic charge for service provided i.e. different fares may be implemented for different services of routes, zones, etc.
Total operating revenue of a transit system will include fare box revenue and other sources. Fare box revenue is computed from multiplying the average transit fare times the annual revenue passengers.

5.3.3 Provincial Subsidy

The provincial subsidy to the transit system is generally determined as a percentage of the operating cost of the system. This percentage is based on the population level of the area in which the transit system operates. Table 5.1 shows the system subsidy for different population levels.

<table>
<thead>
<tr>
<th>Population</th>
<th>Subsidy as % of Operating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100,000</td>
<td>25%</td>
</tr>
<tr>
<td>100,000-150,000</td>
<td>22.5%</td>
</tr>
<tr>
<td>150,000-200,000</td>
<td>20%</td>
</tr>
<tr>
<td>200,000-1,000,000</td>
<td>17.5%</td>
</tr>
<tr>
<td>Over 1,000,000</td>
<td>13.75%</td>
</tr>
</tbody>
</table>

However, the subsidy may be provided as a function of the rate of growth of population. When population increases by more than four percent during a year, a special subsidy should be adopted. A rate of 1.5% of annual operating cost for each percent growth in population in excess of four percent (32).

* Source: Reference (32)
Furthermore, the capital expenditure of the transit system is subsidized by the provincial government. In the case of the province of Ontario, the government subsidizes 75 percent of the capital expenditures of the system.

5.3.4 Transit System Deficit

Since the three basic components in evaluating a public transit system have been determined (i.e. total expenditures, operating revenues and subsidy), the deficit of the system can be easily obtained.

The system deficit was estimated based on 1977 O. C. Transpo data for the various transportation policies tested in the area-wide analysis level described in Chapter 4. The deficit (in cents per passenger) for these policies are shown in Figures 5.2, 5.3, 5.4 and 5.5. The flowchart and computer program used in developing this deficit are given in Appendix D.4 and D.5 respectively.

It can be concluded from these figures that although reducing the transit fare may increase its ridership, but it will increase the system deficit as shown in Figures 5.2, 5.4 and 5.5. While if the transit fare is constant, the system deficit will decrease as the transit ridership increases due to other transportation policies (such as increased auto cost) as shown in Figure 5.3. The transit system deficit changes due to travel time savings at a given transit fare do not vary significantly (i.e. the curves are almost horizontal). While if the transit fare is decreased, substantial increase in the system deficit will occur as shown in Figures 5.3, 5.4 and 5.5. Thus, it is important
FIGURE 5.2

SYSTEM DEFICIT CHANGES TO TRANSIT
FARE AND AUTO OUT-OF-POCKET COST POLICIES
FIGURE 5.3

SYSTEM DEFICIT CHANGES TO TRANSIT TRAVEL TIME AND AUTO OUT-OF-POCKET COST POLICIES AT BASE YEAR TRANSIT FARE
FIGURE 5.4
SYSTEM DEFICIT CHANGES TO TRANSIT TRAVEL TIME AND TRANSIT FARE POLICIES AT BASE YEAR AUTO OUT-OF-POCKET COST
FIGURE 5.5

SYSTEM DEFICIT CHANGES TO TRANSIT TRAVEL TIME
AND COMBINATIONS OF TRANSIT FARE AND AUTO OUT-OF-POCKET COST POLICIES
to point out that the fare is the key issue affecting the deficit of the public transit system.

5.4 Transit System Efficiency Measures

The efficiency of the public transit operating in an urban area is usually measured in terms of ratios of the input and output for the various areas of the different points of view acting on the system. Formulating these ratios will in turn assist the planner to compare different plans and select the most appropriate strategy in operating the system.

In this research, the two most important points of view (operator and user) which have direct impacts on the system are presented. Note that only unit cost was used in the financial efficiency from the operator point of view in this chapter. But for the purpose of comprehensiveness the various areas of concern are elaborated to enable the reader to appreciate the depth of the subject. Data and time limitations prohibited the exploration of all the areas of concerns described in the next two subsections.

5.4.1 Areas of Concern from the Operator's Point of View

1. Unit Cost: This may be derived by dividing total operating expenditures by the production units in terms of total vehicle-miles, total passenger-miles or total number of passengers carried. Obviously, the higher the unit cost, the greater the economic pressure on the operator and less efficient the system is.
2. **Input Resources:** These may be derived by dividing the direct input resources (labor, energy, etc.) by the three main output units (vehicle-miles, passenger-miles and passengers transported).

3. **Relative Distribution of Costs:** These are indirect measures of the system efficiency. They concern two measures of particular significance. The first focuses on the proportion of costs dedicated directly to the production of transportation services within the system and the second focuses on the ratio between the capacity produced (seat-miles) by the system and capacity utilized (passenger-miles) during a specific time period.

It appears obvious that the greater the proportion of total costs dedicated to directly producing transportation services, the greater the efficiency of the system. Also, the greater the ratio between available and utilized capacity the greater the efficiency of the system (30).

4. **Provision of Direct Services:** This may be expressed in terms of vehicle-miles, passenger-miles or passengers transported divided by total passengers, man-hour of labour, and total vehicles respectively.

5. **Collection of Revenues:** This may describe the overall efficiency of the system by dividing the operating revenue by any unit of production (vehicle-miles, passenger-miles, vehicles, passenger or man-hour of total labor input).
5.4.2 Areas of Concern from the User's Point of View

1. **Cost of Travel for His Trip:** Assuming he has limited input resources of money and time, the efficiency of service from the user's point of view may be expressed as total travel cost or time cost per unit distance of his origin-destination trip.

2. **Quality of Travel:** This may be described in terms of convenience and comfort of service. The convenience may be expressed in terms of the frequency of service while the comfort can be quantitatively described in terms of floor area of vehicle per passenger carried or the ratio of average number of seats available to the average number of passengers carried. Other measures of comfort may be used in addition to the space measure.

3. **Reliability of Service:** This may seem to concern mostly the operator of the system, but in fact it is of greater importance to the user of the system. It can be measured in terms of "on-time arrival" of vehicles or "delayed" arrivals or departure of vehicles per number of all movements.

4. **Safety:** This may be measured in terms of total number of fatal accidents per vehicles miles or passengers carried.

5.5 Financial Efficiency Study Findings

As mentioned earlier, data and time problems limited the analysis to unit per passenger as the basic measure of financial efficiency from the operator's point of view.
UNIT COST CHANGES TO TRANSIT FARE AND AUTO OUT-OF-POCKET COST POLICIES
FIGURE 5.7

UNIT COST CHANGES TO TRANSIT TRAVEL
TIME AND TRANSIT FARE POLICIES AT BASE YEAR AUTO COST
FIGURE 5.8

UNIT COST CHANGES TO TRANSIT TRAVEL TIME
AND AUTO OUT-OF-POCKET COST POLICIES AT BASE YEAR TRANSIT FARE
FIGURE 5.9

UNIT COST CHANGES TO TRANSIT TRAVEL TIME AND COMBINATIONS OF TRANSIT FARE AND AUTO OUT-OF-POCKET COST POLICIES
The unit cost per passenger for the various transportation policies tested in Chapter 4 was estimated as shown in Figures 5.6, 5.7, 5.8 and 5.9. Since the unit cost is a direct function of ridership, as expected the unit cost decreases as ridership increases through the introduction of various transportation policies.

Furthermore, one of the most popular indicators in measuring the transit system financial efficiency is the revenue/cost ratio (R/C). Obviously the higher the ratio the more financially efficient the system is. In this regard, the study findings are presented in terms of policies affecting gasoline prices and parking charges based on the R/C ratios from the operator's point of view. The analysis considered the following avenues which are described in more details later in this section:

1. Increasing public transit service supply, i.e., providing extra buses to the existing fleet for any additional generated demand, and
2. Allowing a higher average design standard for the existing fleet capacity instead of increasing the public transit service supply.

Firstly, the supplementary service required for any additional generated demand was based on the relationship given in Appendix D.1. This linear relationship was accepted by the Transit Planning Branch of the Regional Municipality of Ottawa-Carleton as a simple tool in estimating the required supplementary service. It should be noted however that this linear relationship occurred

* Data used in this exercise were developed from Reference (33).
due to basic factors including:
1. The rather long average transit trip length brought about by the introduction of transit services to developing areas outside the greenbelt.
2. The introduction of limited stop express bus services in many areas of the region, and
3. Providing the minimum frequency service particularly for suburban areas.

However, in recent years (1978 onward) this linear relationship becomes flatter because of the improved overall productivity of the transit system particularly when the proposed rapid transitway system is implemented.

Tables 5.2 and 5.3 show changes in R/C (from the operator's point of view i.e. the provincial subsidy is not included) with respect to variation in gasoline prices and parking charges for different transit fare operating strategies respectively. It is clearly apparent that although R/C increases as the transit fare increases for both policies of increasing gasoline and parking charges, there is no change in the values of R/C itself with respect to these policies. This is so because as the ridership increases and revenues increase, these revenues are offset by capital expenditures which tends to stabilize the R/C ratio except for small decreases brought about by the additional operating expenditures. It is important to point out that in Table 5.4, the system will be self supported (i.e. not in need to provincial subsidy) if the fare is increased from 32 to about 56 cents.
<table>
<thead>
<tr>
<th>Fare Cents</th>
<th>90¢/gallon</th>
<th>120¢/gallon</th>
<th>150¢/gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Revenue</td>
<td>TCOST</td>
<td>R/C</td>
</tr>
<tr>
<td>32</td>
<td>26.25</td>
<td>42.62</td>
<td>0.61</td>
</tr>
<tr>
<td>40</td>
<td>31.20</td>
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<td>0.77</td>
</tr>
<tr>
<td>48</td>
<td>35.70</td>
<td>38.25</td>
<td>0.93</td>
</tr>
<tr>
<td>56</td>
<td>39.80</td>
<td>36.39</td>
<td>1.09</td>
</tr>
<tr>
<td>64</td>
<td>43.54</td>
<td>34.64</td>
<td>1.26</td>
</tr>
<tr>
<td>72</td>
<td>46.98</td>
<td>33.05</td>
<td>1.42</td>
</tr>
<tr>
<td>80</td>
<td>50.16</td>
<td>31.58</td>
<td>1.59</td>
</tr>
</tbody>
</table>

* Revenue and total expenditures in Millions of dollars
### TABLE 5.3

**Changes in R/C (From the Operator Point of View)**

**W.R.T. Parking Charges and Transit Fare Changes**

**When Supplementary Service Is Provided**

<table>
<thead>
<tr>
<th>Fare Cents</th>
<th>Parking Charge 2.0$</th>
<th>Parking Charge 2.5$</th>
<th>Parking Charge 3.0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Revenue</td>
<td>TCOST</td>
<td>R/C</td>
</tr>
<tr>
<td>32</td>
<td>27.68</td>
<td>45.19</td>
<td>0.61</td>
</tr>
<tr>
<td>40</td>
<td>33.24</td>
<td>43.24</td>
<td>0.77</td>
</tr>
<tr>
<td>48</td>
<td>38.39</td>
<td>41.46</td>
<td>0.93</td>
</tr>
<tr>
<td>56</td>
<td>43.17</td>
<td>39.80</td>
<td>1.08</td>
</tr>
<tr>
<td>64</td>
<td>47.62</td>
<td>38.26</td>
<td>1.24</td>
</tr>
<tr>
<td>72</td>
<td>51.76</td>
<td>36.83</td>
<td>1.41</td>
</tr>
<tr>
<td>80</td>
<td>55.64</td>
<td>35.5</td>
<td>1.56</td>
</tr>
</tbody>
</table>

+ Revenues and total expenditures in Millions of Dollars
Secondly, changes in R/C ratio with respect to changes in gasoline prices and parking charges for different transit fare levels when a higher bus loading design standard is used. This would mean that supplementary transit service for the additional demand generated as a result of increasing of these two policies can be accommodated by the existing fleet. This in turn may reduce the level of comfort and convenience of the transit system as a result of accepting more standees. The analysis in this case based on the standard bus of the existing O. C. Transpo 57 seat layout which may be used to load within an ultimate capacity of 77 passengers (34).

Figures 5.10 and 5.11 show changes in R/C with respect to gasoline prices and parking charges for different transit fare operating strategies. It is obvious that R/C from the operator point of view will increase as gasoline prices or parking charges increases at a specific transit fare level. This is so because of the fact that more riders will get into the system which in turn means more revenue for the operator. A substantial increase in R/C would occur if a higher transit fare strategy is implemented. It is important to point out that the existing system wide average load factor (point 1 in the two figures) is 17 passengers per bus as it was provided by the Transit Planning Branch, Regional Municipality of Ottawa-Carleton. The maximum average load factor (point 2 in the same figures) occurred as a result of loading the existing system with the additional generated demand was 24 passengers per bus. Although the existing system may be able to accommodate additional generated ridership, it may be required and necessary to provide supplementary service for many other reasons as described earlier in this section rather than demand need requirements only.
FIGURE 5.10

CHANGES IN R/C (FROM THE OPERATOR POINT OF VIEW) W.R.T. GASOLINE PRICES AND TRANSIT FARE CHANGES AT THE EXISTING PUBLIC TRANSIT SYSTEM CAPACITY.
FIGURE 5.11

CHANGES IN R/C (FROM THE OPERATOR POINT OF VIEW)
W.R.T. PARKING CHARGES AND TRANSIT FARE CHANGES AT
THE EXISTING PUBLIC TRANSIT SYSTEM CAPACITY
Thus it may be concluded from this study that the financial efficiency from the operator's point of view may be improved if gasoline prices and parking charges are increased and a substantial improvement can be achieved if the transit fare is increased as well. Although, such increase in the transit fare may reduce the ridership as was described by the modal split models developed in Chapter 4, it is believed that increasing the transit fare in conjunction with any other transportation policy tested in this Chapter or the previous one will improve the financial efficiency of the public transit system as well as achieving the modal shift in the study area.
CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

This research has attempted to develop a tool based on disaggregate behavioural approach. The tool is a binary choice logit model formulation calibrated by stepwise least square regression technique. It is believed that such a tool can be used to assess the impacts of various transportation policies and changes to the transportation system on mode choice in the Ottawa-Hull area.

The approach adopted assumes that the individual is the basic unit of observation and that his mode choice decision may be expressed as a function of the level of service provided by the two competing modes (private automobile and public transit), between trip origin and trip destination as well as his socio-economic characteristics.

Origin-destination data obtained through telephone survey interviews conducted in the Ottawa-Hull area were used to develop four models, namely:
1. work, core oriented travel,
2. work, non-core oriented travel,
3. non-work, core oriented travel, and
4. non-work, non-core oriented travel.

Furthermore, each of the above models were attempted in association with three different measures of transportation attributes (travel times and travel costs), namely; impedance differences, impedance ratios and relative impedance ratios measured in terms of impedance difference divided by the average impedance value.
It was found that the models based on relative impedance ratios produced significantly better results than those based on impedance differences and impedance ratios. Furthermore, the research results based on the relative impedance ratio models have indicated that for the work, CBD model, the only significant variable was the travel cost.

For the work, non-CBD, travel time, travel cost, total vehicles per household and trip maker's age were significant. Travel cost and the number of transfers were significant in the non-work, CBD model. In the non-work, non-CBD model, travel time, travel cost, age and the number of transfers were the significant variables.

The ability of the developed models to predict mode choice was tested (validated) using the same input data used in this calibration. The results of the validation based on the percentage of the maximum and average errors between the observed and estimated mode choice have indicated that the relative impedance ratio models are the best predictive tool.

Sensitivity to changes in the independent variables was carried out for the relative impedance ratio models. This sensitivity was described by means of the associated elasticities which were computed at the mean values of the transportation system variables (travel time and travel cost). It was found that the first model (work, CBD) was the most sensitive to changes in the transit fare and automobile out-of-pocket cost. While the fourth model (non-work, non-CBD) was elastic with respect to changes in transit total travel time and it was sensitive to changes in the automobile total travel time.
The main objective of developing a modal choice tool is to use it for assessing the shift in mode choice. Particularly in identification those factors which contribute to increases in transit usage and to a decrease in the use of private automobiles. Thus, the derived modal split models were used to identify for example, different pricing and level of service policies which may achieve a high transit usage. This in turn improves the financial efficiency of the public transit system.

The models were applied at two different levels. In the area wide level, the mean values of the independent variables for the generalized travel function were used. In the zonal level, the interzonal transportation variables (travel time and travel cost) and P.M. peak hour person trips were considered and developed for simplified road and transit networks of 60 districts representing the study area.

The public transit system was evaluated by identifying the major components of the expenditures and revenues. The subsystems of the public were presented as well as the efficiency measures from the operator and user points of view. The system deficit and unit cost were estimated for the various transportation policies developed earlier using O.C. Transpo data for 1977. It was found that the transit fare is the key issue affecting the financial efficiency of the public transit system. In other words, if the transit fare increased from 32 to 56 cents, the public transit system will not be in need to the government subsidy.
6.2 Conclusions

This research has shown that binary choice logit formulation is quite appropriate in studying travel demand shifts. It is so because of the fact that the transportation system attributes in this formulation have to be described in terms of relative values between the two competing modes instead of the absolute values as the case in multinomial models. This in turn will provide the planner with the opportunity to assess and evaluate the indirect influence of the two modes. For example, the household's need for owning more than one car is expected to decrease as the transit level of services increases.

The research has shown also that the specification of transportation system attributes in terms of difference between the two competing modes which is well known as the standard logit formulation is not the most general specification because the relative impedance ratios model produced better results than those based on either differences or ratios. A more general specification was suggested.

The disaggregation of the models by geographic destination (CBD and non-CBD) and by trip purpose (work and non-work) was important. This is because individuals have often many destinations from which to choose for non-work travel unlike for work travel in which the place of work is fixed. The choice is often dependent upon the level of availability of transportation service which can be described in the study area by such disaggregation.
From the results based on the relative impedance ratios model, the following conclusions were drawn regarding the individuals mode choice behaviour:

1. As would be expected, automobile ownership is a very important attribute affecting mode choice particularly for work, non-CBD model. The higher the total vehicles per household, the more likely an individual will travel by automobile.

2. The transit level of service attributes, portal-to-portal travel time and number of transfers contribute as a group as much to transit choice as automobile ownership particularly for non-CBD travel for any trip purpose.

3. The perceived user cost (auto out-of-pocket cost and transit fare) has more influence upon mode choice than transit attributes (particularly travel time) for CBD travel (work and non-work). While it has less influence for non-CBD travel. This is so because of the fact that free parking is available which in turn will reduce significantly the automobile out-of-pocket cost.

As far as the reliability of the results are concerned, it is concluded that:

1. The sensitivity of traveller's choice of mode to changes in travel cost was most sensitive for work, CBD model and elastic to changes in transit travel time for non-work, non-CBD model. These results are also comparable to what has been observed empirically and estimated by other studies (13).

2. Although the sample sizes were relatively small in calibrating the four basic models by least square regression technique, the statistical measures used as indicators to evaluate the reliability of the results confirm that the models are reasonable except the non-work, CBD model.
3. The predictive power of the models was tested in terms of the percentage of maximum and average errors using the same input data as in the calibration stage, it appears that the models were able to predict individual's mode choice rather well.

As far as the model applications are concerned it is concluded that the models are sensitive to changes in transportation policies within a certain range. Once this range is exceeded, no significant changes occur since the logistic curves become almost horizontal. This explains why R/C changes to gasoline prices and parking charges are not significant at these extreme bounds.

6.3 Recommendations

The modal split models developed in this research may be used for assessing the impact of transportation policies in transit planning and financial efficiency studies. However, there is room for improvements. In this regard the following is recommended:

1. The sample size, which is a very important factor in model calibration by stepwise least square regression should be increased for improved results.

2. Further research should include disaggregation of models according to trip maker's socio-economic characteristics instead of including them indirectly as was carried out in this research.

3. Since several studies including this research have indicated that the most important characteristics of the transportation system to the trip maker are modal travel times, further investigation is needed to incorporate the various components of door-to-door travel time (walking time, waiting time and in-vehicle time) as independent variables into the mode choice model.
4. The model validation (i.e. predictive power) should be tested using a new sample of individual trips instead of the same sample used in their development and calibration as done in this research because of time and cost considerations. However, model validation as is suggested by some researchers involves using one-half of the data to calibrate the models and the other half to test their validation. This in turn will test the transferability of the models to other urban areas. This procedure is recommended even though it was not used because of data and time limitations.

5. Since the telephone survey did not contain enough data particularly for the automobile, out-of-pocket cost, it is necessary to find out a more reliable way for obtaining such data than what was used in this research.

6. The criteria used for choosing the appropriate aggregation procedure in the area-wide level were based on the time resources and the availability of data specified by the developed models. The aggregation procedure used in this research was based on the mean values of the independent variables in the generalized travel function. This aggregation procedure does not take into consideration the actual distribution of the independent variables in the population. Therefore, it is recommended to apply the methodology used in the area-wide level using another aggregation procedure in order to increase the accuracy of the aggregation prediction.
7. The aggregation at the zonal level was based on the transportation system attributes (modal travel times and travel costs) only for each pair of zones. Further study should include other variables specified in the derived modal split models. These variables include: the number of transfers and socio-economic characteristics (such as age, sex, income and total vehicles per household) within each zone in order to determine the inter-zonal modal choice behavior as in the case of individual situation.

8. Travel demand shift achieved in this research was based on the quantifiable variables of the transportation system attributes specified in the derived modal split models. However, the distribution of this travel shift as well as the non-quantifiable variables were not explained by the models. Therefore, it is recommended to carry out a special attitudinal survey of travellers using private automobile and public transit to establish their preference patterns. This will help the planner to improve upon his understanding of those areas which were not explicitly treated in the developed modal split models.

9. Further research is required to study the public transit system and provide a comprehensive methodology for the optimum design of the system which maximizes its financial efficiency.
REFERENCES


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(20) Institute of Traffic Engineers (ITE), Transportation and Traffic Engineering Handbook, 1976.

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APPENDIX A

A.1 Generated Variables.

A.2 Alphabetic Order of the Final Computer File Variables

A.3 List of Variable Labels in the Final Sample Records

A.4 Flowchart of the Development of the Final Sample Records
A.1 GENERATED VARIABLES

A work trip is defined as a trip for which work is one of its ends. A non-work trip has neither of its trip ends as work.

A core oriented trip is defined as a trip which has its origin or destination in the CBD area. A non-core oriented trip is a trip which has its origin or destination otherwise.

Automobile out-of-pocket cost (ACOST) is estimated based on the following assumptions:

a. Automobile travel costs are 13 and 26 cents per mile for non-CBD and CBD trips respectively, and
b. The average speeds are 25 and 15 m.p.h. for non-CBD and CBD trips respectively.

This in turn will yield that the coefficients for estimating the automobile travel cost from the travel time (ATIME) are 0.65 and 0.54 for CBD and non-CBD respectively. Minimum trip cost is assumed to be 30 cents. Therefore, ACOST is estimated as following:

\[
\begin{align*}
ACOST &= 0.65 \times ATIME \text{ for CBD Trips} \\
&= 0.54 \times ATIME \text{ for Non-CBD Trips} \\
HWYTT &= ATIME + 70^* \text{ for CBD} \\
&= ATIME + 40^* \text{ for Non-CBD} \\
TRSTT &= WALKT + RGBRT - EXBRT - WAIT1 - WAIT2 \\
WAKW1 &= WALKT + WAIT1 \\
WAKW2 &= WALKT + WAIT2 \\
GHWYC &= \frac{ACOST}{AOCCP} \text{ for Auto Passenger} \\
&= ACOST \text{ for Auto Driver}
\end{align*}
\]

* Out-of-vehicle travel times (access and egress time) are assumed 7 and 4 mins) for CBD and non-CBD trips respectively. This assumption is provided by Systems Planning Branch, RMOC.
The transit average fare for 1977 is estimated as 32 cents. It is a result of various types of users and type of fares which they pay. The estimation is based on the following:

**Adults**

- Cash: 50¢
- Ticket: 5 for $2.00
- O.C. Trans Pass: $13.00
- O.C. Uni Pass (Express): $16.00

**Children, Students and Senior Citizen**

- Cash: 25¢
- Tickets: 5 for $1.00
- Senior Citizen Annual Pass: $20.00
- Student Monthly Pass: $8.50

**Premium Fares (not required with O.C. Uni Pass)**

- On Express: 50¢
- On Tele Transpo: 50¢

Therefore, the average transit fare is considered as 32 cents in the following generated variable.

- TCDAT = GHWYC - 32
- TTDAT = HWYTT - TRSTT
- AEXCS = HWYTT - ATIME
- EXCTD = AEXCT - WALKT
- RETAT = AEXCT/WALKT
- RTCAT = GHWYC/32
- RTTAT = HWYTT/TRSTT
- INVTD = ATIME - RGBRT - EXBRT
\[
\begin{align*}
RINV &= \frac{ATIME}{(RGBRT + EXBRT)} \\
CDAAT &= \frac{TCDAT}{(GHWYC + 32)/2} \\
TDAAT &= \frac{TTDAT}{(HWYTT + TRSTT)/2}
\end{align*}
\]
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<td>Auto Occupancy</td>
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<td>Auto Availability</td>
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<td>Drive Auto</td>
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<td>Destination Time Min.</td>
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**A.3 LISTING OF VARIABLE LABELS.**

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<td>VAR049</td>
<td>Travel Time Ratio A by T</td>
<td>TTRAT</td>
</tr>
<tr>
<td>VAR050</td>
<td>In-Vehicle Time Difference A-T</td>
<td>INVTD</td>
</tr>
<tr>
<td>VAR051</td>
<td>Relative In-Vehicle Travel Time A by T</td>
<td>RINVT</td>
</tr>
<tr>
<td>VAR052</td>
<td>Travel Cost Difference Divided by the Average</td>
<td>CDAAT</td>
</tr>
<tr>
<td>VAR053</td>
<td>Travel Time Difference Divided by the Average</td>
<td>TDAAT</td>
</tr>
</tbody>
</table>
A.4 FLOWCHART OF THE DEVELOPMENT
OF THE FINAL SAMPLE RECORDS
APPENDIX B

Computer Program Used in the Area-Wide Level Analysis.
TRAVEL DEMAND SHIFT SENSITIVITY TO THE AUTO COST

**AIC1** : AUTO TRAVEL COST FOR MODEL I

**I=1** : WORK CBD MODEL

**I=2** : WORK NON CBD MODEL

**I=3** : NON WORK CBD MODEL

**I=4** : NON WORK NON CBD MODEL

**TC** : TRANSIT TRAVEL COST (AVERAGE FAKE)

**XFER** : NUMBER OF TRANSFERS

**TOTV** : NUMBER OF VEHICLES PER HOUSEHOLD

**ATI** : AUTO TRAVEL TIME FOR MODEL I

**TTI** : TRANSIT TRAVEL TIME

**PERI** : PM PEAK HOUR PERSON TRIPS CORRESPONDING TO MODEL I

**AC1=48.16**

**AC2=56.97**

**AC3=39.69**

**AC4=39.0**

**IFLG=0**

**TC=32.0**

**TCX=TC**

**XFER=0**

**TOTV=1**

**AT2=189.19**

**AT4=153.86**

**TT2=373.9**

**TT4=342.701**

**PER1=19457**

**PER2=68639**

**PER3=2906**

**PER4=31769.0**

**AC1X=AC1**

**AC2X=AC2**

**AC3X=AC3**

**AC4X=AC4**

**PRINT5 \* AC1**

**5 FORMAT(‘ FOR AC= ’, F10.1, ‘ TTRB, TTRBX, TRS, TC ’,**

**‘ 1 ‘ AC1 AC2 AC3 AC4’)**

**10 Y1=0.44935-1.82462* ((AC1-TC)*2/(AC1+TC))**

**22.000**

**Y2=1.63658+0.562123*((AT2-TT2)*2/(AT2+TT2))-0.23355**

**23.000**

**Y3=-0.70764+0.32483*((AC3-TC)*2/(AC3+TC))+0.07165**

**24.000**

**XFER**

**26.000**

**Y4=1.34289+1.50623*((AT4-TT4)*2/(AT4+TT4))-**

**27.000**

**1 0.75811*((AC4-TC)*2/(AC4+TC))**

**28.000**

**TR1=(1-(EXP(Y1)/(1+EXP(Y1))))**

**29.000**

**TR2=(1-(EXP(Y2)/(1+EXP(Y2))))**

**30.000**

**TR3=(1-(EXP(Y3)/(1+EXP(Y3))))**

**31.000**

**TR4=(1-(EXP(Y4)/(1+EXP(Y4))))**

**32.000**

**TTRB=TR1+TR2+TR3+TR4**

**33.000**

**IF(IFLG,NE,0)GO TO 20.**

**34.000**

**TTRBX=TTRB**

**35.000**

**IFLG=1**

**36.000**

**20 TRS=TTRB-TTRBX**

**37.000**

**PRINT30, TTRB, TTRBX, TRS, TC, AC1, AC2, AC3, AC4**
30 FORMAT('OF10.1')
31 FORMAT('TF10.1')
32 FORMAT('CF10.1')
33 FORMAT('EF10.1')
34 FORMAT('GF10.1')
35 FORMAT('HF10.1')
36 FORMAT('IF10.1')
37 FORMAT('MF10.1')
38 FORMAT('NF10.1')
39 FORMAT('OF10.1')
40 FORMAT('TF10.1')
41 FORMAT('CF10.1')
42 FORMAT('EF10.1')
43 FORMAT('GF10.1')
44 FORMAT('HF10.1')
45 FORMAT('IF10.1')
46 FORMAT('MF10.1')
47 FORMAT('NF10.1')
48 FORMAT('OF10.1')
49 FORMAT('TF10.1')
50 FORMAT('CF10.1')
51 FORMAT('EF10.1')
52 FORMAT('GF10.1')
53 FORMAT('HF10.1')
54 FORMAT('IF10.1')
55 FORMAT('MF10.1')
56 FORMAT('NF10.1')
57 FORMAT('OF10.1')
58 FORMAT('TF10.1')
59 FORMAT('CF10.1')
60 FORMAT('EF10.1')
61 FORMAT('GF10.1')
62 FORMAT('HF10.1')
63 FORMAT('IF10.1')
64 FORMAT('MF10.1')
65 FORMAT('NF10.1')
66 FORMAT('OF10.1')
67 FORMAT('TF10.1')
68 FORMAT('CF10.1')
69 FORMAT('EF10.1')
70 FORMAT('GF10.1')
71 FORMAT('HF10.1')
72 FORMAT('IF10.1')
73 FORMAT('MF10.1')
74 FORMAT('NF10.1')
75 FORMAT('OF10.1')
76 FORMAT('TF10.1')
77 FORMAT('CF10.1')
78 FORMAT('EF10.1')
79 FORMAT('GF10.1')
80 FORMAT('HF10.1')
81 FORMAT('IF10.1')
82 FORMAT('MF10.1')
83 FORMAT('NF10.1')
84 FORMAT('OF10.1')
85 FORMAT('TF10.1')
86 FORMAT('CF10.1')
87 FORMAT('EF10.1')
88 FORMAT('GF10.1')
89 FORMAT('HF10.1')
90 FORMAT('IF10.1')
91 FORMAT('MF10.1')
92 FORMAT('NF10.1')
93 FORMAT('OF10.1')
94 FORMAT('TF10.1')
95 FORMAT('CF10.1')
96 FORMAT('EF10.1')
97 FORMAT('GF10.1')
98 FORMAT('HF10.1')
99 FORMAT('IF10.1')
100 FORMAT('MF10.1')
101 FORMAT('NF10.1')
102 FORMAT('OF10.1')
103 FORMAT('TF10.1')
104 FORMAT('CF10.1')
105 FORMAT('EF10.1')
106 FORMAT('GF10.1')
107 FORMAT('HF10.1')
108 FORMAT('IF10.1')
109 FORMAT('MF10.1')
110 FORMAT('NF10.1')
111 FORMAT('OF10.1')
112 FORMAT('TF10.1')
113 FORMAT('CF10.1')
114 FORMAT('EF10.1')
115 FORMAT('GF10.1')
116 FORMAT('HF10.1')
117 FORMAT('IF10.1')
118 FORMAT('MF10.1')
119 FORMAT('NF10.1')
120 FORMAT('OF10.1')
121 FORMAT('TF10.1')
122 FORMAT('CF10.1')
123 FORMAT('EF10.1')
124 FORMAT('GF10.1')
125 FORMAT('HF10.1')
126 FORMAT('IF10.1')
127 FORMAT('MF10.1')
128 FORMAT('NF10.1')
129 FORMAT('OF10.1')
130 FORMAT('TF10.1')
2.000 **--------------------------------------------**
3.000 C
4.000 C TRAVEL DEMAND SHIFT SENSITIVITY TO THE TRANSIT TRAVEL
5.000 C TIME
6.000 **--------------------------------------------**
7.000 C
8.000 C
9.000 C INITIALIZATION OF VARIABLES
10.000 C
11.000 IMPLICIT REAL (N)
12.000 TOTV = 1.0
13.000 XFER = 0.0
14.000 TC = 32.0
15.000 AT2 = 189.192
16.000 AT4 = 153.86
17.000 TT2 = 373.943
18.000 TT4 = 342.7
19.000 AC1 = 48.16
20.000 AC2 = 56.97
21.000 AC3 = 39.69
22.000 AC4 = 39.0
23.000 FER1 = 19457.
24.000 FER2 = 68639.
25.000 FER3 = 2906.
26.000 FER4 = 31769.
27.000 A = 1.63658
28.000 B = 0.562123
29.000 C = 1.23355
30.000 D = 0.0625
31.000 A1 = 1.34288
32.000 A2 = 1.50623
33.000 C1 = 0.75811
34.000 C
35.000 C
36.000 C THIS SECTION IS DESIGNED TO EXAMINE THE EFFECT WHEN AT2
37.000 C AND TT4 ARE DECREASED BY 10% AT A TIME, WHILE ALL OTHER
38.000 C PARAMETERS REMAIN CONSTANT
39.000 FACTOR = 1.0
40.000 PRINT 54
41.000 PRINT 106
42.000 DO 50 I = 1,5
43.000 NEWTT2 = FACTOR * TT2
44.000 NEWTT4 = FACTOR * TT4
45.000 Y1 = 0.44935 - 0.82462 *((AC1 - TC) / ((AC1 + TC) / 2))
46.000 1 Y2 = A + B * ((AT2 - NEWTT2) / (AT2 + NEWTT2) / 2) - C* 
47.000 1 ((AC2 - TC) / ((AC2 + TC) / 2)) + B * TOTV
48.000 1 Y3 = -0.26764 + 32483 * ((AC3 - TC) / ((AC3 + TC) / 2))
49.000 1 0.07165 * XFER
50.000 1 Y4 = A1 - B1 * ((AT4 - NEWTT4) / ((AT4 + NEWTT4) / 2)) - C1 *
51.000 1 ((AC4 - TC) / ((AC4 + TC) / 2))
52.000 F1 = 1 - (EXP(Y1) / (1 + EXP(Y1)))
53.000 F2 = 1 - (EXP(Y2) / (1 + EXP(Y2)))
54.000 F3 = 1 - (EXP(Y3) / (1 + EXP(Y3)))
55.000 F4 = 1 - (EXP(Y4) / (1 + EXP(Y4)))
56.000 TR1 = F1 * FER1
56.000  IR2 = F2 * FER2
57.000  TR3 = F3 * FER3
58.000  TR4 = F4 * FER4
59.000  TRRB = TR1 + TR2 + TR3 + TR4
60.000  IF (1.EQ.1) TTRBO = TTRB
61.000  TRS = TTRB - TTRBO
63.000  PRINT 107, NEWTT2, NEWTT4, TC, TTRB, TRS
64.000  FACTOR = FACTOR - .10
65.000  50 CONTINUE
66.000  C
67.000  C THIS TO EXAMINE THE EFFECT OF CHANGING
68.000  C THE VALUE FOR IC BY -25% AT A TIME
70.000  FRACT = 1.0
71.000  PRINT 104
72.000  DO 100 J = 1, 5
73.000  NEWTC = FRACT * TC
74.000  PRINT 105, J, FRACT
75.000  PRINT 106
76.000  FACTOR = 1.0
77.000  DO 80 I = 1, 5
78.000  NEWTT2 = FACTOR * TT2
79.000  NEWTT4 = FACTOR * TT4
80.000  Y1 = 0.44935 - 1.082462 * ((AC1 - NEWTC) / (AC1 + NEWTC))
81.000  1 / (2)
82.000  Y2 = A - B * ((AT2 - NEWTT2) / (AT2 + NEWTT2) / 2) - C
83.000  Y3 = (AC2 - NEWTC) / (AC2 + NEWTC) / 2)) + 100
84.000  Y4 = A - B * ((AT4 - NEWTT4) / (AT4 + NEWTT4) / 2) - C
85.000  Y5 = A - B * ((AT5 - NEWTT5) / (AT5 + NEWTT5) / 2) - C
86.000  C Y6 = A - B * ((AT6 - NEWTT6) / (AT6 + NEWTT6) / 2) - C
87.000  C
88.000  P1 = 1 - (EXP(Y1) / (1 + EXP(Y1)))
89.000  P2 = 1 - (EXP(Y2) / (1 + EXP(Y2)))
90.000  F3 = 1 - (EXP(Y3) / (1 + EXP(Y3)))
91.000  F4 = 1 - (EXP(Y4) / (1 + EXP(Y4)))
92.000  F5 = 1 - (EXP(Y5) / (1 + EXP(Y5)))
93.000  TR1 = P1 * FER1
94.000  TR2 = P2 * FER2
95.000  TR3 = P3 * FER3
96.000  TR4 = P4 * FER4
97.000  TTRB = TR1 + TR2 + TR3 + TR4
98.000  IF (1.EQ.1) TTRBO = TTRB
99.000  TRS = TTRB - TTRBO
100.000  PRINT 107, NEWTT2, NEWTT4, TC, TTRB, TRS
101.000  FACTOR = FACTOR - .10
102.000  80 CONTINUE
103.000  FRACT = FRACT - .25
104.000  100 CONTINUE
105.000  C
106.000  C THIS SECTION IS DESIGNED TO EXAMINE THE EFFECT OF CHANGING
107.000  C THE VALUES OF AC'S BY +25% AT A TIME
108.000  C
109.000  FRACT = 1.0
110.000  PRINT 204
111.000  DO 200 J = 1, 5
112.000  NEWAC1 = FRACT * AC1
113.000  NEWAC2 = FRACT * AC2
114.000  NEWAC3 = FRACT * AC3
115.000  NEWAC4 = FRACT * AC4
116.000 PRINT 205, J+FRAC1
117.000 PRINT 206
118.000 FACTU1 = 1.0
119.000 DO 180 I=1.5
120.000 NEWT2=FACTU1*TT2
121.000 NEWT4=FACTU1*TT4
122.000 Y1= .44935 - 1.82462**((NEWAC1-TC)/(NEWAC1+TC)/2)
123.000 Y2=A1-1*((AT2-NEWT2)/(AT2+NEWT2)/2)
124.000 -C*((NEWAC2-TC)/(NEWAC2+TC)/2))U*TOTUV
125.000 Y3=-.70764+.32483**((NEWAC3-TC)/(NEWAC3+TC)
126.000 (2))+.07165*XFER
127.000 Y4=A1-1**((AT4-NEWT4)/(AT4+NEWT4)/2))-C1*
128.000 ((NEWAC4-TC)/(NEWAC4+TC)/2)
129.000 F1=1-(EXP(Y1)/(1+EXP(Y1)))
130.000 F2=1-(EXP(Y2)/(1+EXP(Y2)))
131.000 F3=1-(EXP(Y3)/(1+EXP(Y3)))
132.000 P4=1-(EXP(Y4)/(1+EXP(Y4)))
133.000 TR1=F1*ER1
134.000 TR2=F2*ER2
135.000 TR3=F3*ER3
136.000 TR4=F4*ER4
137.000 TTRB = TR1 + TR2 + TR3 + TR4
138.000 IF(I.EQ.1) TTRBO=TTRB
139.000 TRS=TTRB-TTRBO
140.000 PRINT 210,NEWT2,NEWT4,NEWAC1,NEWAC2,NEWAC3,NEWAC4,
141.100 1 TTRB,TRS
142.000 FACTOR=FACTOR-.10
143.000 DO 180 CONTINUE
144.000 FRACT = FRACT+.25
145.000 DO 180 CONTINUE
146.000 C
147.000 C THIS SECTION IS DESIGNED TO EXAMINE THE EFFECT OF CHANGING
148.000 C THE VALUES OF THE AC'S BY +25%.
149.000 C
150.000 C FACT1=1.0
151.000 FRAC24=1.0
152.000 PRINT 304
153.000 DO 300 J=1.5
154.000 NEWTC=FRAC1*TC
155.000 NEWAC1=FRAC24*AC1
156.000 NEWAC2=FRAC24*AC2
157.000 NEWAC3=FRAC24*AC3
158.000 NEWAC4=FRAC1*AC4
159.000 PRINT 305, J,FRAC1,FRAC24
160.000 FACTOR=1.0
161.000 PRINT 206
162.000 DO 280 I=1.5
163.000 TNEWT2=FACTU1*TT2
164.000 TNEWT4=FACTU1*TT4
165.000 Y2=A1-1*((AT2-NEWT2)/(AT2+NEWT2)/2)-C*
166.000 ((NEWAC2-NEWTC)/(NEWAC2+NEWTC)/2))U*TOTUV
167.000 Y3=-.70764+.32483**((NEWAC3-NEWTC)/(NEWAC3+NEWTC)
168.000 (2))+.07165
169.000 1 **XFER
170.000 Y4=A1-1**((AT4-NEWT4)/(AT4+NEWT4)/2))-C1*
174.000 1 \((\text{NEWAC4-NEWTC})/((\text{NEWAC4+NEWTC})/2))
175.000 \text{F1}=1-(\text{EXP(Y1)}/(1+\text{EXP(Y1)}))
176.000 \text{F2}=1-(\text{EXP(Y2)}/(1+\text{EXP(Y2)}))
177.000 \text{F3}=1-(\text{EXP(Y3)}/(1+\text{EXP(Y3)}))
178.000 \text{F4}=1-(\text{EXP(Y4)}/(1+\text{EXP(Y4)}))
179.000 \text{TR1}=\text{F1}+\text{FER1}
180.000 \text{TR2}=\text{F2}+\text{FER2}
181.000 \text{TR3}=\text{F3}+\text{FER3}
182.000 \text{TR4}=\text{F4}+\text{FER4}
183.000 \text{TRKH}=\text{TR1}+\text{TR2}+\text{TR3}+\text{TR4}
184.000 \text{TR1}=\text{F1}+\text{FER1}
185.000 \text{FRC}=\text{FRC}+\text{FER3}
186.000 \text{PRINT} 210, \text{NEWT2}, \text{NEWT4}, \text{NEWTC}, \text{NEWAC1}, \text{NEWAC2}, \text{NEWAC3},
187.000 \text{NEWAC4}, \text{TRKH}, \text{TRS}
188.000 \text{FACTOR}=\text{FACTOR}-.10
189.000 \text{280} \text{CONTINUE}
190.000 \text{FRACT1}=\text{FRACT1}-.25
191.000 \text{FRACT1}=\text{FRACT1}+.25
192.000 \text{300} \text{CONTINUE}
193.000 \text{STOP}
194.000 \text{C}
195.000 \text{C} \text{FORMAT SECTION.}
196.000 \text{54} \text{FORMAT(1,'SUMMARY OF OUTPUT WHEN TC'S ARE DECREASED'.}
197.000 \text{1} \text{BY 10% AT A TIME IS AS FOLLOWS;')}
198.000 \text{104} \text{FORMAT(1,'SUMMARY OF OUTPUT WHEN TC IS DECREASED',}
199.000 \text{1} \text{BY 25% AT A TIME IS AS FOLLOWS;')}
200.000 \text{105} \text{FORMAT(2X,1X,+'OF ORIGINAL TC')}
201.000 \text{106} \text{FORMAT(2X,1X,+'OF ORIGINAL TC')}
202.000 \text{107} \text{FORMAT(5X,5F(10,3,5X))}
203.000 \text{204} \text{FORMAT(1,'SUMMARY OF OUTPUT WHEN AC'S ARE INCREDIBLE',}
204.000 \text{1} \text{BY 25% AT A TIME IS AS FOLLOWS;')}
205.000 \text{205} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
206.000 \text{206} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
207.000 \text{207} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
208.000 \text{208} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
209.000 \text{209} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
210.000 \text{210} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
211.000 \text{211} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
212.000 \text{212} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
213.000 \text{213} \text{FORMAT(2X,1X,+'OF ORIGINAL AC'S')}
214.000 \text{END}
APPENDIX C

C.1 Conversion Table: 300 Zones to 60 Districts.
C.2 Road Link and Transit Link-Line Data Sheets.
C.3 Flowchart for Building the Transit Network.
C.4 Flowchart for Building the Road Network.
C.5 Flowchart for Developing the Total Transit Trip Table Using MTC Computer Package.
C.6 Flowchart and Computer Programme Used in Developing the Total Transit Trip Table Using FORTRAN Programming.
C.7 Flowchart for the Transit Network Assignment.
### C.1 CONVERSION TABLE: 300 ZONES TO 60 DISTRICTS

<table>
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<th>ZONES</th>
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<td>33</td>
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<td>27-35</td>
<td>35</td>
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<td>27</td>
<td>179,180,183</td>
<td>57</td>
<td>290-296 (ONT.)</td>
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### C.2 ROAD LINK DATA SHEET

#### 360 TRANSPORTATION ROAD PACKAGE - LINK DATA INPUT

**May 1975**

**STUDY NAME**

**NETWORK DESCRIPTION**

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<th>B</th>
<th>LENGTH</th>
<th>TYPICAL</th>
<th>B</th>
<th>S</th>
<th>C</th>
<th>D</th>
<th>T</th>
<th>C</th>
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</tbody>
</table>

**NOTES:**
- Leave blank if speed is coded, code 1 if time is coded.
- Direction - Code 2 for two-way links when B-A is identical to A-B, and omit details of B-A code for one-way links.
- Leave blank when B-A is different than A-B and code details for B-A.
- Update - Code 1 for deletion of link, otherwise leave blank.

*Used in conjunction with program IN 1933*
### C.2 (Continued)

**TRANSIT LINE DATA SHEET**

**LINE DATA INPUT**

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
<th>Column 4</th>
<th>Column 5</th>
<th>Column 6</th>
<th>Column 7</th>
<th>Column 8</th>
<th>Column 9</th>
<th>Column 10</th>
<th>Column 11</th>
<th>Column 12</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

*Note: The table is not fully legible due to the quality of the image. The columns represent various data points related to transit line data input.*
C.3 FLOWCHART FOR BUILDING THE TRANSIT NETWORK
C.4 FLOWCHART FOR BUILDING THE ROAD NETWORK
C.5 FLOWCHART FOR DEVELOPING THE TOTAL TRANSIT TRIP TABLE USING MTC COMPUTER PACKAGE
C.6 FLOWCHART AND COMPUTER PROGRAMME USED IN DEVELOPING THE TOTAL TRANSIT TRIP TABLE USING FORTRAN PROGRAMMING
C **DEVELOPING TOTAL TRANSIT PERSON TRIP TABLE**

**ABBREVIATIONS**

- X1 = AUTO TRAVEL TIME IN MIN
- X2 = TRANSIT TRAVEL TIME IN MIN
- Y1 = PERSON TRIPS FOR WORK - CBD MODEL 1=1
- Y2 = PERSON TRIPS FOR WORK - NON CBD MODEL 1=2
- Y3 = PERSON TRIPS FOR NON WORK - CBD MODEL 1=3
- Y4 = PERSON TRIPS FOR NON WORK - NON CBD MODEL 1=4
- ATC1 = AUTO TRAVEL COST FOR CBD TRAVEL
- ATC2 = AUTO TRAVEL COST FOR NON - CBD TRAVEL
- CA1 = COST DIffERENCE DIVIDED BY AVERAGE VALUE FOR CBD TRAVEL
- CA2 = COST DIffERENCE DIVIDED BY AVERAGE VALUE FOR NON CBD TRAVEL
- TDA = TIME DIFFERENCE DIVIDED BY AVERAGE VALUE
- G1 = GENERALIZED TRAVEL COST FUNCTION FOR MODEL I
- P1 = TRANSIT PROBABILITY CHOICE FOR MODEL I
- B1 = TRANSIT PERSON TRIPS FOR MODEL I
- TTTNM= TOTAL TRANSIT PERSON TRIPS FROM ZONE N TO ZONE M

```plaintext
10 READ(105,100)X1,X2,Y1,Y2,Y3,Y4
100 FORMAT(2F4.1,4F4.0)
   IF(X,E0,-1) GO TO 99
   ATC1=0.595*X1
   ATC2=0.544*X1
   CDA1=(ATC1-32)/(ATC1+32)
   CDA2=(ATC2-32)/(ATC2+32)
   TDA=(X1-X2)/((X1+X2)/2)
   G1=0.4494-1.8246*CDA1
   G2=1.7172-0.2377*CDA2-0.5498*TDA
   G3=-0.613+0.3614*CDA1
   G4=1.3429-0.7581*CDA2-1.5062*TDA
   P1=1-EXP(G1)/(1+EXP(G1))
   P2=1-EXP(G2)/(1+EXP(G2))
   P3=1-EXP(G3)/(1+EXP(G3))
   P4=1-EXP(G4)/(1+EXP(G4))
   B1=P1*Y1
   B2=P2*Y2
   B3=P3*Y3
   B4=P4*Y4
   TTTNM=B1+B2+B3+B4
50 FORMAT(5X,'TTTNM')
   PRINT 60,TTTNM
60 FORMAT(5X,F5.1)
   GO TO 10
99 STOP
END
```
C.7 FLOWCHART FOR THE TRANSIT NETWORK ASSIGNMENT
APPENDIX D

D.1 Development of Bus Fleet and Annual Ridership Relationship

D.2 Development of Revenue-Miles and Bus Fleet Relationship.


D.4 Flowchart of Evaluation of the Public Transit System.

D.5 Computer Program of Evaluation of the Public Transit System.
Bus Fleet = 0.01211 x Annual Ridership - 60.184

$R^2 = 0.984$

D.1 DEVELOPMENT OF BUS FLEET AND ANNUAL RIDERSHIP RELATIONSHIP
Revenue-miles = 36.654 x Bus Fleet - 3,870
in thousands

$R^2 = 0.964$

D.2 DEVELOPMENT OF REVENUE-MILES
AND BUS FLEET RELATIONSHIP
1. Operating Expenditures
   a. Cost per Vehicle-Hour
      The average operating cost per vehicle-hour for various type of services (i.e. Weekday, Saturday, Sunday and Evening) was estimated as $10.46. It was assumed that vehicle-hours can be derived as a ratio of the existing scheduled hours and bus fleet i.e. 1,805,000 hours ÷ 723 = 2496.5, therefore, scheduled hours = 2496.5 X Bus Fleet
   b. Cost per Vehicle-Mile
      The average cost per vehicle-mile has been estimated as 39.0¢
   c. Cost per Vehicle
      The average annual cost per vehicle has been estimated as $7,500 per vehicle.
   d. Other Fixed Cost
      It includes the plant maintenance, administration and planning. It was estimated as 13.6% of the above cost. Therefore, the total operating expenditures of the transit system in terms of bus fleet was estimated as TOE;

      \[ \text{TOE} = 54,423 \times \text{Bus Fleet} - 1,714,565 \]
2. **Capital Expenditures**

a. **Vehicle Capital Cost**

The capital cost per standard bus (40 ft.) delivered in 1977 was considered as $70,000 or $9,200 annually by assuming 10% interest rate and a 15 year service life using the following formula:

\[
A = P \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right]
\]

where:

- \( i \) = Interest rate per interest period
- \( n \) = Number of years of interest period
- \( P \) = Present sum of money
- \( A \) = End-of-period payment or receipt in a uniform series continuing for \( n \) periods, in the future the entire series equivalent to \( P \) at interest \( i \).

b. **Garage Capital Cost**

The construction cost for garages (excluding property), used in the evaluation was $4.2 million. This cost includes the cost of equipping the garage as well as the cost of the building. The planned capacity of the garage is 200 buses, but it can be expanded to 260 buses, with an additional cost of $750,000. Assuming a 10% interest rate and a 30 year service life, the annual garage capital cost was estimated as $446,000.

---

At the present time, O.C. Transpo has 4 garages with capacity of 720 bus based on the standard 40-foot buses. If the required additional number of buses (Bus Fleet - 720) is 50 or less, no new garage costs will be assumed. If between 50 and 115 buses are required an allowance of $750,000 or $83,000 per annum will be assumed, while between 115 and 260 additional buses, a new 200 bus garage should be assumed at a cost of $4.2 million or $446,000 annually.
D.4 FLOWCHART OF EVALUATION OF THE PUBLIC TRANSIT SYSTEM

Average Transit Fare

Operating Revenues

PM Ridership

Annual Ridership

Operator Unit Cost Per Pass.

Bus Fleet

Is Garage Capacity OK

Yes

Is Bus Fleet OK

No

Total Operating Expenditures

Vehicle Annual Capital Cost

Garage Annual Capital Cost

Total Annual Expenditures

Provincial Subsidy

System Deficit per Passenger
**COMPUTER PROGRAM OF EVALUATION OF THE PUBLIC TRANSIT SYSTEM**

**EVALUATION OF THE PUBLIC TRANSPORTATION SYSTEM**

**ABBREVIATIONS**

- TC = Transit Average Fare
- TTRB = PM Peak Hour Transit Ridership
- ANRD = Annual Transit Ridership
- OPRV = Operating Revenue
- BF = Bus Fleet Requirements
- VACC = Vehicle Annual Capital Cost
- AGCC = Garage Annual Capital Cost
- TOE = Total Operating Expenditures
- TAOE = Total Annual Operating Expenditures
- FS = Provincial Subsidy
- SD = System Deficit
- E1 = Deficit, Per Passenger in Cents
- E2 = Operating Cost Per Passenger in Cents

```
10          READ(2,100)TC,TTRB
100         FORMAT(F6.0,F10.0)
          IF(1.C.EQ.-1)GO TO 99
          ANRD=1564.29*TTRB
          OPRV=TC*ANRD/100
          BF=0.01211*(ANRD/1000)-0.184
          PRINT 14
          FORMAT(2X,'TC',8X,'TTRB',8X,'ANRD',8X,'OPRV',8X,'BF')
          PRINT 15,*TC,TTRB,ANRD,OPRV,BF.
          FORMAT(5(X,F12.3))
          IF(BF.GT.660)NOARB=BF-660
          VACC=NOARB*92000
          I1=NOARB/260
          I2=NOARB-I1*260
          IF(I2.LT.50)AGCC=0.0
          IF(I2.GT.50.AND.I2.LT.115)AGCC=83000
          AGCC1=AGCC+I1*446000
          TOE=(54423*BF-1714565)*1000000
          TAOE=TOE+VACC+AGCC1
          FS=0.175*TOE+0.75*(VACC+AGCC1)
          SD=TAOE-(OPRV+FS)
          E1=100*SD/ANRD
          E2=100*TOE/ANRD
          PRINT 50
50         FORMAT('/2X','TOE',10X,'TAOE',10X,'FS',10X,'SD',
1     10X,'E1',10X,'E2')
          PRINT 60,TOE,TAOE,FS,SD,E1,E2
60         FORMAT(6(5X,F12.3))
          GO TO 10
99         STOP
END
```
APPENDIX E

E.1 Listing of SPSS Procedures Used in the Research.

E.2 Listing of MTC Computer Packages Used in the Research.

E.3 Listing of Other Computer Programs Used in the Research.
E.1 **LISTING OF SPSS* PROCEDURES USED IN THE RESEARCH.**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONDESCRIPTIVE</td>
<td>Provides descriptive statistics for variables such as mean, standard</td>
</tr>
<tr>
<td></td>
<td>deviation, min., max., variance, etc.</td>
</tr>
<tr>
<td>CROSSTABS</td>
<td>Crosstabulate two-way to n-way tables for any discrete variables.</td>
</tr>
<tr>
<td>REGRESSION</td>
<td>Provides either standard multiple regression or stepwise procedures</td>
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<tr>
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<td>in a manner which provides considerable control over the inclusion of the</td>
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<tr>
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<td>independent variables into the regression equation.</td>
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<tr>
<td>SCATTERGRAM</td>
<td>Produces bivariate plots of data where the coordinates of the points</td>
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<tr>
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<td>are the values of the two variables being considered. One variable defines</td>
</tr>
<tr>
<td></td>
<td>the vertical axis and the other defines the horizontal axis.</td>
</tr>
<tr>
<td>PEARSON CORRELATION</td>
<td>Computes Person Product - moment correlations for pairs of variables.</td>
</tr>
</tbody>
</table>

*SPSS* Statistical Package for Social Sciences
### E.2 LISTING OF MTC* COMPUTER PACKAGES USED IN THE RESEARCH

<table>
<thead>
<tr>
<th>Program</th>
<th>Program Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR02031</td>
<td>Conversion of data card of network description from U.T.P.S. format to M.T.C. format</td>
</tr>
<tr>
<td>TR02032</td>
<td>Conversion of network files stored on tape from U.T.P.S. format to M.T.C. format</td>
</tr>
<tr>
<td>TR02123</td>
<td>O/D Survey Record Manipulation</td>
</tr>
<tr>
<td>TR02451</td>
<td>Transit Network Builder Program</td>
</tr>
<tr>
<td>TR02452</td>
<td>Transit Path Builder</td>
</tr>
<tr>
<td>TR02453</td>
<td>Minimum Path Summary Program</td>
</tr>
<tr>
<td>TR02459</td>
<td>Loading the transit network using all-or-nothing assignment</td>
</tr>
<tr>
<td>TR02460</td>
<td>Print the selected reports from the loaded network</td>
</tr>
<tr>
<td>TR02501</td>
<td>Print Trip Table</td>
</tr>
<tr>
<td>TR02506</td>
<td>Road Network Builder Program</td>
</tr>
<tr>
<td>TR02508</td>
<td>Road Path Builder</td>
</tr>
<tr>
<td>TR02509</td>
<td>Skim Tree Builder</td>
</tr>
<tr>
<td>TR02512</td>
<td>Trip Table Modifier</td>
</tr>
<tr>
<td>TR02515</td>
<td>Trip Table Manipulator</td>
</tr>
<tr>
<td>TR03302</td>
<td>Road Network Generation and Assignment</td>
</tr>
<tr>
<td>TR03303</td>
<td>Transit Network Generation and Assignment</td>
</tr>
<tr>
<td>TR03305</td>
<td>Matrix Manipulation</td>
</tr>
</tbody>
</table>

* Ministry of Transportation and Communications of Ontario.
### E.3 LISTING OF OTHER COMPUTER PROGRAMS USED IN THE RESEARCH

<table>
<thead>
<tr>
<th>Program</th>
<th>Program Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEHMOVE</td>
<td>Copy Files from Tapes to Online</td>
</tr>
<tr>
<td>IEHPROGM</td>
<td>Scratch, Rename, Catalogue, or Uncatalogue a Data Set or a Member.</td>
</tr>
<tr>
<td>LBPRINT</td>
<td>Prints IBM Standard Tape Labels on &quot;easy-to-read&quot; Form.</td>
</tr>
<tr>
<td>SDLCOPY</td>
<td>Copy Files from Tape to Another.</td>
</tr>
</tbody>
</table>
END
08 12 80
FIN