THE UNIVERSITY OF MANITOBA

A PROPOSED MODAL CHOICE MODEL FOR URBAN TRANSPORTATION SYSTEMS

by

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ABSTRACT

The purpose of this thesis was to develop a modal choice model and to study the relative importance of the factors affecting modal choice. The model was based upon an extrapolation of Wardrop's, (1952) first principle, which forms the basis of many existing traffic assignment models, to a bimodal choice situation. The model should, in a practical situation, be capable of analysing multiple mode and multiple route transportation systems.

The model was calibrated using data on work trips from the 1971 City of Winnipeg Origin-Destination study. Although the method of calibration and the theoretical analysis leading up to it were found, in later discussion, to be inappropriate, the results of the calibration were good. However, the predictive accuracy of the model remains untested. It was recommended that further work is necessary to properly calibrate the model and to test and refine its methodology and predictive accuracy.

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CHAPTER I

INTRODUCTION

The purpose of this thesis was to develop a proposed modal choice model based upon an analysis of the modal choice behavior of an individual. Using the model developed, an attempt was made to assign relative weights to the factors affecting modal choice.

In recent years it has become obvious that the private car is not necessarily the best solution for urban transportation problems. This, along with an increased desire to use more energy-efficient transportation systems, has resulted in renewed interest in mass public transit. This, in turn, has created a need for reliable models to predict demand for the various modes of transportation, often called modal choice or modal split models. This facilitates the planning, design, and economic analysis of transportation systems. This need has resulted in much research into these kind of models.

Modal choice models use empirical relationships or simulation of the decision process to estimate the demand volumes for each mode, that is the number of people using each mode. Unfortunately, as suggested by Paquette, Ashford, and Wright (1972), p. 329, none of the existing models can be considered reliable for general use in urban transportation planning. It is the objective of this thesis to develop and evaluate a modal choice model, which incorporates a better understanding of the behavior of people in simulating the modal choice decision process.

The model itself is an extension of traffic assignment models based upon Wardrop's first principle - that traffic will settle into an equilibrium state where no individual can reduce his travel time by a change in route - to bimodal transportation systems. Within the financial and time constraints of this thesis, it is not possible to test the predictive accuracy of the model, and only the testing of the assumptions associated with calibration of the model is performed. A method for testing of the model is suggested in Chapter VI.

Outline of Study

Chapter II takes a look at a number of studies of modal choice, value of time and traffic assignment. The importance of each in the development of the model is pointed out.

Chapter III develops the theory for the model. The behavior of an individual is analysed, and is then placed in the context of group behavior. Finally, a basis for numerical analysis and application is proposed.

Chapter IV deals with the numerical analysis. The variables used are described and the results of the calibration are presented.

Chapter V discusses the results of calibration presented in the preceding chapter, the courses of errors in analysis, and the implications of the model on transportation policy.

Chapter VI points out areas which deserve further study and draws conclusions from the material presented in the thesis.

Definitions

In the interest of better understanding it is necessary that a number of terms with special meanings in this thesis be explicitly defined.

Utility - In consumer theory the utility is defined as the satisfaction an individual derives from consuming. Marginal utility is the additional utility derived from the consumption of one unit of a specific good or service. In this thesis the marginal utility will be defined as that utility which is derived intrinsically from a particular travel choice.

This is in some contrast to the definitions of utility used in many other modal choice models, where utility is taken to be some form of cost function. Unless this difference in meaning is understood, confusion could result.

Modal Split - This is the ratio of the number of persons taking a given mode to the total number of persons traveling. Most modal choice models attempt to predict this ratio using probabilistic techniques, then estimate the traffic volumes based on this prediction. The model developed in this thesis is deterministic; rather than probabilistic; and goes directly to the estimate of traffic volumes.

Traffic Assignment - This refers to the techniques whereby the traffic volumes on each link of the road system under consideration are estimated. These techniques are currently restricted to single mode transport systems, although the ideas presented in this thesis could lead to multiple mode traffic assignment models.

Mode - This term refers to the mode of travel, for example: car, bus, walk, etc.

Trip Distribution - Trip distribution refers to the model that is used to determine the number of trips between each origin zone and each destination zone. Modal split models can be applied prior to trip distribution (Pre-distribution), or after trip distribution (Post-distribution).

Link Volume - In describing transportation systems, analysts use graphs made up of links and modes representing streets and intersections. The number of people using a given link is referred to as the link volume.

Origin-Destination Pair (O-D Pair) - This refers to a single origin zone and a single destination zone between which trips can be made.

Captive and Choice Patrons - This phrase comes from the concept that there are two groups of transit users. The captive rider who has no car must use transit, and the choice rider who has a car and uses transit because he finds it better.

In-Vehicle Travel Time - The in-vehicle travel time is the time spent by a traveler in a vehicle, either a car or bus.

Non-Vehicle Travel Time - The non-vehicle travel time is the time spent by a traveler outside a vehicle, for example: walking to or from a bus stop or parking lot.

CHAPTER II

REVIEW OF RELEVANT LITERATURE

Before development of a new model, a review of related work is useful. Three main areas of interest to the author are modal choice models, value of time and traffic assignment. Each area will be discussed separately, although there is a great deal of overlap between the areas.

Modal Split Models

There has been a great deal of research into modal choice models in recent years largely because of the shift in public policy toward low energy systems such as public transit. Existing models were not considered adequate to meet the demands placed upon them in developing transportation plans.

The Roads and Transportation Association of Canada (RTAC) recently published "Report on Urban Modal Split Models" by B.G. Hutchinson et al. A number of new theoretical models are also studied. Since this report is available, an extensive review of these models is not necessary. Only the basic models will be described.

The RTAC report discusses a number of important points regarding modal split models, the most significant of which is that transit ridership is made up of captive and choice patrons. The report makes this point several times and advocates using a modal split model which explicitly treats the two groups separately. This type of model is called a two-stage model. This distinction between the two groups of riders is misleading, and the model to be developed will not explicitly differentiate between the two groups. Considering transit as having a "captive" market may lead to overestimation of transit use if that market is depleted by improved economic status.

A second point made is the concept of disaggregation. This is the idea that models should be based upon the behavior of individuals and not upon the behavior of a group. In the model developed in this thesis, analysis of individual behavior is used to gain an understanding of group behavior, which is then used in development of the model.

The RTAC report breaks the types of modal choice models into four major groups: 1) traditional models, 2) two-stage models, 3) behavioral models and 4) econometric models. A brief description of each follows.

Traditional Models - The traditional modal choice model uses a diversion curve relating percentage of transit users to the ratio of the travel times of alternative modes. A number of curves may be used to account for other factors, such as income or trip purpose. As many as 80 to 160 different curves have been developed for some studies. The main differences between the models include: whether pre or post-distribution; the types of variables accounted for in the diversion curves; and the form in which the variables are used. The RTAC report describes the models used in seven transportation studies done in Canada in recent years.

There has been a great deal of criticism of the traditional models, primarily due to their poor predictive accuracy. The traditional models suffer from an oversimplification of the modeling process. Because of this, more sophisticated models have been developed.

Two-Stage Models - As mentioned above, the two-stage model divides the public into two groups: captive transit, and choice transit riders. The RTAC report looks at a modal choice model developed for the city of Calgary. Two separate models are developed for the two types of rider. The captive transit model is a simple linear regression model. The choice transit model is a diversion curve model.

It would seem that the most important factor affecting the number of captive travelers would be income, i.e., car-buying ability. Since this variable is not explicitly included in the Calgary model, the model may mislead transportation planners into assuming they have a fixed captive market for transit. About twenty to thirty years ago, the "captive" market was quite large. However, increases in income, plus deterioration in transit service relative to other modes have caused this captive market to shrink drastically. There is no reason to believe that the current captive market will remain the same size.

Captive riders are only captive in the short run and poor service, combined with a higher income, can cause a captive rider to shift to car use in spite of the high cost associated with that shift. Once this has happened, the reverse is quite unlikely. Therefore, this type of model is still an oversimplification of the modal choice process.

Behavioral Modal Split Models - The two main features of models in this category are: a) disaggregation and b) the use of the concept of generalized cost. Disaggregation means that a model examines only the behavior of individuals rather than that of groups. This approach has been taken because many researchers felt that disaggregation leads to a better understanding of the aggregate situation.

The concept of generalized cost is also important. The generalized cost, which has also been called utility, or marginal utility, is a linear combination of all factors affecting modal choice. The generalized costs of the modes may be combined in a number of ways to produce an estimated modal split. These methods usually take the form of an estimate of the probability of an individual taking a given mode. This probability is assumed to hold for the aggregated population.

It should be noted that the basic idea of generalized cost is incorporated in the model to be developed in this thesis. However, because of the substantially different nature of the model, a comparison between the two models can be misleading. In this thesis the concept of generalized cost has been superceded by the concepts of marginal utility and travelers expected price, as specifically defined at later points.

A number of models using disaggregation and generalized cost are discussed in the RTAC publication.

Econometric Models - These models are developed using concepts from economic theory. The traditional sequential approach to demand forecasting is replaced by more complex demand and supply interactions. The models developed are unproven in application and much work has yet to be done. The RTAC report describes two models of this type.

In addition to the work reported in the RTAC report there has been a number of other models developed. While most of the models in the RTAC report are exclusively devoted to work trips, some of these other studies deal with other trip types. Some of the more interesting studies are:

Florian and Nguyan,(1977); Richards and Ben-Akiva, (1975), Domencich and McFadden, (1975); Watson, (1974), DeDonnea, (1971); and Heggie, et al., (1976). The models being developed in these studies combine aspects of both the behavioral models and the econometric models. This author suggests that these models still do not adequately model the modal choice decision process. An article by Lovelock, (1975) does provide a proposed decision tree for an individual making a trip decision. While this was interesting, the author contends that another approach would be more fruitful.

None of the traditional models is considered reliable and many of the proposed models are not properly tested or work only in special cases. The form of most models is complex and does not reflect the way in which the various factors affect the decision process.

The bibliography contains a list of publications related to modal choice and modal split models and modeling.

Value of Time

When performing economic analyses of transportation projects, engineers and economic analysts are interested in what monetary value to place upon time savings. Many studies have been done in an attempt to estimate this value. Some of these results can be used in connection with modeling modal choice behavior. The results of some of these studies are included in the study by Domencich and McFadden, (1975). Other sources included: Lee and Dalvi, (1968); Watson, (1974); Guttman, (1975); and McGillivray, (1972).

In general, a value of time is estimated from the study of situations where there is a trade-off between time and cost. This can occur with toll roads and toll bridges, or modal choices. In simple terms, the value is the ratio of money saved (or spent) divided by time lost (or saved). Because the situation may not be a pure exchange, only minimum or maximum values of time may be estimated, although more sophisticated techniques are being studied.

One result of a number of studies is the observation that not all portions of travel time are valued equally. After reviewing literature on the subject, Domencich and McFadden, (1975) conclude that the value of in-vehicle travel time is about 20 to 50 per cent of the wage rate, while non-vehicle travel time is valued at two to three times that of in-vehicle travel time. This wide range of values may be a result of the diversity between the populations considered in each of the studies. However, the fact that in-vehicle travel time and non-vehicle travel time have different values would tend to indicate that when computing the generalized cost equations of a behavioral modal choice model, the factors should be broken down into as many variables as possible, since each may be valued differently. This was attempted in the model developed in this thesis. Some other studies on value of time are listed in the bibliography.

A study by Goodwin, (1976) uses biomedical techniques to measure the value of travel time. Some of the measurements considered were energy expenditure, heart rate and galvanic skin response. The study showed a relationship between heart rate and the value of time. This approach may be useful in further study.

Traffic Assignment

Traffic assignment refers to the estimation of link volumes in a road network. In recent years traffic assignment algorithms have developed to the point where it can be said that they are the only reliable tool available to the transportation planner. Equilibrium trip assignment procedures are based upon the first principle of Wardrop, (1952). This principle states that traffic will settle into an equilibrium state where no individual can reduce his journey time by choosing a new route. A program which estimates this equilibrium state was developed at the University of Montreal by M. Florian and S. Nguyen and subsequently tested on the City of Winnipeg using 1971 data (Florian, Nguyen, 1975). In their publication they stated that "the validity of the method is well established". Testing of this type has been done by Edwards and Robinson, (1977) on the twin cities of Minneapolis-St. Paul using a different assignment method.

These models assume that travelers perceive travel time as the only cost. But in Florian and Nguyen, (1975), it is noted that distance, as well as time, can be considered. Although this is not elaborated upon, it can be seen in the context of the results of value of time studies and behavioral modal split models that, if a more generalized cost (or price) function is used, the equilibrium trip assignment methods might be successfully extended to multimodal systems. The result is a combined modal choice traffic assignment model.

This was attempted by Wigan and Bamford, (1973). However, while the model proposed used the concept of travel cost, it did not consider factors other than in-vehicle travel time and operating cost in estimation the travel cost. This ignores the results of value of time studies. The assumptions that the model was based upon are not explicitly stated or supported by arguments. The model was developed by analogy to traffic assignment models. Further no attempt is made to test the predictive ability of the model or the validity of the assumptions.

It is important that a new model be explicitly developed from assumptions which can be evaluated. The model developed in the next chapter, while similar to the one proposed by Wigan and Bamford, (1973), will incorporate many of the ideas developed in other areas of modal choice research.

CHAPTER III

THEORETICAL ANALYSIS OF MODAL CHOICE BEHAVIOR

This chapter will concern itself with the analysis of the modal choice decision process and the development of a modal choice model from that analysis. The following assumptions are made in developing the model.

1. An individual will choose the travel option which he perceives to be the best.
2. What an individual perceives to be the situation is related to the actual situation.
3. The population of individuals being considered is homogeneous in their perception.
4. The effects of special interests and prejudices among individuals are not significant in the modal choice behavior of the group.
5. There are two aspects to each choice: i) Marginal Utility (MU), which embodies all the positive aspects of travel; and ii) Price (P) or Traveler's Expected Price (TEP), which embodies all the negative aspects of travel.
6. The best option, in assumption 1 above, is defined as that option with the highest MU/TEP ratio.
7. The marginal utility (MU) derived from a trip is independent of the mode or route taken.
8. Travelers in a transportation system will tend to settle into an equilibrium state where no individual can improve his MU/TEP ratio by changing the mode or route he takes.

9. The relationships between TEP and the variables affecting TEP are linear.

These assumptions will be discussed in the three sections of this chapter. The first section models the decision process of an individual making a trip choice. Subsequently, the second section will extend this analysis to behavior of a group. Finally, the third section will look at calibration of the model, which will be analyzed further in later chapters.

The Trip Decision Process of an Individual

The factors affecting an individual's behavior can be broken into two groups: 1) the characteristics of the individual; and 2) the characteristics of the choices available. These shall be looked at separately.

Characteristics of an Individual in Making Trip Decisions - It is very common in development of travel demand models to make the assumption of "rationality". Rationality is often taken to mean that the individual will take the "best" route or mode, where best may be decided upon in terms of travel time or money or, more recently, both.

This definition and assumption can be improved. In this thesis it will be assumed that an individual will choose the option which he perceived to be the best. A further explanation of what is meant by this statement is necessary.

The term perception, here, means the individual's estimation of reality. Because of faulty perception, or occasionally, mental or physical abnormalities, the perceived reality need not bear any resemblance to the real situation. Many models make the assumption of perfect knowledge. But, as just noted, this assumption is very dubious in that it assumes that all persons perceive reality as it is. Indeed, many studies have indicated that persons taking a given mode will tend to overestimate the cost and travel time and underestimate the comfort and service provided by an alternative mode. This may in part be necessary for a self-justification for the choice that was made. Also, it has been noted that many people will avoid using major interchanges in favor of circuitous routes on minor streets which often take much longer. The assumption of perfect knowledge is obviously not valid.

Since the assumption to perfect knowledge has been eliminated, an alternative assumption must be made to replace it. It is therefore assumed that the perceived reality of the individual is a function of the actual reality. This is a much less rigid requirement than the assumption of perfect knowledge and, as a result, fits a much larger proportion of the population, making it much more nearly true. This assumption still allows us to develop a model using observed times and costs.

Several characteristics of individuals are likely to affect the way in which they perceive reality. Primary among these is social or economic positions. This is usually measured in terms of income, but this might be better measured by the employment classification of the tripmaker. A laborer and an executive may have the same income, yet they may not value their time in the same way. Nevertheless, income levels will be used in this study since these values are much easier to obtain.

Other characteristics are the various interests and prejudices of the individual. These are difficult to measure and indeed it may be beyond the mandate of a government, or anyone else, to collect such information in a democratic society. It is likely, however, that the effects of these characteristics among individuals are not significant in the modal choice behavior of the group. This is what will be assumed.

Characteristics of the Choices Available - In the previous section it was stated that an individual will make his decisions based upon what he perceives to be the situation. Therefore, the characteristics of the choices available that are of interest are those which are perceived by the individual. An individual perceives two aspects to every choice situation. These are: a) the utility (or marginal utility); and b) the price. These are in some ways analogous to benefits and costs in economic analysis. The utility (U) or marginal utility (MU) can be seen as the benefit, in terms of money, goods, enjoyment, or status, derived from choosing a particular option. The price (P) can be seen as the cost, in terms of time, money, frustration, and decision costs of choosing the option. This price is often called the generalized cost.

The questions is now "How does an individual combine these two aspects in making a decision?" Would an individual choose the highest MU/P ratio or the highest (U-P) net utility? Many models use the second concept of net utility, often calling it the marginal utility or generalized cost, which indicates that the distinction between price and utility has not been made. This is the problem with the second formulation. The use of the ratio is more reasonable since the two aspects remain distinct. But does this reflect the actual decision mechanism of all individuals? Since it is the most reasonable formulation, it will be assumed that an individual will choose the option with the highest MU/P ratio.

What factors affect the marginal utility and price of a trip? The marginal utility derived from a trip should be about the same for all modes or routes between a given O-D pair. There will be some fluctuation due to individual preferences. However, it was decided to assume that, even if unequal, the relative marginal utilities would be constant with respect to each other and could be treated as equal by adjusting the price. More advanced work could check this assumption.

The price should consist of a weighted summation of all the negative aspects of travel. These are mainly travel times and monetary costs. In traffic assignment algorithms, the equivalent of price is assumed to be total travel time. But it has been shown that people evaluate travel times differently, depending on the classification of travel time; i.e. access time, waiting time, and egress time must all be considered as separate parts of travel time with different valuations by travelers. The actual variables used will be discussed later.

It must be noted that the term 'price' refers to the price, in terms of time, etc., which the traveler expects to pay to make a trip. Hereafter the term Traveler's Expected Price (TEP) will be used to represent this value.

Since an individual cannot anticipate the travel times he will experience on any given day, the decision is made based upon past experience.

Modal Choice Behavior of a Group

The travel choices a particular individual makes are not of any particular interest to transportation planners. The planner is only interested in total numbers of travelers making a given decision. Therefore, it is necessary to extend the analysis of an individual's decision process to that of a group.

It will be assumed that the group under consideration is homogeneous in their evaluation of the factors affecting the price. This assumption is probably not valid for real situations, but this may not be necessary to produce a valid model. If there is a large percentage of travelers who value their time in the same way the results would be an acceptable approximation of the situation where 100 per cent value their time in the same way.

Since an individual will choose the mode or route of travel which has the highest MU/TEP ratio, as assumed in the initial hypothesis, a group of travelers must be assigned to the transportation system in such a way that no individual can improve his MU/TEP ratio by changing the mode or route taken. This is an elaboration of Wardrop's (1952) first principle.

This will hold no matter how much diversity there is in evaluation of time. In the situation that has been assumed, where the evaluation of time is homogeneous, the method of solution is much simpler. Taking a hypothetical example of a single origin-destination pair with two active modes connecting them and a homogeneous population, it can be deduced that the MU/TEP ratio will be the same for each mode. This is the equilibrium state where no individual can increase his MU/TEP ratio by a change of mode.

This model can be described mathematically as a set of equations.

$$MU_i = \mu_i + \sum_{j=1}^{n_i} \beta_{ij} X_{ij} + \varepsilon_i(J) \qquad \text{(Eq. 3.1)}$$

where: $MU_i \equiv$ marginal utility of mode i

$\mu_i \equiv$ utility derived from making a trip

$X_{ij} \equiv$ variable j affecting the marginal utility of mode i

$\beta_{ij} \equiv$ coefficient

$n_i \equiv$ number of factors affecting MU_i

$\varepsilon_i(J) \equiv$ error term

$$TEP_i = \alpha_i + \sum_{k=1}^{m_i} \beta_{ik} X_{ik} + \varepsilon_i(K) \qquad \text{(Eq. 3.2)}$$

where: $TEP_i \equiv$ TEP of mode i

$\alpha_i \equiv$ inherent "price" of mode i

$X_{ik} \equiv$ variable k affecting TEP of mode i

$\beta_{ik} \equiv$ coefficient

$m_i \equiv$ number of factors affecting TEP_i

$\varepsilon_i(K) \equiv$ error term

As noted before TEP is a function of the volume V , of traffic using mode i. It can be written that:

$$\frac{MU_i}{TEP_i} = f_i(V_i) \qquad \text{(Eq. 3.3)}$$

There will be one equation such as Eq. (3.3) for each mode under consideration. In an applied situation an explicit function of V_i may not exist. In the hypothetical case under consideration, we now have two equations with four unknowns (V_1, V_2, $\frac{MU_1}{TEP_1}$, $\frac{MU_1}{TEP_2}$). From the above discussion of the equilibrium situation for a homogeneous population a third equation can be added.

$$\frac{MU_1}{TEP_1} = \frac{MU_2}{TEP_2} = \frac{MU_e}{TEP_e} \quad \text{(Eq. 3.4)}$$

There must also be a equation which constrains the system such that the sum of the traffic volumes on all modes is equal to the total volume.

$$V_1 + V_2 = V_T \quad \text{(Eq. 3.5)}$$

This equation adds another variable (V_T). This variable may be constant or a demand equation may be available.

$$V_T = g(\frac{MU_e}{TEP_e}) \quad \text{(Eq. 3.6)}$$

The solution of these equations gives the equilibrium traffic volumes. A hypothetical example where the marginal utilities are equal, allowing them to be eliminated from consideration, is illustrated in Figure 1. The supply curves are the equivalent of Equation (3.3)

$$\frac{MU_i}{TEP_i} = f_i(V_i) \quad \text{(Eq. 3.3)}$$

A combined supply curve is also shown as it may be used in the graphical solution of the problem. The combined supply curve is obtained by considering the two modes as a single system.

One problem with this model is the assumption of homogeneity of traveler preceptions. Whether or not this assumption will affect the resulting model will be discussed later. A possible method of handling nonhomogeneous populations will be suggested.

In an application of the model an algorithm similar to any of the existing traffic assignment models might be used.

Calibration of the Model

The next two chapters are concerned with performing a calibration of the model developed above. In order to do this a method whereby the coefficient can be estimated must be found. A number of techniques were tried but only two were considered worth describing.

In the previous section it was stated that the MU/TEP ratios of two active modes between an origin-destination pair will be equal with a homogeneous population. If a further assumption is made, that the marginal utilities of the two modes are equal, then it can be seen that the TEP of both modes are equal. Since most, if not all, of the factors affecting the TEP are known or can be estimated, these factors being costs and times, this relationship can be used to estimate the coefficients of the TEP equation (3.2).

$$TEP_i = \alpha_i + \sum_{k=1}^{m_i} \beta_{ik} X_{ik} + \varepsilon_i(K) \qquad \text{(Eq. 3.2)}$$

This relationship can be expressed as

$$TEP_1 = TEP_2 = 0 \qquad \text{(Eq. 3.7)}$$

The values of the variables to be considered can be found for a large number of cases which are believed to fit the requirements of the

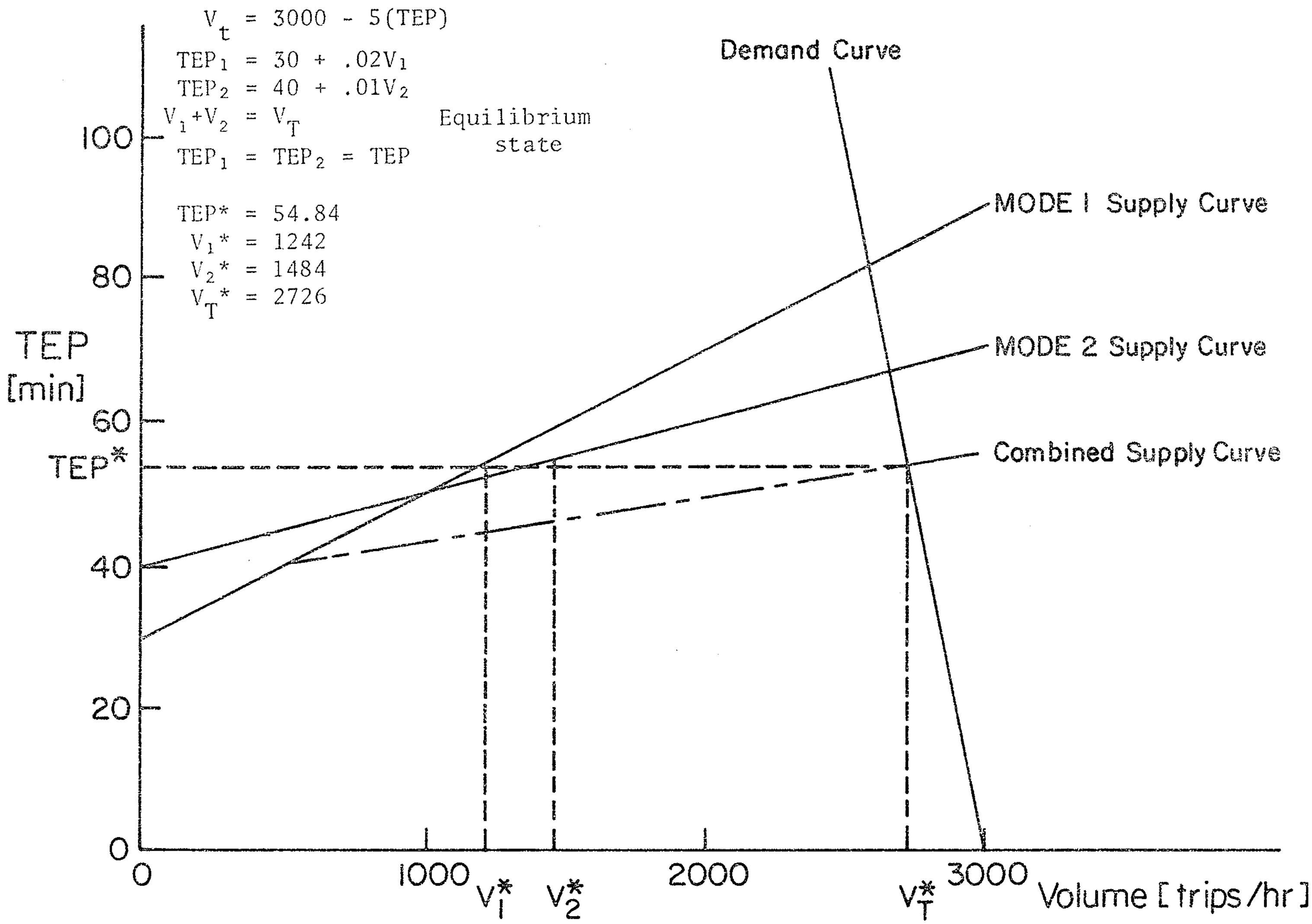

FIGURE 1: EXAMPLE OF MODEL APPLICATION

assumptions, both modes active and population homogeneous. In the next chapter 15 variables are considered with 92 samples. Initially it seems that some simple method should be found which could be used for estimating the coefficients. However it was noted that the set of equations derived from Equation (3.7) were mathematically homogeneous, that is there were an infinite set of solutions. Therefore the tendency of most methods was to settle into a trivial solution where all the coefficients were equal to zero. One attempt to by-pass this was to use a relative difference formula.

$$Z = \sum_{j=1}^{92} \left(\frac{TEP_{1j}-TEP_{2j}}{TEP_{1j}+TEP_{2j}}\right) \qquad \text{(Eq. 3.8)}$$

In this case one of the coefficients was assumed to be 1.00000 and the values of the other coefficients were varied in order to minimize Z. The results from this method were unsatisfactory. Therefore, an alternative method was decided upon.

The method used in the following chapter again started with some initially assumed coefficients adapted from Domencich and McFadden, (1975). Based upon these assumed coefficients the TEP of each mode in each sample was estimated. Then, using the estimated TEP for the one mode as the dependent variable, and the variables for the other mode as independent variables, a linear regression estimate of the coefficients for each mode was made. These derived coefficients were then compared statistically for equality with the coefficients which were assumed. The assumed coefficients were continually adjusted until the hypothesis of equality could be rejected.

This technique, while much more reasonable than the others considered, has several faults, primarily due to the fact that initial values of the coefficients must be assumed, which could lead to some important variables not being considered. The problems associated with the method will be discussed in more detail in a later chapter. The next chapter presents the actual variables considered and the results of the calibration.

CHAPTER IV

CALIBRATION OF MODEL

Data Base

The data used were collected from the City of Winnipeg origin-destination study done in 1971. The city of Winnipeg was Canada's fourth largest urban area in 1971 and is the capital and largest city of Manitoba. The population was slightly in excess of 500,000 people. The 1971 study divided the city into 126 traffic zones, from which 20 origins and 7 destinations were chosen for use in this calibration. (See Figure 2). Out of a potential of 140 interchanges, 92 were found in which both the auto and transit modes were active. In addition, there were 22 interchanges where both the walk mode and the auto mode were active. Although it was initially intended to include the walk mode as part of the study, it was decided that there was no real advantage in including a third mode. Worktrip data only were collected.

After collection of the data, a Fortran program was used to prepare card decks containing all the variables to be considered. A second program calculated the TEP values based upon assumed coefficients. This second program also set up and ran a multiple linear regression program which produced a set of estimated coefficients. (See Appendix for listings).

Variables Considered

Initially it was decided to combine many of the variables. For example, the access times to and from the transportation system were considered in total. This produced undesirable results, since the character-

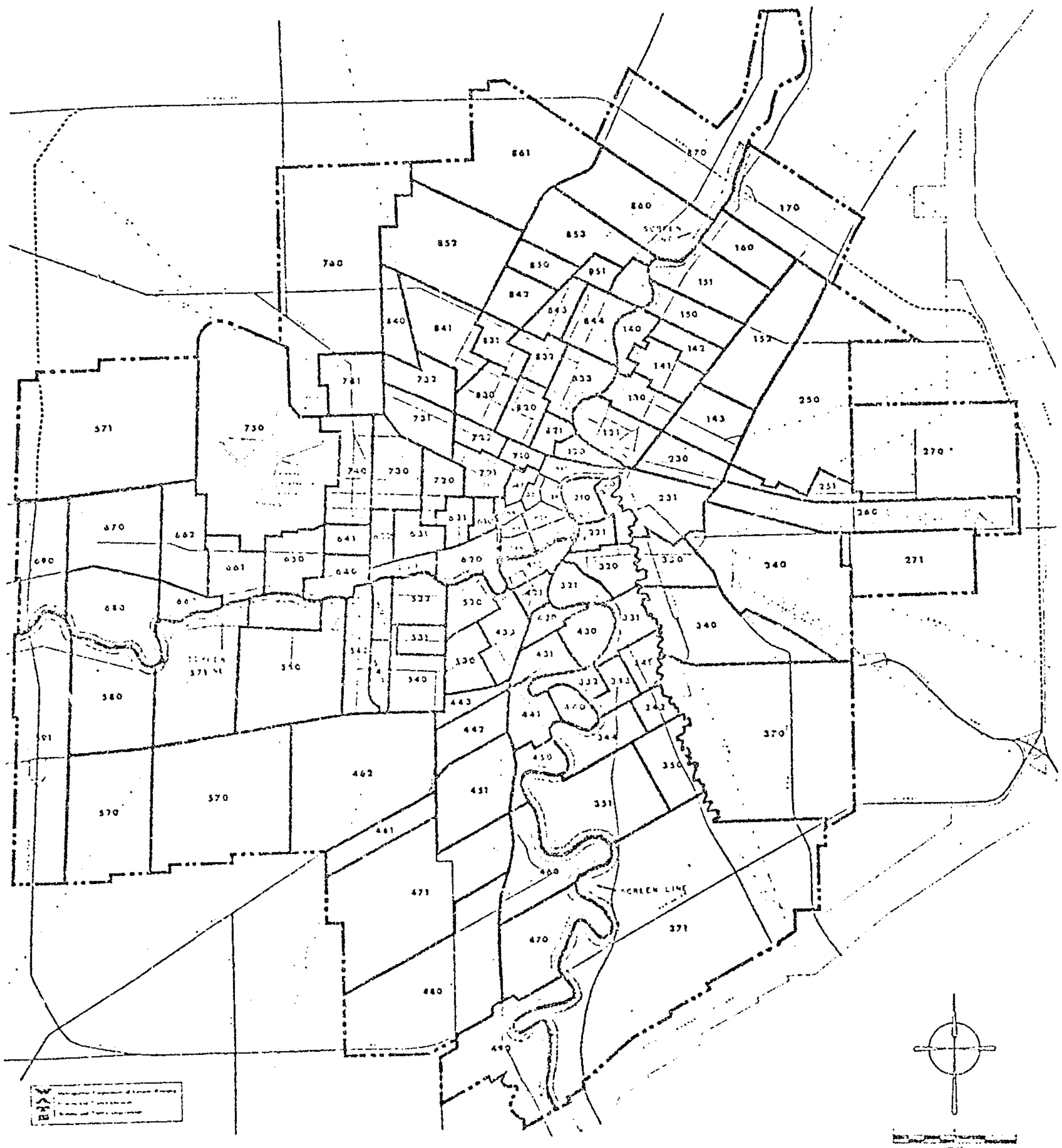

Figure 2. Traffic Zone map of Winnipeg

istics of the variables combined were often quite different. In effect it has been assumed that the coefficients of these variables were the same. In later analysis the uncombined variables were used. Only these uncombined variables will be considered. Table IV-1 lists the variables, their means, and their standard deviations. The variables are defined below:

1. Origin Access Time for Bus (OATB) is the time (in minutes) it takes an individual to walk from his home to the bus stop. It does not include the time spent waiting at the bus stop for the bus.
2. Destination Access Time for Bus (DATB), often called the egress time, is the time (in minutes) spent walking from the bus stop to the individual's destination.
3. Passive Access Time for Bus (PATB) is the time (in minutes) spent waiting for a bus at the origin and at any transfer points. It was estimated to be equal to ¼ of the bus headway, up to a limit of 5 minutes for the origin access, plus ½ of the bus headway at the transfer points.
4. The number of Transfers which must be made during a given bus trip.
5. Travel Time by Bus (TTB) is the total in-vehicle travel time (in minutes).
6. Marginal Cost Divided by Income for Bus (MCIB) is the marginal cost (i.e. the additional monetary payment) which is paid by the traveler, divided by the income of the individual (given in dollars per minute worked) to put the cost in terms of time, in order that the travel and access times can be included with cost. The marginal cost in the case of the bus is the average fare. Based on information regarding fares for 1971 obtained from Jarvis Kohut, the City's Transit Planning

TABLE IV-1 AVERAGE OF VALUES OF VARIABLES CONSIDERED

VARIABLES	NAME	AVERAGE
1	OATB	5.59400
2	DATB	4.77823
3	PATB	2.35684
4	Transfers	0.33696
5	TTB	26.98727
6	MCIB	2.27227
7	OATC	1.59336
8	DATC	1.06021
9	TTC	12.42262
10	CCIC	8.71070
11	CCICPP	6.29123
12	FCIC	3.76388
13	FCICPP	2.84792
14	VCIC	4.09898
15	VCICPP	2.75836

Engineer, an average fare of $0.17459 was obtained. This value was used in all calculations.

7. Origin Access Time for Car (OATC) is the time (in minutes) spent by an auto traveler in reaching the regional street system from his place of origin (i.e., home). It includes walking from the house to the car.

8. Destination Access Time for Car (DATC) is the time (in minutes) spent by the traveler walking from his parked car to his destination, often called the egress time.

9. Travel Time by Car (TTC) is the total in-vehicle travel time by auto.

10. Capital Cost Divided by Income for Car (CCIC) is an estimate of the capital cost of shifting from the bus mode to the auto mode. This is estimated to be the capital cost of a car (assumed to be $1.00 per trip) multiplied by one minus the ratio of cars to people for a given zone. This is then divided by the income (in dollars per person minute) of the traveler to give the variable in terms of time.

11. Capital Cost Divided by Income for Car per Passenger (CCICPP) is variable 10 divided by the observed number of passengers per car for each interchange.

12. Fixed Cost Divided by Income for Car (FCIC) is that portion of the operating cost of an auto which is not affected by trip length. It was assumed to consist solely of the parking cost at the destination. This is divided by income to put the variable in terms of time.

13. Fixed Cost Divided by Income for Car per Passenger (FCICPP) is variable 12 divided by the observed number of passengers per car for each interchange.

14. Variable Cost Divided by Income for Car (VCIC) is the portion of marginal cost of automobile use which is a function of the distance of travel. Based upon calculations from the M.Sc. thesis by K. Rosin, (1972), a value of $0.062 per mile was estimated for 1971. This value was multiplied by the distance of the trip and divided by the income of the traveler to produce the variable used.

15. Variable Cost Divided by Income for Car per Passenger (VCICPP) variable 14 divided by the observed number of passengers per car for each interchange.

Results of Analysis

Two methods are used to analyse the data. Firstly the correlations between all the variables used were estimated and presented in Tables IV-2, IV-3, and IV-4. This gives an indication about how these variables interact. Secondly the results of the calibration procedure are presented with the results of the t-test testing the hypothesis of equality of each of the assumed coefficients and its corresponding derived coefficient. This is given in Table IV-5, along with the multiple correlation coefficients.

Table IV-2 gives the internal correlations between the six transit system variables, Table IV-3 gives the internal correlations between the nine auto system variables, and Table IV-4 gives the correlations between the transit system variables and the auto system variables. These three tables are useful in determining which variables should be considered for further analysis. Each of the selected variables should have high correlations with the variables selected for the other mode and low correlations with variables selected for its own mode.

TABLE IV-2 CORRELATIONS BETWEEN BUS VARIABLES

		1 OATB	2 DATB	3 PATB	4 TRANS.	5 TTB	6 MCIC
1	OATB	1.00000					
2	DATB	.0992535	1.00000				
3	PATB	.0600752	.1888955	1.00000			
4	Trans.	.1565918	.0202908	.7984368	1.00000		
5	TTC	.0229108	-.1055660	.5412370	.5721228	1.00000	
6	MCIC	.3024294	.0620562	-.2570123	-.0635747	-.2548208	1.00000

TABLE IV-3 CORRELATIONS BETWEEN AUTO VARIABLES

		1 OATC	2 DATC	3 TTC	4 CCIC	5 CCICPP	6 FCIC	7 FCICPP	8 VCIC	9 VCICPP
1	OATC	1.00000								
2	DATC	.0637937	1.00000							
3	TTC	.3869891	-.2579331	1.00000						
4	CCIC	-.2414550	.0701108	-.2995710	1.00000					
5	CCICPP	-.1839765	.2385200	-.3323533	.6519231	1.00000				
6	FCIC	-.0999684	-.0608919	-.3792132	.2872847	.3067105	1.00000			
7	FCICPP	-.1134089	-.0195636	-.3166454	.1555619	.5039135	.8757035	1.00000		
8	VCIC	.3231005	-.2500107	.8308104	-.0117150	-.2777222	-.4954774	-.4938846	1.00000	
9	VCICPP	.3864065	-.0703928	.7777048	-.0916304	.0905177	-.3591209	-.2081016	.7558692	1.00000

TABLE IV-4 CORRELATIONS BETWEEN BUS VARIABLES AND AUTO VARIABLES

		1 OATC	2 DATC	3 TTC	4 CCIC	5 CCICPP	6 FCIC	7 FCICPP	8 VCIC	9 VCICPP
1.	OATB	-.0361184	-.0315341	-.0552527	.3771800	.2305833	.0542137	.0004625	-.0611888	-.0637048
2.	DATB	-.0402125	0.0641792	-.0202375	.0721049	.4022188	-.0536634	.0048104	-.1366082	.2766212
3.	PATB	.3444617	-.1456686	.4748337	-.2359578	-.2577285	-.5679383	-.5204399	.4770079	.4076856
4.	Trans	.2260298	-.1906411	.4997645	-.0454507	-.2764997	-.4499520	-.4924819	.5873227	.4134009
5.	TTB	.3961073	-.1838541	.9192125	-.2292191	-.3406457	-.4272683	-.3845701	.8703266	.7458138
6.	MCIB	-.2829307	.0573234	-.3227130	.9893119	.6302962	.3003308	.1506207	-.0188945	-.1111968

TABLE IV-5 COMPARISON OF ASSUMED AND DERIVED COEFFICIENTS

VARIABLE	ASSUMED COEFFICIENT	DERIVED COEFFICIENT	STD. DEVIATION OF ESTIMATE	t-STATISTIC TO TEST EQUALITY	MULTIPLE CORRELATION COEFFICIENT
Transit Constant*	.2569	8.00705	5.29659	1.46323	.92412
DATB	1.68	1.02361	.45651	1.43784	
TTB	1.00	.91810	.04158	1.96970	
MCIB	1.70	.54232	1.14294	1.01290	
Auto Constant*	0.00	4.22528	5.33841	.79149	.92282
DATC	4.35	2.66017	1.69106	.99927	
TTC	2.35	2.14908	.09878	1.93278	
CCIC	0.60	.59291	.21100	.03360	

* This refers to the constant in the TEP functions for the respective modes.

Table IV-5 gives the assumed and derived coefficients, the standard deviation of estimation, and the t-test for equality. The critical t-value for 95% confidence is 1.988 in this case. Using the assumed coefficients the following equations are obtained.

$$TEP(BUS) = 0.2569 + 1.68\ (DATB) + 1.00\ (TTB) + 1.70\ (MCIB) \qquad (Eq.\ 4.1)$$

$$TEP(CAR) = 4.35\ (DATC) + 2.35\ (TTC) + 0.60\ (CCIC) \qquad (Eq.\ 4.2)$$

If the model worked perfectly, the result of a plot of the TEP(car) vs TEP(bus) using these equations and the data collected would approximate a perfect 45° line. Figure 3 shows a plot of the TEP's obtained in this case. This shows how close the statistical solution comes to the assumption.

These equations and coefficients will be discussed in more detail in the following chapter.

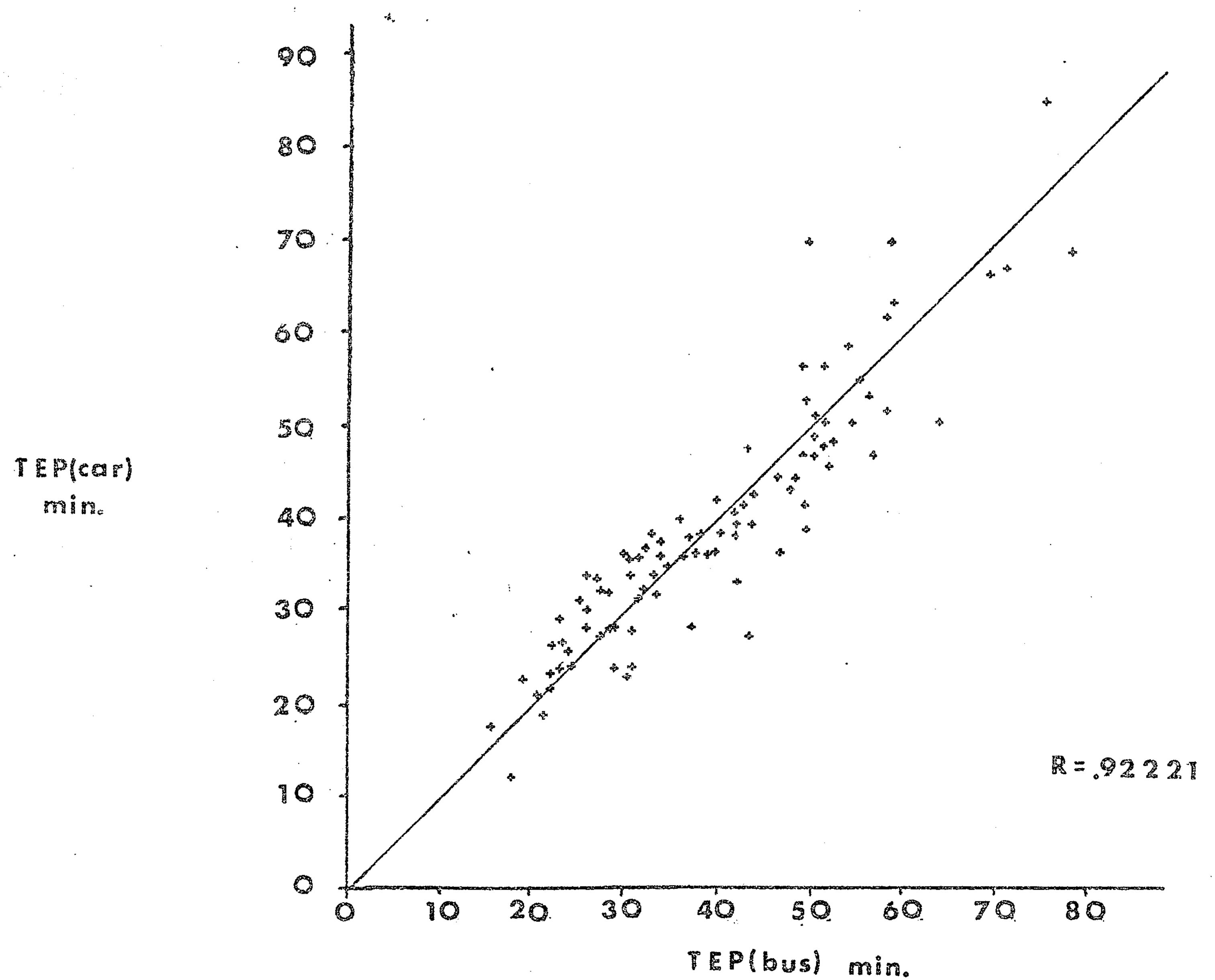

Figure 3: TEP(car) vs TEP(bus)

CHAPTER V

DISCUSSION

The purpose of this chapter is to discuss the calibration results and the important ideas which are brought up in this thesis. The chapter is broken into three sections.

The first section, Calibration Results, will look at the relative importance of the variables as indicated by the results of the analysis. These results are compared with expectations based upon results from other studies and personal observation. Unexpected results are discussed.

The second section, Sources of Errors, looks at the method of calibrating the assumptions in light of the results, and the data used.

The third section, Implications of the Model on Transportation Policy, concentrates on the effects of the model in evaluating policy regarding transit. The primary points here are which variables affect transit demand most and the elasticity of that demand.

Calibration Results

The results of the calibration are given in Table IV-5. A further analysis is given in Table V-1. It should be noted that there are two sets of calibration results, these being the assumed coefficients and the estimated coefficients. The question is which of these two sets should be used in the model.

The calibration procedure used can be seen as a test to see if the set of assumed coefficients is acceptable. If this point of view is accepted, then only the assumed coefficients are of interest. However, the estimated coefficients will also be looked at. In addition, Table

TABLE V-1 ANALYSIS OF CALIBRATION RESULTS

VARIABLE	ASSUMED COEFFICIENT	AVERAGE CONTRIBUTION TO TEP VALUE	STANDARDIZED b	DERIVED COEFFICIENT	AVERAGE CONTRIBUTION TO TEP VALUE	STANDARDIZED b
Constant for* bus	.2569	.00660	-	8.00705	.20580	-
DATB	1.68	.20632	.15088	1.02361	.12571	.09193
TTB	1.00	.69363	1.01768	.91810	.63682	.93433
MCIB	1.70	.09928	.09928	.54232	.03167	.02000
Constant for* car	0.00	0.00000	-	4.22528	.10860	-
DATC	4.35	.11854	.10931	2.66017	.07249	.06685
TTC	2.35	.75032	1.05698	2.14908	.68617	.96661
CCIC	0.60	.13433	.12237	.59291	.13274	.12092

* This refers to the constant in the TEP functions for the respective modes.

IV-5 gives the 95% confidence intervals for the coefficients. This gives an indication of the range of values that each coefficient may have.

Table V-1 gives the coefficients, both assumed and estimated, along with the average proportion of contribution to the TEP and the standardized b. These two measurements give an indication of the importance of each of the variables in the equation. These show that in all cases the most important variable is the travel time (TTB or TTC). In the case of the bus equation the next most important variables is the egress time (DATB). This is followed by the cost variable (MCIB). In the case of the car equation, the second variable is the capital cost (CCIC) followed by the egress time (DATC). In addition, there are the constants. In the set of assumed coefficients the constants are zero or very nearly zero, about one half of one per cent of the TEP. In the case of the estimated coefficients the constants account for about 10 per cent and 20 per cent of the average TEP's for car and bus respectively. While this is quite large, the major portion of the TEP is explained by the variables.

How do the results obtained here compare with the values of time obtained in other studies? Based upon the discussion of this topic in Domencich and McFadden, (1975), it was expected that the coefficients for the travel time (TTB, TTC) would be 20 to 50 per cent of the coefficient for the cost factor (MCIB, CCIC), and the coefficient of the access time (DATB, DATC) would be two to three times the travel time coefficient. The assumed coefficients fit the expected values fairly well, except for the CCIC coefficient. The estimated coefficients do not fit as well.

Based upon personal experience, it was also expected that several of the other variables considered should be in the equations, for example:

OATB, OATC, and PATB. These did not enter the equations; a coefficient of zero is assumed.

How might these deviations be explained? The easiest explanation is that these expectations are wrong. In the case of the access times at the origin (OATB, OATC), this may be true. A study by Lisco, (1967) cited by Domencich and McFadden, (1975) may indicate that the origin access time may in fact have a zero coefficient. In the case of the capital cost (CCIC) coefficient, the low value may be a result of a overestimation of the capital cost per trip. An individual may not assign all of the capital cost toward the work trip, but may assign a portion to other trips or status. Although, as can be inferred from the above discussion, the methodology and the analysis upon which it is based are somewhat inappropriate; the results of the calibration are good. This indicates that the model as a whole is strong enough to survive the problems discussed.

Sources of Errors

There are three main areas which may cause errors in the resulting calibration. These are: the method of calibration, the assumptions made in developing the model, and the data used in the calibration.

1) The Method of Calibration

The method of calibration was chosen largely because no other method investigated was considered to be as reasonable. Only two of several methods considered are described in this thesis. This does not, however, mean that this method is the correct or best method for calibrating the model under consideration.

There are two major problems encountered in the model. The first major problem is that initially a set of coefficients must be assumed. If these coefficients are too far from the real values, then it may be impossible to achieve a reasonable estimate. Because the coefficients are assumed, there is a potential for bias introduced by the analyst. This can result in important variables not being considered.

The second problem is in the use of linear regression. Linear regression uses the least squares method of finding the best fitting line. Because of the inherent limitations of the statistical techniques used, the relationships between two variables may differ, depending upon which is used as the dependent variable. This is true of the case in question, where two groups of variables are considered. The tendency is to produce constants which are too large.

These two considerations make it difficult to accept the results of the method.

2) The Assumptions Made in Developing the Model

The procedure did not allow for the testing of all the assumptions. Of those tested, only one, the third assumption, was found to be inappropriate. The second, seventh and ninth assumptions, for various reasons, were considered questionable, although their continued use cannot be ruled out. Each assumption will be discussed.

The first assumption was that an individual will choose the travel option which he perceives to be the best. This assumption is self evident. However, problems can arise when the "best option" is being defined. This is covered in a separate assumption. An option is defined as a course of action open to the decision maker.

The second assumption was that what an individual perceives to be the situation is related to the actual situation. This assumption is questionable. Although it may be valid for a large portion of the population, it does not hold for many people. There is a fair degree of "irrational" behavior observed among travelers. This can be interpreted as invalidating the first assumption above. It is more reasonable, however, to define this "irrationality" as being the result of a poor relationship between the perceived and actual situation. There is not sufficient proof to invalidate this assumption, since planners are not interested in the behavior of a small group which may radically deviate from the major portion of the population. It may be necessary to modify this assumption if this group is sufficiently large. This would have to be studied further.

The seventh assumption was that the marginal utility derived from a trip is independent of the mode or route taken. It is obvious that a person may well derive more utility from one mode than from another. However, it is possible that this problem can be handled by adjusting the TEP functions.

The ninth assumption was that the relationship between the TEP and the variables affecting the TEP are linear. This assumption is questionable and further study should look at both linear and nonlinear TEP functions.

The third assumption was that the population of individuals

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being considered is homogeneous in their perceptions. This is the key assumption that the method of calibration is based upon. Sharma, (1978) shows that, for residential location, there is significant differences in the evaluation of travel time for different income groups. The third assumption is inappropriate in light of these differences. Therefore, data used should be stratified socioeconomically. In the mathematical model the third assumption is expressed in Equation (3.4).

$$\frac{MU_1}{TEP_1} = \frac{MU_2}{TEP_2} = \frac{MU_e}{TEP_e} \qquad \text{(Eq. 3.4)}$$

This equation, which also incorporates the eighth assumption, can no longer be used. Therefore a more appropriate mathematical formulation, incorporating the eighth assumption, as well as the socio-economic stratification is required to replace Equation 3.4.

The remainder of the assumptions are insufficiently tested.

The fourth assumption states that the effects of special interests and prejudices among individuals are not significant in the modal choice behavior of a group. Although the more recent trip distribution models do include a factor to account for such effects, it is not known whether these effects are significant in the choice of mode. The special interests and prejudices are virtually impossible to quantify, except by empirical study of their effects. In this study these effects are difficult to separate from the effects of group perceptions. After the predictive ability of the model has been tested and validated, as suggested in Chapter VI, it may be necessary to modify this assumption in order that the model will better fit the observed situation.

The fifth assumption defines the concepts of Marginal Utility (MU) and Traveler's Expected Price (TEP. Further research is necessary before the validity and usefulness of this assumption can be tested.

The sixth assumption defines the best option in assumption 1, which stated that an individual will choose the option with the highest MU/TEP ratio. Further research, such as is described in Chapter VI, is necessary before the validity of this assumption can be tested.

The eighth assumption states that travelers in a transportation system will tend to settle into an equilibrium state where no individual can improve his MU/TEP ratio by changing the mode or route he takes.

This assumption is an elaboration of Wardrop's first principle (Wardrop, 1952), traffic will tend to settle into an equilibrium state where no individual in a road network can decrease his travel time by any change in route. While this principle has been proven in practice (Florian and Nguyan, 1975), the modification made here must be tested further, as described in Chapter VI.

3) Data Used in Calibration

The last area of potential errors is in the data collected. The data obtained from the City of Winnipeg are considered to have inherent error of about 10 percent. In addition to this, the data used were chosen because it was believed that the assumption of homogeneity and the resulting equality of TEP were valid. It does not seem likely that the data as a whole fit these conditions. Indeed, only a small percentage of persons need have a different evaluation of time in order to invalidate the data used.

Implications of the Model in Transportation Policy

The point of interest in trying to develop a modal choice model is the formulation of policies to encourage transit ridership. Planners would like to know if and how transit ridership can be increased, especially by attracting travelers away from the auto mode.

It must be remembered that when considering the relative importance of the variables it is the coefficient, rather than the relative contribution to TEP or the standardized b, that must be looked at. In developing policy, planners are interested in the tradeoffs between two factors and this is determined by the coefficients. For example, a one-minute decrease in DATB has a greater effect than a one-minute reduction in TTB, thus making DATB a more important factor.

The most common method of attracting transit riders is to reduce the travel time, often at the expense of increased cost or access time. Based upon value of time studies and the results obtained in this thesis, it can be seen that these two factors are valued more highly than travel time. More extensive study is necessary to determine if the reduction in travel time is offset by the increase in the other factors.

The inclusion of the capital cost per car (CCIC) shows that the cost of shifting from a "captive" transit user to an auto user is significant. This is also a "one way" cost encountered only by persons shifting from bus to car. This means that, once a person has shifted the TEP of traveling by auto is substantially reduced, thus making a shift in the opposite direction less likely. The importance of the capital cost can be seen in Table IV-4.

The demand for transit has been considered to be inelastic. This is discussed in Baum, (1973). However, if the elasticity is looked at in terms of TEP, rather than fare (or MCIB) it can be seen that the demand is much more elastic than previously thought. Thus, a relatively small rise in the TEP function can result in a substantial shift away from the transit mode. Since, as noted before, the shift from bus to car reduces the TEP by eliminating the capital cost (about 13 per cent of the TEP), these shifted travelers are unlikely to shift back unless there is a large reduction in the transit TEP. However, once the TEP for transit has eliminated the effect of the capital cost, then dramatic shifts in the modal split are possible.

If the relationship of the TEP for transit to the volume of transit users is studied, it can be seen that it is relatively insensitive to volume changes. This would result in an elastic demand for transit, since a small change in TEP would cause a large change in volume.

CHAPTER VI

CONCLUSIONS AND FURTHER RESEARCH

This chapter draws conclusions regarding the results obtained in the thesis and summarizes the potentials for further research engendered by the model proposed.

Conclusions

There are a number of conclusions which can be drawn from the results and discussion in this thesis. The modal choice model and the assumptions it is based on are examined first. Then a number of important points derived from the study are discussed.

The predictive ability of the model remains untested, so no conclusion regarding the overall validity of the model can be made. However, it can be said that the model is a significant advance over the model proposed by Wigan and Bamford, (1973). This is a result of the more explicit nature of the model development and the stronger theoretical foundation that resulted from this. The concepts of marginal utility (MU) and traveler's expected price (TEP) provide for more flexibility in the model, allowing a wider range of situations to fit the model. The testing of some of the assumptions provides information which will allow further model improvements to be made.

Of the nine assumptions which form the basis of the model, one was found to be inappropriate, and three are considered useful, but questionable. The remainder of the assumptions, except for the self-evident first assumption, remain untested, although they are reasonable.

The third assumption, that the population under consideration was homogeneous in its perceptions, was found to be inappropriate. A calibration technique which does not rely on this assumption must be developed before further work can be done.

The three questionable assumptions were: the second, which assumed that the situation perceived by an individual is related to the actual situation; the seventh, which assumed that the marginal utility (MU) was independent of the mode or route taken; and the ninth, which assumed that all the relationships between the traveler's expected price (TEP) and the variables affecting TEP were linear. The model as a whole remains unproven, although some modification is needed. Further research should continue to use these assumptions but the investigator must be ready to modify or eliminate them.

In addition, there are two points which are important to transportation policy which are brought out in discussion of the model. The first concerns the importance of the capital cost of buying a car. Many existing models ignore the capital cost, and concentrate on the maintenance cost of running a car. The effect of the capital cost is to place a barrier between transit and auto, which is removed once an individual has shifted from transit to auto, thus making the reserve shift less likely.

The second point concerns the elasticity of transit demand. This demand has long been considered to be inelastic. Looking at the demand for transit in terms of the model developed shows that the demand is elastic. This is important in that it indicates that large shifts in the model split are possible.

The calibration results indicate that travel time is more heavily weighted by car users than by transit users. Also, access times for both modes are weighted more heavily than actual travel times.

Since the calibration results compare favorably with results given by Domencich and McFadden, (1975), it can be concluded that further research in this direction is justified.

Further Research

There are two major opportunities for further research. The first and most important is the development of an adequate calibration process. This was attempted in this thesis, but the results are not considered adequate. The other opportunity is to validate the model and prepare it for practical application. The calibration technique used must be acceptable before any attempt at validation is made.

The method of calibration used in this thesis is awkward and time consuming. In addition, there are serious doubts as to its validity. Several alternative methods were considered, but none seemed as good as the one used. This did not, however, exhaust all possible avenues of research and it is reasonable to expect that a more reliable calibration technique can be developed.

Once an acceptable technique has been developed, a further attempt to calibrate the model should be made. When performing this, some changes in the data collected should be made. Because it has been shown that different groups may evaluate time differently, calibrating the model separately for each group should be considered. A number of possible grouping could be based upon: income, type of employment, location within the city, and ethnic background. Which groups should be used may be decided by analysing the effect of the groups considered upon the difference between the estimated TEP's for auto and transit modes.

In addition, the variables used should be reconsidered. The variables should be expressed in the forms in which they are likely to be perceived by the traveler. Combining variables should be avoided. For example, it might be thought that the access times should be combined (OATB + DATB), but this is making the assumption that the coefficients of these two variables are the same, and there is no reason to expect that this is true.

In their publication "An Application and Validation of Equilibrium Trip Assignment Methods", Florian and Nguyan, (1975) state, "It is clear that most efficient and internally coherent algorithm for traffic assignment would be worthless if the resulting flows bear no resemblance to the actual observed flows". This statement is true of any model.

In this case a computer program should be developed which would implement the model. Then information on network characteristics, trip origins and destinations and other factors used in the model would be collected for a sample city. The information would be processed and fed into the computer program in order to predict flows of travelers. This prediction would be compared with observed flows to test the validity of the model and program.

The computer program itself would be similar to any number of existing trip assignment programs. A good example of the type of program that could be developed is what is called an incremental assignment program. In this type of algorithm, the minimum travel time path between each zone is found, and then a small fixed percentage of total trips is assigned to that path. New travel times are then calculated and new minimum travel time paths are found. Again a small fixed percentage of total trips are assigned to these paths. This process is continued until 100 per cent of trips have been assigned. This algorithm can be modified to handle a multimodal system by replacing the travel times used in calculating the minimum paths with the expression TEP/MU. A flow chart for such a model is shown in Figure 4.

However, a paper by Ferland, Florian, and Achim, (1975) shows that incremental assignment algorithms do not produce the equilibrium state desired. An alternative assignment algorithms proposed by Nguyan, (1974). This algorithm should also be investigated before developing a program. The Nguyan algorithm has been validated by Florian and Nguyan, (1975) for the City of Winnipeg. Once a program similar to the one described above has been written, it should be tested with one or more cities to verify that the model can produce adequate predictions.

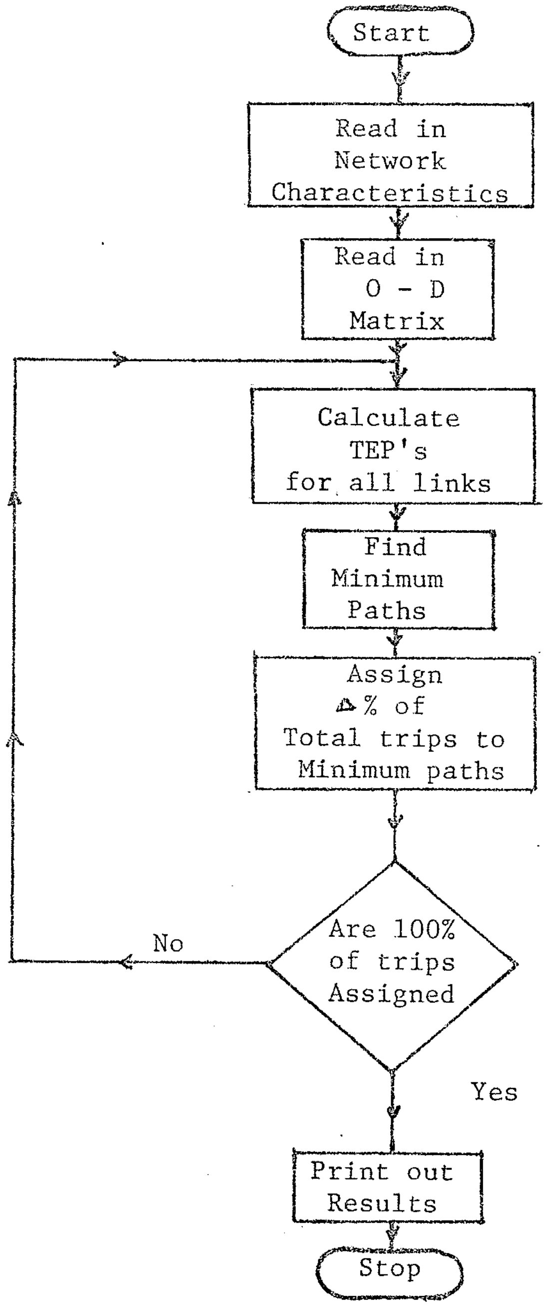

FIGURE 4. PROPOSED MULTIPLE MODE TRIP ASSIGNMENT ALGORITHM FLOWCHART

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APPENDIX

Program 1: Prepares Data for Further Analysis

```
      DIMENSION  X(16,120),XII(20),FCC(7),J(3,120),AT(7),PR(20),RCA(20)
     &,RCB(7),A(17)
     &DATC(20),OATC(7),DATB(20),OATB(7)
     &,CPT(20)
      REAL MCB,MCC,MCIC,MCIB
      MCB=0.17459
      CPMC=0.062
      READ104,(X(5,N),N=1,114)
  104 FORMAT(16F5.2)
      READ106,(X(12,N),N=1,114)
  106 FORMAT(80F1.0/34F1.0)
       READ,  (CPT(K),K=1,20)
      READ,(DATC(K),K=1,20)
      READ,(OATC(K),K=1,7)
      READ,(DATB(K),K=1,20)
      READ,(OATB(K),K=1,7)
      READ,(RCA(N1),N1=1,20)
      READ,(RCB(N2),N2=1,7),EXP
      READ,(XII(JJ),JJ=1,20)
      READ,(FCC(K),K=1,7)
      READ,(PR(N4),N4=1,20)
      READ,(AT(N3),N3=1,7)
      PRINT 25
   25 FORMAT ('1INCOMES BY ZONE (IN $/MIN.)')
      DO 50 L=1,20
      XII(L)=XII(L)/124800
   50 PRINT60,L,XII(L),RCA(L),PR(L),DATC(L),DATB(L),CPT(L)
   60 FORMAT('   ZONE=',I6,'   INCOME =',F9.4,'  % WHITE COL =',F
     &9.5,'    TRIP PROD.   =',F7.0,'    DATC=',F7.2,'    DATB =',F7.2,
     &'  CPT =',F8.5)
      PRINT 70
   70 FORMAT ('1PARKING COSTS AT DESTINATIONS (IN $/TRIP)')
      DO 80 N=1,7
   80 PRINT90,N,FCC(N),RCB(N),AT(N),OATC(N),OATB(N)
   90 FORMAT('  ZONE =',I6,'   PARKING COST=',F7.3,'     % WHITE COL =',F9.5
     &,'     TRIPS ATT. =',F7.0,'    OATC =',F7.2,'    OATB=',F7.2)
      PRINT 100
  100 FORMAT ('1  NC   IO   IA   JD   IB    K  AATC  AATB  PATB   TTC    TTB
     &  DC     PPC    MCC   MCIC   MCIB    TTW  TC   TB  TW        RC1          RB1')
      DO 500 I=1,120
      READ 200,NC,IO,JD,K,AATC,AATB,PATB,TTC,TTB,DC,PPC,IA,IB,
     &TC,TB,TW
  200 FORMAT(3I4,I2,3F5.2,4F6.2,I4,I3,3F4.0)
      IF (NC.EQ.9999)GOTO 650
      MCC=(FCC(IB)+CPMC*DC)
      MCIC=MCC/XII(IA)
      IF(K.EQ.2)J(3,I)=0
      IF(K.EQ.2)GOTO 500
      MCIB=MCB/XII(IA)
      XIN=XII(IB)*124800.0
      TTW=20.0*DC
      J(2,I)=IB
      J(1,I)=IA
      J(3,I)=NC
      X(1,I)=DATB(IA)
      X(2,I)=OATB(IB)
      X(5,I)=DATB(IA)+OATB(IB)
      X(3,I)=X(5,I)
      X(4,I)=X(12,I)
      X(5,I)=TTB
      X(6,I)=MCIB
      X(7,I)=DATC(IA)
      X(8,I)=OATC(IB)
      X(9,I)=TTC
      X(10,I)=(1.0-CPT(IA))/XII(IA)


      X(11,I)=X(10,I)/PPC
      X(12,I)       =FCC(IB)/XII(IA)
      X(13,I)=X(12,I)/PPC
        X(14,I)=CPMC*DC/XII(IA)
      X(15,I)=X(14,I)/PPC
      X(16,I)=X(14,I)+X(15,I)
      RC1=X(15,I)
      RB1=X(14,I)
  300 PRINT 400,NC,IO,IA,JD,IB,K,AATC,AATB,PATB,TTC,TTB,DC,PPC,MCC,MCIC,
     &MCIB,TTW,TC,TB,TW,RC1,RB1
  400 FORMAT (' ',6I4,11F6.2,3F4.0,2F9.1)
  500 CONTINUE
  650 NST=I-1
  700 PRINT800,(I,I=1,16)
  800 FORMAT('1',I4,15I6,'     O     D    NC')
      DO 1100 M=1,NST
      IF(J(3,M).EQ.0)GOTO 1100
      PRINT 900,(X(I,M),I=1,16),(J(I,M),I=1,3)
  900 FORMAT(' ',16F6.2,3I5)
      PUNCH1000,(X(I,M),I=1,16),(J(I,M),I=1,3)
 1000 FORMAT(2F4.2,F5.2,F2.0,2F5.2,2F4.2,8F5.2,2I2,I3)
 1100 CONTINUE
      STOP
      END

$ENTRY
```

Program 2: Calculates TEP's and sets up Linear Regression

```
$JOB
      DIMENSION  X(18),A(18)
      CHARACTER*80  CARD
      READ 675, CARD
      WRITE(7,675) CARD
      READ 675, CARD
      WRITE(7,675) CARD
      READ,(A(I),I=1,17)
      PRINT20,(I,A(I),I=1,17)
   20 FORMAT('1 VALUE OF A''S ASSUMED'/17(/'   A(',I2,')=',F11.5))
      PRINT50,(J,J=1,18)
   50  FORMAT('1',I3,17I6)
      DO 100 I=1,92
      READ150,(X(J),J=1,15),KC
  150 FORMAT(2F4.2,F5.2,F2.0,2F5.2,2F4.2,7F5.2,5X,I2)
      X(16)=X(15)+X(13)
      X(17)=A(1)+A(2)*X(1)+A(3)*X(2)+A(4)*X(3)+A(5)*X(4)+A(6)*X(5)
     &+A(7)*X(6)
      X(18)=A(8)+A(9)*X(7)+A(10)*X(8)+A(11)*X(9)+A(12)*X(10)
      PRINT 200,(X(J),J=1,18)
  200  FORMAT(13F6.1)
  100  PUNCH250,(X(J),J=1,18)
  250  FORMAT(9F8.3/9F8.3)
      READ725,N1
  725 FORMAT(I5)
      DO 750  JJJ=1,N1
      READ 675 , CARD
  750 WRITE(7,675) CARD
  675 FORMAT(A80)
      STOP
      END
$ENTRY
```

Variables used for Auto mode

Sample No.	O.	D.	OATC	DATC	TTC	CCIC	CCIC PP	FCIC	FCIC PP	VCIC	VCIC PP
NC	10	JD	7	8	9	10	11	12	13	14	15
1	121	20	1.56	1.08	5.45	11.24	2.25	7.71	1.54	1.95	0.39
3	121	21	1.56	1.08	6.34	11.24	7.76	5.14	3.52	2.06	1.41
4	121	25	1.56	0.96	7.68	11.24	6.73	7.33	4.39	2.37	1.42
5	121	460	1.56	0.84	18.69	11.24	5.16	1.52	0.70	8.97	4.12
7	121	841	1.56	2.13	9.96	11.24	11.24	1.65	1.65	3.17	3.17
8	141	20	1.89	1.08	4.05	8.14	5.42	5.91	3.94	2.23	1.45
9	141	21	1.89	1.08	8.94	8.14	8.14	3.94	3.94	2.31	2.31
10	141	25	1.89	0.96	10.28	8.14	6.56	5.62	4.53	2.54	2.05
11	141	460	1.89	0.84	22.94	8.14	3.43	1.16	0.49	12.43	5.25
12	150	20	2.44	1.08	9.09	8.13	5.35	6.10	4.01	2.82	1.60
13	150	21	2.44	1.08	9.98	8.13	7.46	4.07	3.73	2.91	2.67
14	150	25	2.44	0.96	11.32	8.13	6.11	5.81	4.37	3.16	2.37
15	150	400	2.44	0.84	25.04	8.13	2.95	1.20	0.44	12.96	4.70
16	270	20	2.72	1.08	17.42	9.26	6.71	6.35	4.60	5.91	4.28
17	270	21	2.72	1.08	18.31	9.26	6.66	4.24	3.05	6.00	4.52
19	270	25	2.72	0.96	19.65	9.26	7.18	6.05	4.69	6.26	4.65
20	270	260	2.72	2.48	3.00	9.26	7.01	1.36	1.03	0.78	0.59
22	270	460	2.72	0.84	25.47	9.26	4.72	1.25	0.64	14.59	7.44
23	270	740	2.72	0.80	32.63	9.26	8.34	1.36	1.22	9.50	8.56
24	270	841	2.72	2.13	45.48	9.26	9.26	1.36	1.30	7.46	7.45
25	320	20	1.47	1.08	7.18	10.69	5.35	7.49	3.75	1.92	0.96
26	320	21	1.47	1.08	6.54	10.69	8.50	5.00	4.00	1.81	1.45
28	320	25	1.47	0.96	4.92	10.69	6.04	7.13	4.03	1.57	0.89
29	320	400	1.47	0.84	15.64	10.69	3.86	1.48	0.53	10.36	3.74
30	340	20	2.74	1.08	12.18	6.83	6.44	5.05	4.77	2.66	2.51
31	340	21	2.74	1.08	11.54	6.83	4.32	3.37	2.13	2.59	1.64
32	340	25	2.74	0.96	9.92	6.83	5.33	4.81	3.76	2.42	1.89
33	340	400	2.74	0.84	14.40	6.83	2.63	1.00	0.38	7.34	2.82
34	340	740	2.74	0.80	27.04	6.83	6.83	1.08	1.08	7.34	7.34
35	344	20	1.46	1.08	14.59	7.47	5.88	5.57	4.39	3.80	2.99
36	344	21	1.46	1.08	13.70	7.47	5.70	3.71	2.84	3.61	2.75
37	344	25	1.46	0.96	11.85	7.47	7.47	5.30	5.30	3.30	3.30
39	410	20	0.67	1.08	6.34	9.00	9.00	6.80	6.80	1.54	1.54
41	410	21	0.67	1.08	5.45	9.00	6.34	4.53	3.19	1.31	0.92
43	410	25	0.67	0.96	3.60	9.00	6.00	6.47	4.31	0.94	0.62
45	410	460	0.67	0.84	10.96	9.00	3.86	1.34	0.57	4.94	2.12
46	410	740	0.67	0.80	13.04	9.00	8.04	1.45	1.30	4.85	4.33
47	430	21	1.52	1.08	10.29	8.22	8.22	4.05	4.05	2.21	2.21
48	430	400	1.52	0.84	10.76	8.22	3.33	1.20	0.49	3.95	1.60
49	470	20	2.28	1.08	17.62	6.49	4.92	5.05	3.83	5.44	4.12
50	470	21	2.28	1.08	16.73	6.49	4.92	3.37	2.55	5.28	4.00
51	470	25	2.28	0.96	14.88	6.49	6.49	4.81	4.61	4.98	4.98
52	470	460	2.28	0.84	1.88	6.49	3.89	1.00	0.60	0.99	0.59
54	441	20	1.05	1.08	12.37	5.33	5.33	4.62	4.62	2.75	2.75
55	441	21	1.05	1.08	11.48	5.33	5.33	3.08	3.08	2.60	2.60
56	441	25	1.05	0.96	9.63	5.33	5.33	4.40	4.40	2.34	2.34
57	441	460	1.05	0.84	6.10	5.33	1.92	0.91	0.33	1.86	0.67
58	441	740	1.05	2.13	18.46	5.33	5.33	0.99	0.99	5.18	5.18
59	532	20	1.04	1.08	14.01	4.32	4.32	3.63	3.83	2.24	2.24
60	532	21	1.04	1.08	13.12	4.32	3.76	2.55	2.22	2.26	1.96
61	532	25	1.04	0.96	11.27	4.32	3.86	3.65	3.25	1.90	1.69
62	532	400	1.04	0.84	12.58	4.32	1.81	0.76	0.32	3.03	1.27
65	580	20	1.40	1.08	23.53	6.52	4.35	5.22	3.48	6.51	4.34
66	580	460	1.40	0.84	16.74	6.52	1.37	1.03	0.22	7.61	1.60
67	620	20	1.37	1.08	6.86	13.12	8.75	8.20	5.47	1.90	1.26
69	620	21	1.37	1.08	6.07	13.12	9.44	5.47	3.93	1.69	1.22
71	620	25	1.37	0.96	5.09	13.12	4.64	7.80	2.76	1.53	0.54
73	620	400	1.37	0.84	12.55	13.12	6.63	1.62	0.82	6.58	3.32
75	620	740	1.37	0.80	11.46	13.12	10.93	1.75	1.46	4.44	3.70
76	640	20	0.68	1.08	11.89	8.44	5.31	6.28	3.95	3.04	1.91
77	640	21	0.68	1.08	11.10	8.44	8.44	4.19	4.19	2.89	2.89
78	640	25	0.68	0.96	10.12	8.44	8.44	5.98	5.98	2.77	2.77
80	640	460	0.68	0.84	13.20	8.44	3.68	1.24	0.54	5.04	2.20
81	640	740	0.68	0.80	6.14	8.44	6.81	1.34	1.08	3.40	2.74
83	661	20	1.60	1.08	15.45	7.34	7.34	5.65	5.65	4.00	4.00
84	661	21	1.60	1.08	14.66	7.34	5.21	3.77	2.67	3.86	2.74
85	661	25	1.60	0.96	13.68	7.34	5.78	5.38	4.24	3.74	2.94
86	661	400	1.60	0.84	17.79	7.34	2.88	1.11	0.44	8.05	3.16
87	661	740	1.60	0.80	8.32	7.34	5.69	1.21	0.94	2.41	1.87
89	670	20	1.94	1.08	19.06	6.96	6.96	5.31	5.31	5.00	5.00
90	670	21	1.94	1.08	18.27	6.96	6.22	3.54	3.16	4.87	4.35
91	670	25	1.94	0.96	17.28	6.96	5.85	5.05	4.25	4.77	4.01
92	670	460	1.94	0.84	21.40	6.96	3.05	1.05	0.46	8.92	3.91
93	670	740	1.94	0.80	12.64	6.96	6.76	1.14	1.10	3.80	3.69
94	721	20	1.00	1.08	6.03	14.75	7.33	9.00	4.50	1.59	0.80
95	721	21	1.00	1.08	4.46	14.75	14.75	6.00	6.00	1.19	1.19
97	721	25	1.00	0.96	5.60	14.75	14.75	8.57	8.57	1.42	1.42
99	721	460	1.00	0.84	16.35	14.75	5.00	1.77	0.60	6.55	2.90
101	721	740	1.00	0.80	5.16	14.75	14.75	1.93	1.93	2.43	2.43
102	721	841	1.00	2.13	6.35	14.75	11.09	1.93	1.45	2.66	2.00
103	833	20	1.06	1.08	6.93	11.85	11.85	7.50	7.50	1.75	1.75
104	833	21	1.06	1.08	7.82	11.85	8.41	5.00	3.55	1.84	1.31
105	833	25	1.06	0.96	9.00	11.85	9.79	7.14	5.90	2.09	1.72
106	833	460	1.06	0.84	25.52	11.85	4.34	1.48	0.54	9.10	3.33
107	833	740	1.06	0.80	14.39	11.85	10.87	1.60	1.47	8.49	7.79
108	833	841	1.06	2.13	6.50	11.85	9.79	1.60	1.33	2.77	2.29
109	842	20	1.74	1.08	11.53	5.45	3.63	4.46	2.97	2.04	1.36
110	842	21	1.74	1.08	12.42	5.45	4.39	2.97	2.40	2.10	1.69
111	842	25	1.74	0.96	13.60	5.45	3.81	4.24	2.97	2.24	1.56
112	842	400	1.74	0.84	23.90	5.45	1.42	0.88	0.23	6.48	1.69
113	842	740	1.74	0.80	13.57	5.45	5.45	0.95	0.95	3.15	3.15
114	842	841	1.74	2.13	2.67	5.45	4.01	0.95	0.70	0.71	0.52

Variables used for Transit mode

Sample No.	O.	D.	OATB	DATB	PATB	Trans.	TTB	MCIB
NO	IO	JD	1	2	3	4	5	6
1	121	20	5.10	5.50	0.94	0.00	8.92	2.82
3	121	21	5.10	4.73	0.94	0.00	9.64	2.82
4	121	25	5.10	3.60	0.94	0.00	12.02	2.82
5	121	460	5.10	3.50	3.44	1.00	44.75	2.82
7	121	841	5.10	5.40	3.44	0.00	16.42	2.82
8	141	20	3.50	5.50	0.94	0.00	12.54	2.16
9	141	21	3.50	4.70	0.94	0.00	15.26	2.16
10	141	25	3.50	3.80	0.94	0.00	15.54	2.16
11	141	460	3.50	3.50	3.44	1.00	49.38	2.16
12	150	20	4.50	5.50	0.94	0.00	17.68	2.23
13	150	21	4.50	4.70	0.94	0.00	18.40	2.23
14	150	25	4.50	3.80	0.94	0.00	20.76	2.23
15	150	460	4.50	3.50	3.44	1.00	36.96	2.23
16	270	20	5.25	5.50	2.00	0.00	36.49	2.33
17	270	21	5.25	4.70	2.00	0.00	37.38	2.33
19	270	25	5.25	3.80	2.00	0.00	40.86	2.33
20	270	260	5.25	3.50	2.00	0.00	9.17	2.33
22	270	460	5.25	3.50	4.50	1.00	70.26	2.33
23	270	740	5.25	7.50	4.75	1.00	55.59	2.33
24	270	841	5.25	5.40	4.75	1.00	51.01	2.33
25	320	20	4.40	5.50	0.94	0.00	15.03	2.74
26	320	21	4.40	4.70	0.94	0.00	13.92	2.74
28	320	25	4.40	3.80	0.94	0.00	11.07	2.74
29	320	460	4.40	3.50	3.44	1.00	46.38	2.74
30	340	20	6.70	5.50	2.00	0.00	27.11	1.85
31	340	21	6.70	4.70	2.00	0.00	26.00	1.85
32	340	25	6.70	3.80	2.00	0.00	25.03	1.85
33	340	460	6.70	3.50	4.50	1.00	38.99	1.85
34	340	740	6.70	7.50	4.75	1.00	33.34	1.85
35	344	20	6.00	5.50	1.25	0.00	30.94	2.04
36	344	21	6.00	4.70	1.25	0.00	28.88	2.04
37	344	25	6.00	3.80	1.25	0.00	25.14	2.04
39	410	20	4.50	5.50	0.75	0.00	10.67	2.49
41	410	21	4.50	4.70	0.75	0.00	9.58	2.49
43	410	25	4.50	3.80	0.75	0.00	4.98	2.49
45	410	460	4.50	3.50	1.25	0.00	24.84	2.49
46	410	740	4.50	7.50	3.50	1.00	24.89	2.49
47	430	21	5.70	4.70	1.38	0.00	22.32	2.23
48	430	460	5.70	3.50	4.50	1.00	24.94	2.23
49	470	20	5.00	5.50	6.50	2.00	39.99	1.85
50	470	21	5.00	4.70	6.50	2.00	38.90	1.85
52	470	25	5.00	3.80	4.50	1.00	35.26	1.85
53	470	460	5.00	3.50	2.00	0.00	7.48	1.85
54	441	20	5.20	5.50	1.25	0.00	19.16	1.69
55	441	21	5.20	4.70	1.25	0.00	17.85	1.69
56	441	25	5.20	3.80	1.25	0.00	16.19	1.69
57	441	460	5.20	3.50	1.25	0.00	11.88	1.69
58	441	740	5.20	5.40	2.00	1.00	37.36	1.69
59	532	20	5.45	5.50	2.00	0.00	28.94	1.40
60	532	21	5.45	4.70	2.00	0.00	26.85	1.40
61	532	25	5.45	3.80	2.00	0.00	24.40	1.40
62	532	460	5.45	3.50	4.50	1.00	29.35	1.40
65	580	20	7.00	5.50	2.00	0.00	45.81	1.91
66	580	460	7.00	3.50	4.50	1.00	32.82	1.91
67	620	20	9.20	5.50	2.45	1.00	22.39	3.00
69	620	21	9.20	4.70	0.45	0.00	20.30	3.00
71	620	25	9.20	3.80	0.45	1.00	19.47	3.00
73	620	460	9.20	3.50	2.95	1.00	27.52	3.00
75	620	740	9.20	7.50	3.20	1.00	25.02	3.00
76	640	20	4.95	5.50	0.58	0.00	25.26	2.30
77	640	21	4.95	4.70	0.58	0.00	24.68	2.30
78	640	25	4.95	3.80	0.58	0.00	23.49	2.30
80	640	460	4.95	3.50	2.00	0.00	30.94	2.30
81	640	740	4.95	7.50	2.00	0.00	14.01	2.30
83	661	20	5.00	5.50	2.00	0.00	34.10	2.07
84	661	21	5.00	4.70	2.00	0.00	33.52	2.07
85	661	25	5.00	3.80	2.00	0.00	32.33	2.07
86	661	460	5.00	3.50	4.50	1.00	40.34	2.07
87	661	740	5.00	7.50	9.00	1.00	25.85	2.07
89	670	20	6.25	5.50	2.00	0.00	45.19	1.94
90	670	21	6.25	4.70	2.00	0.00	42.61	1.94
91	670	25	6.25	3.80	2.00	0.00	41.42	1.94
92	670	460	6.25	3.50	4.50	1.00	45.13	1.94
93	670	740	6.25	7.50	9.00	1.00	29.71	1.94
94	721	20	7.25	5.50	1.25	0.00	12.55	3.30
95	721	21	7.25	4.70	1.25	0.00	10.46	3.30
97	721	25	7.25	3.80	1.25	0.00	11.15	3.30
99	721	460	7.25	3.50	3.75	1.00	39.29	3.30
101	721	740	7.25	7.50	2.00	0.00	10.98	3.30
102	721	841	7.25	5.40	1.38	0.00	26.13	3.30
103	833	20	5.25	5.50	0.82	0.00	11.50	2.74
104	833	21	5.25	4.70	0.82	0.00	12.59	2.74
105	833	25	5.25	3.80	0.82	0.00	14.59	2.74
106	833	460	5.25	3.50	3.32	1.00	48.67	2.74
107	833	740	5.25	7.50	0.82	0.00	34.21	2.74
108	833	841	5.25	5.40	1.50	0.00	13.40	2.74
109	842	20	5.60	5.50	2.00	0.00	21.83	1.63
110	842	21	5.60	4.70	2.00	0.00	22.87	1.63
111	842	25	5.60	3.80	2.00	0.00	26.14	1.63
112	842	460	5.60	3.50	4.50	1.00	63.10	1.63
113	842	740	5.60	7.50	4.75	1.00	32.91	1.63
114	842	841	5.00	5.40	2.00	0.00	9.53	1.63

ATTRACTIONS, PRODUCTIONS, INCOMES AND CARS/PERSON
OF ORIGINS AND DESTINATIONS

	DESTINATIONS	ATTRACTIONS
1	020	4495
2	021	4650
3	025	6243
4	260	1562
5	460	9997
6	740	3954
7	841	1195

	ORIGINS	PRODUCTIONS	INCOME/HOUSEHOLD	CARS/PERSON
1	121	1919	7725	.304
2	141	1198	10071	.343
3	150	1661	9759	.364
4	270	2715	9372	.305
5	320	1508	7950	.319
6	340	2618	11781	.356
7	344	943	10683	.360
8	410	2604	8761	.368
9	430	746	9784	.355
10	441	709	12879	.450
11	470	1159	11781	.387
12	532	1036	15538	.462
13	580	510	11407	.404
14	620	2756	7263	.237
15	640	1054	9485	.359
16	661	2159	10533	.380
17	670	2153	11207	.374
18	721	1639	6614	.218
19	833	2014	7937	.246
20	842	1251	13366	.417