AN ANALYTICAL METHODOLOGY FOR SHORT RUN URBAN TRANSPORTATION POLICY QUESTIONS

by

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ABSTRACT

The purpose of this paper was to develop an analytical framework to answer short range policy questions. This type of framework is needed because until recently most models dealt with long range capital investment decisions while many urban transportation problems may be solved through low capital cost policy decisions.

The literature indicated that equilibrium techniques were essential in providing solutions to short run policy questions. The features of equilibrium theory in general were examined. The theory was then discussed in terms of an application. It was found that the equilibrium state may be obtained through a direct or indirect modelling approach. The direct approach utilizes a single modelling step while the indirect approach utilizes several sub-models. The state of the art is such that it appeared that the sequential indirect approach was the best method to use.

A computer modelling framework was developed which included modifications and additions to a system produced at the University of British Columbia. The purpose of the U.B.C. system was to provide detailed analysis of traffic movements over localized traffic networks. The modelling contributions of this paper were the detailed description of the transit user through his trip from origin to destination and the assembly of an automobile assignment model, parking allocation model, transit assignment model and an auto-transit demand model into an equilibrium framework.

The new system was tested on a small network. It produced "reasonable results". Reasonable in this case implied:

(1) that any changes in service levels or parking costs will result in shifts of demand in the appropriate direction and;

(2) that changes in demand will be in proportion to the change in level of service and vice versa.

Two parking policies were analysed. The first policy approximated the case where a municipality decides to increase the rates in its own parking lots. Prices were increased on one out of four lots in the test network. The second policy approximated the case where the government is able to levy a tax on all parking lots. Prices were increased on all lots in the test network. The outcome produced by the model confirmed the experience with parking price increases; that is, for parking policies to be effective in reducing congestion, it is necessary to control all parking spaces in the C.B.D..

A number of recommendations arose from the analysis of the results from the test network.

It was recommended that further tests be carried out on a more realistic network, and that a set of refinements and sensitivity tests be made on some of the sub-models in the system.

In general the model appeared to be sensitive to changes in attributes of transportation alternatives.

The development of this system was a step to fill the gap in the armoury of analytical tools. Further work and research may show it to be useful in practical applications.

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CHAPTER 1

1.0 INTRODUCTION

The urban planning process which developed during the 1950's and the 1960's was directed primarily towards the analysis of long range capital intensive transportation projects. In the past few years investments in large scale transportation projects have become expensive. Although this increased expense has not excluded the necessity of providing costly new infrastructure, it has shifted the focus of the transportation planner to the need for optimizing the operation of existing facilities.

The early planning tools were designed to produce results for long range investment projects. Few were developed which explicitly analysed short run transportation problems. None were really designed to be sensitive to policy changes.

Methods which have been introduced recently in an attempt to optimize the system have included a variety of traffic management policies. They ranged from the provision of reserved bus lanes to restraints on automobiles in selected areas of the city. The demand side of the problem has also been addressed with flexible work hours, car-pooling and various methods of pricing being attempted. Few of these methods have been analytically evaluated before implementation, partly because there was no appropriate analytical framework available for such evaluations. Most of the work in this area is experimental, hence cities have become laboratories where untested hypotheses have been implemented and have met with varying degrees of success and failure.

It has become apparent that an analytical, systematic approach to this problem where the supply side, demand side, the transportation system and the interaction of these three elements are taken into full account is

needed.

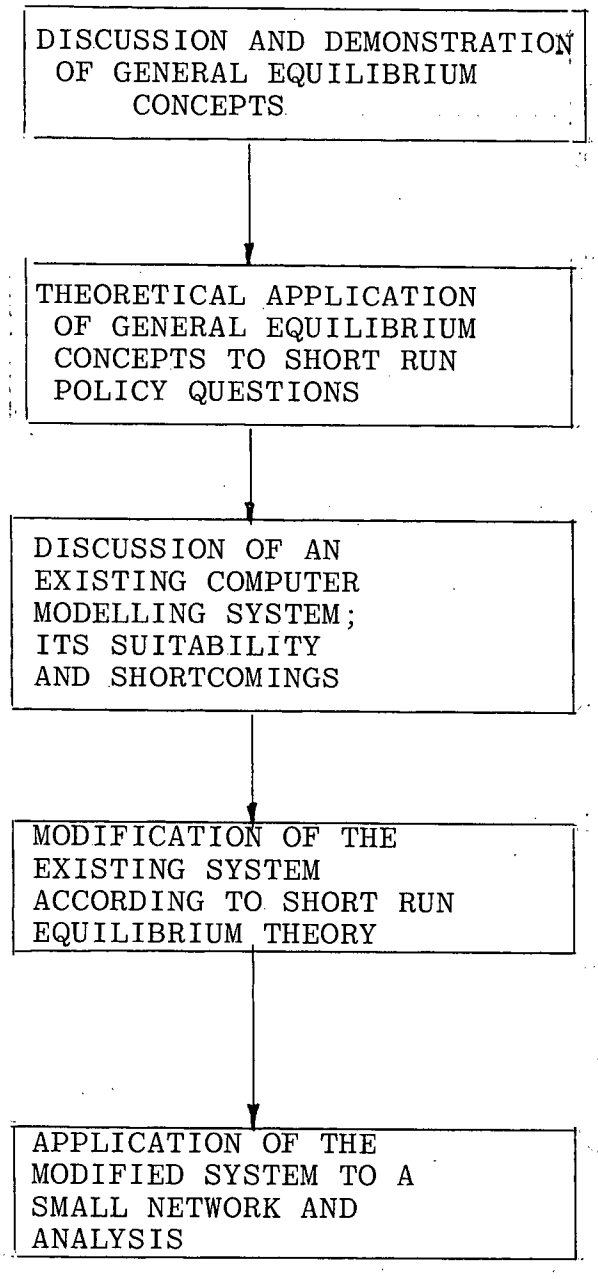
Work performed for a paper entitled "An Examination of the Costs and Benefits of Various Parking Pricing Policies in the C.B.D." was the genesis for this thesis. A relatively crude model was developed and the analysis was done using a crude network. The need for both the analysis of short run policy questions and a more precise analytical framework for the analysis of the questions were recognized in that paper [1].

The purpose of this paper is to develop a more detailed analytical framework. The methodology is focused primarily on the analysis of altering parking charges in the C.B.D.. With little effort it could be modified to handle a number of short run transportation problems.

This paper provides two major contributions to the field of modelling these problems. Much work has been addressed in the past to developing models which describe the movement of automobiles through a road network. Some work (but not a great deal) has been expended in describing the movement of a transit passenger through the transit network. Little work has been done to link the service levels arising on the two networks in a dynamic sense to the demand levels on the networks. The contribution of this paper is the detailed description of the transit user through his trip from origin to destination and the assembly of an auto assignment model, parking allocation model, transit assignment model and an auto-transit demand model into a dynamic framework.

This paper is divided into five sections. Figure 1 graphically illustrates the flow of the work. The first section examines the literature and discusses general equilibrium concepts. The second section deals with a theoretical application of the concepts to short run policy questions and delves into the approaches available for producing a technique to provide equilibrium solutions. In the third section the assumptions and functions

FIGURE 1. FLOW CHART SHOWING THE MAJOR ACTIVITIES OF THE PAPER



of an existing computer modelling system are discussed. Its shortcomings with respect to the theory set out in the second section are also illustrated. The fourth part sets out the modifications and additions to the current modelling methodology. Finally, an application of the revised modelling system to a small street and bus network is made and an analysis of the results is given.

FOOTNOTES

1. T. E. Culham, "An Examination of the Costs and Benefits of Various Parking Pricing Policies in the C.B.D.", Student Paper Number 21, Centre for Transportation Studies, University of British Columbia, 1977.

CHAPTER 2

2.0 THEORETICAL CONSIDERATIONS

Traditional aggregate models of travel demand have proven to be inadequate for short range policy planning[1]. Three distinct topics must be addressed in the development of a methodology which solves transportation policy questions. First, a general behavioural assumption should be stated which describes the process to be modelled. Secondly, a set of requirements must be established which ensure that the process does in fact model the behaviour. Thirdly, a technique ought to be chosen which is appropriate to the scale of the problem and is capable of satisfying the stated conditions.

Wardrop's first principle states that traffic between origins and destinations will tend to settle into an equilibrium state where no driver can reduce his journey time by choosing a new route[2]. This behavioural assumption was generalized to include all travel choices available to the urban traveller. It is stated as follows: Travel by car or any other mode between origins and destinations will tend to settle into an equilibrium state where no person travelling can reduce the generalized costs incurred in his journey by choosing another route or by changing the mode of travel. The concept of generalized cost refers to the monetary costs of travel, invehicle travel time, out of vehicle travel time and comfort, convenience, reliability, safety etc.[3]. According to Florian the simplest and most general definition of equilibrium is that equilibrium is a steady state that is reached when the demand for transportation gives rise to a service level that maintains that demand[4]. The concept of equilibrium will be discussed in greater detail in part one of Chapter 2.

Atherton et al set out two basic conditions which must be satisfied by short range planning models[5]. First, they should be sensitive to changes

in attributes of transportation alternatives that would result from policies being analysed (i.e. the models must be policy sensitive). Secondly, the models must be structured in such a way that they accurately reflect the choice process of an individual deciding between alternatives.

Planning may be done at different urban scales ranging from regional to local micro and have several purposes ranging from operational to strategic. Table 1 illustrates the relationship between the urban scale and purpose of planning.

TABLE 1 URBAN SCALE VERSUS PLANNING PURPOSE

URBAN SCALE \ PLANNING PURPOSE	OPERATIONAL	FUNCTIONAL	STRATEGIC
REGIONAL	-	-	X
SUBREGIONAL	-	X	X
URBAN	-	X	X
LOCAL URBAN	X	X	-
LOCAL MICRO	X	-	-

Wigan draws a fine but important distinction between the scales of 'urban' and 'local urban'[6]. The former refers to the analysis of major schemes of construction while the latter refers to the analysis of short run low capital cost schemes. He discusses the applicability of equilibrium

techniques to the various urban scales and comes to the conclusion that without equilibrium techniques it is unlikely that the results of a local urban analysis would be of any practical value[7]. The methodology being developed in this paper is directed at solving problems at the local urban level.

At the beginning of this chapter a generalized behavioural assumption was stated. In it the concept of equilibrium was introduced and was later defined. In the discussion above it was recognized that equilibrium techniques provide the theoretical basis with which to fabricate a methodology to solve short run policy questions. The following discussion enumerates a set of conditions which are necessary to ensure consistency in equilibrium models. It also discusses the degree with which these models meet the requirements of Atherton.

The conditions as set out by Manhiem are the following[8]:

(1) The level of service factors such as invehicle, out of vehicle travel times, distance, convenience etc. enters at each stage in the sequence, including generation, unless it is explicitly found to be superfluous.

(2) The same attributes of service should enter at each step unless the data indicates otherwise. Service attributes are bus fares, bus frequencies, parking costs etc.

(3) The same values of the level of service should influence each sub-model.

(4) The level of service provided by each mode should influence the demand to some degree.

These are general conditions which apply to all equilibrium models. These conditions are applicable from the general definition and approach

to the model through to the details of the sub-models.

Various procedures may be utilized in order to attain equilibrium of transportation flows. As long as the procedure chosen meets the conditions set out above then the first requirement of Atherton et al will be satisfied. The second requirement will be satisfied if the model is structured so that the significant service levels of the various modes are made available to a behavioural choice model. The conditions of equilibrium partially satisfy the second requirement. The selection of a disaggregate choice model will fulfill the remaining requirements. This selection will be discussed later in the paper.

2.1 Transportation Systems In Equilibrium

Before delving into the development of the analytical framework, a general explanation of the notion of a transportation system in equilibrium will be given.

A transportation system in equilibrium is seen to have four components which operate interactively. They are the following:

T, The transportation infrastructure which is the basic supply.

A, The transportation systems associated socio-economic activities. These activities include locations of work, recreation and home.

V, The demand which the activities put on the system. This demand takes the form of volume of trips by various modes on the links of the system.

L. The level of service on the system arising out of the volume of traffic on the system and the system configuration or infrastructure.

The level of service in this discussion is comprised of the following components:

1. The service attributes which are controllable system parameters such as bus frequencies, bus fares, parking charges etc..
2. The remaining portion is made up of what is typically thought of as the level of service factors ; these are, travel times and distances by the two modes, convenience etc..

The level of service as referred to here is equivalent to the idealized generalized cost concept. Later in the paper specific references will be made to service attributes and the limited level of service concept. For the graphical presentation and discussion in parts one and two of Chapter 2 the broader concept of level of service is used.

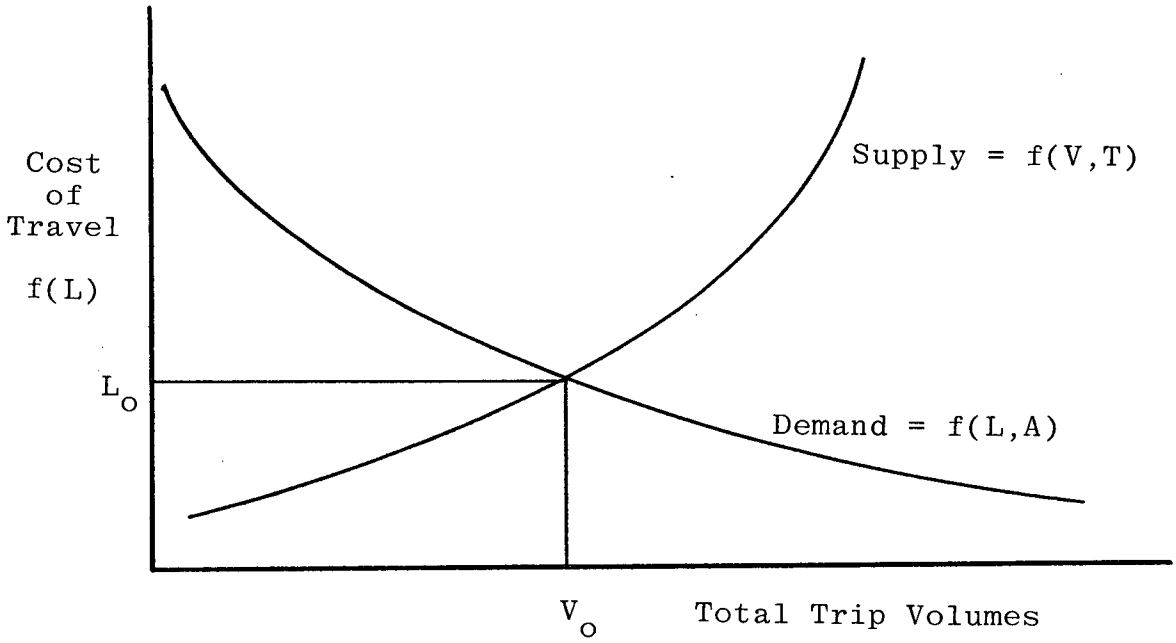
A final variable is introduced here which is not normally included in the literature because it is a function of the level of service. However, for clarity in the following discussion, generalized cost or simply cost of travel as function of the level of service will be included.

C = the generalized cost of travel as a function of the level of service

Generally when one thinks of the level of service improvement one thinks of an improved service where travel times are shorter and convenience is better. Figure 2 is a typical representation of a transportation system in equilibrium. In the literature the horizontal axis represents the total demand and the vertical axis the level of service. Under these conventions one tends to think that the level of service increases up the vertical axis. However, the diagram makes more sense if one assumes that the costs of travel increase up the vertical axis and the level of service deteriorates.

Each of the variables above are vectors. The transportation infrastructure is a vector of links with associated traffic characteristics. The socio-economic activities are the places of residence, recreation and work

FIGURE 2



A GENERAL REPRESENTATION OF A TRANSPORTATION SYSTEM IN EQUILIBRIUM

throughout the region. The demand is the number of persons moving between these activities and may be specified by population subgroups, by time of day, by mode etc.. Finally the service levels are vectors of travel time, distance, cost, comfort etc. for each mode.

Generally the demand for travel is a function of the level of service L on the system and the socio-economic activities A of the region. The volume of traffic V on the system is a result of that demand and is given by:

$$V = f(C,A) \quad \text{----------} \quad 1$$

where

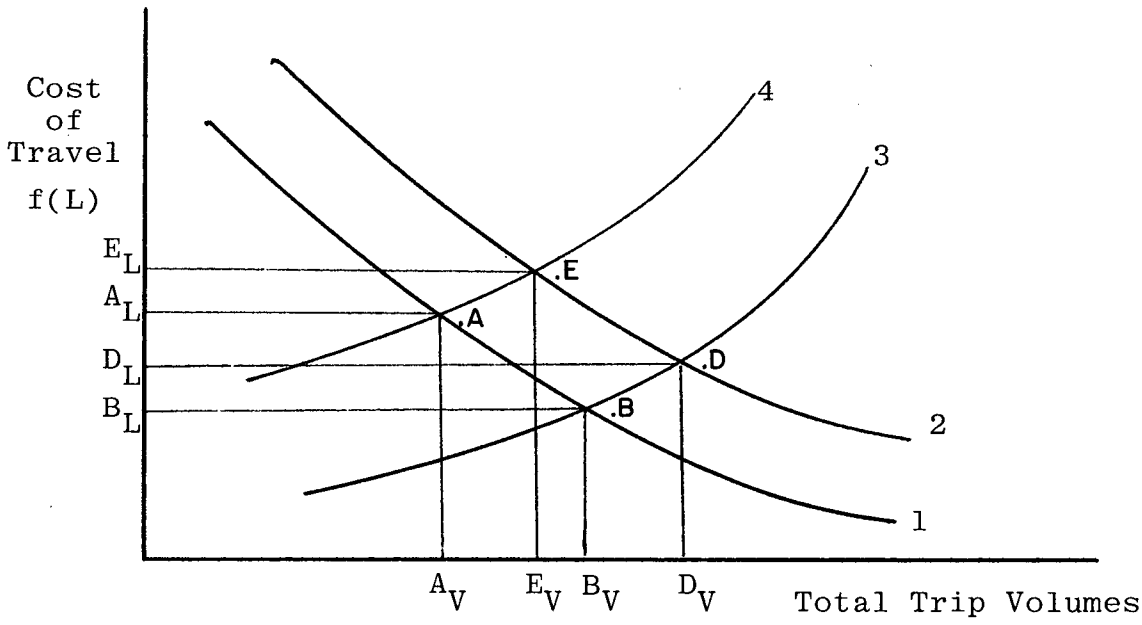
$$C = f(L) \quad \text{----------} \quad 2$$

Note that the cost C is a function of the level of service L and it is determined by the volume of traffic V on the transportation system T.

$$C = f(L) = f(V,T) \quad \text{----------} \quad 3$$

A graphical representation of the equilibrium state is achieved by supposing that equations 1 and 2 are continuous for the given A and T. A whole family of curves may be defined for each of the equations in the plane defined by the aggregate level of service and total demand axis; refer to Figure 3. For each given A and every level of service, there is

FIGURE 3



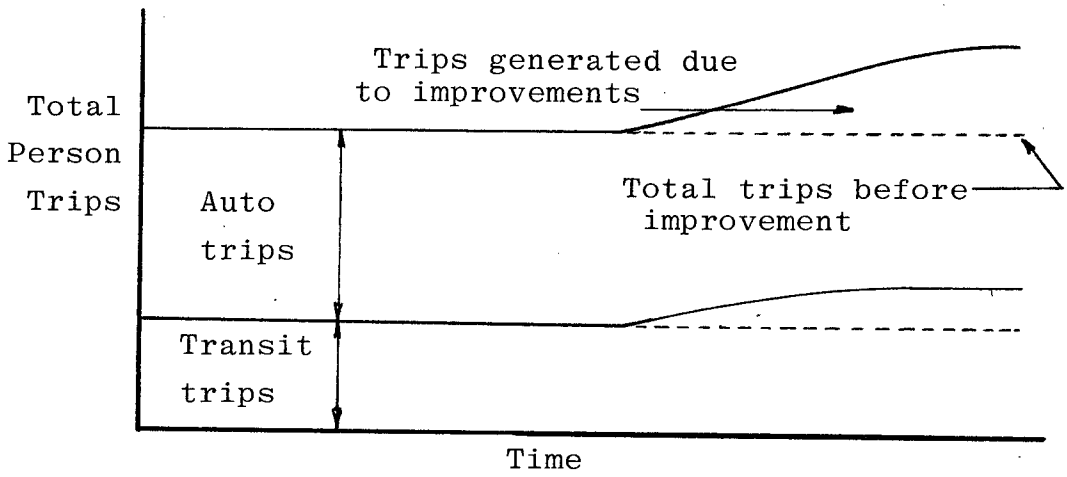
THE EFFECTS OF SHIFTS IN THE DEMAND AND SUPPLY ON EQUILIBRIUM IN A TRANSPORTATION SYSTEM

a curve which describes the demand on the system. Similarly, for each given T and every demand there is a separate curve which describes the possible level of service along it. Their intersection defines the equilibrium demand and service level. Figure 3 shows a pair of curves in the family of curves of each relationship.

An important notion of generalized equilibrium analysis is that total demand for transit is not fixed. It supposes that an improvement in any facet of the transportation system will lead to an improvement in the overall system and hence increase the total number of trips made. Figure 4 illustrates this concept. The source of the additional demand lies in the

FIGURE 4

TRANSPORTATION DEMAND AND FACILITY IMPROVEMENTS



latent demand - a topic which is addressed in greater detail in Chapter 3.

With this concept in mind an illustration of the intersection of equation 1 and 2 will be given with references to Figure 3. It must be remembered that Figure 3 is a general representation of the complete transportation system including all modes.

The planner or engineer can directly influence the equilibrium of the system by influencing the service attributes of the modes, altering socio-economic activities and changing the transportation system. An example of changes in each of these areas will be discussed.

For example, point A on Figure 3 is assumed to be the existing

equilibrium. Service level A_L and volumes or demand A_V result. In the first case, the level of service is increased by increasing the frequency of bus service. Suppose that through this change the bus becomes more reliable and bus travel times are reduced. Two things occur. Some people will be attracted to the bus mode from their cars and new riders will be attracted to both modes. The system reaches equilibrium at point B with new service levels B_L and B_V . The difference between A_V and B_V is the generated demand. It is important to note that Figure 3 is only a pictorial representation. The slope of curve 1 could be entirely different. It may be vertical in the range of the analysis, in which case no new demand would be generated. Also, although one factor of the level of service has been made more attractive it may have produced an overall net negative result. In this case the aggregate level of service would be reduced.

In the second case, a new rapid transit system is installed. It affects significant improvements in the level of service. When the facility opens, the new equilibrium conditions are defined by point B. However, over a period of years of operation, the improved level of service offered by the system influences location decisions. The socio-economic activities of the city increase and the new equilibrium conditions are described by point D. The difference in demand between A_V and B_V represent newly generated trips from the existing pool of demand. The differnece between B_V and D_V represent trips generated by the growth of the city and by location decisions influenced by the installation of the facility.

In the third case, the city is allowed to grow without any improvement in transportation services. Point E describes the new equilibrium. The level of service has increased in cost from A_L to E_L and A_V to E_V represents newly generated trips due to the growth of the city.

FOOTNOTES

1. T. J. Atherton, J. H. Suhrbier, and W. A. Jessiman, "Use of Disaggregate Travel Demand Models to Analyse Car Pooling Policy Incentives", Transportation Research Board, 599., 1976, p. 35.

2. J. G. Wardrop, "Some Theorectical Aspects of Road Traffic Research", Proc. Inst. Civil Engineers, Part II 1952, p.345.

3. J. H. Shortreed (ed.), "Urban Bus Transit: A Planning Guide", The Transport Group, Department of Civil Engineering, University of Waterloo, 1974, pp 93 - 102.

4. M. A. Florian et al, "EMME: A Planning Method for Multi-Modal Urban Transportation Systems", Universite de Montreal Publication #62, Centre de recherche sur les transports, March 1977, p.3.

5. Atherton, loc. cit..

6. M. R. Wigan, M. A. Florian (ed.), "Equilibrium Models in Use: Practical Problems and Proposals for Transport Planning", Traffic Equilibrium Methods Proceedings of the International Symposium, at the University of Montreal, Springer-Verlag, New York 1976, p. 18.

7. Ibid.

8. M. L. Manhiem, "Practical Implications of Some Fundamental Properties of Travel Demand Models" Highway Research Record, 422, 1973, p.24.

CHAPTER 3

3.0 THEORETICAL DEVELOPMENT OF A SHORT RUN EQUILIBRIUM MODEL

The previous discussion has dwelled on the general concepts of equilibrium from a long range point of view. Its purpose was to introduce the concepts and give a general overview of a transportation system in equilibrium. The following discussion is more specific. The criteria for the development of a methodology for the analysis of short run policies are set out. The idea of equilibrium in terms of the solution of short run policy questions are discussed. Proceeding to the theory of the structure of the system, the modelling approach to short run equilibrium solutions is addressed. Finally the framework of that approach is explained.

The stated purpose of this paper is to develop an analytical framework which provides solutions to short run policy questions. Implementation of a policy implies that the planner wishes to improve the efficiency of the existing system or reduce its negative impacts such as pollution, noise etc. on society. In order to determine the effects of a policy the pertinent conditions associated with the existing state of equilibrium and those associated with the state of equilibrium under the new policy must be known. Of utmost importance is the ability to accurately predict the conditions due to the new short run policy. The following is a discussion of the criteria which were established for the development of a equilibrium model to satisfy the above goal. A set of assumptions were made based on the criteria and the validity of these assumptions is discussed with respect to the general concepts of equilibrium previously set out.

The following criteria were established for the development of a new equilibrium model:

1. Utilize the state of the art concepts as much as possible with regard to equilibrium models.
2. The emphasis of the framework would be on the short run, giving results which would be applicable from the present to two or three years in the future.
3. The model could be applied in an operational mode as well as a planning mode within two years.
4. The model would tabulate and possibly evaluate cost-benefit factors of the proposed plan against the existing situation.
5. The framework would utilize existing models as much as possible, choosing them and assembling them into the framework so as to be consistent with equilibrium concepts.
6. The model would focus on AM peak work trips only.
7. The model would consider both transit and automobile trips in equilibrium.
8. Both the network interaction and the choice between the two modes would be considered.
9. The choice process would consider the significant level of service characteristics of both modes.

In order to simplify the solution process the following assumptions were made.

1. The total demand for travel would be fixed. Only trip making trade-offs between the two modes would be considered.
2. The socio-economic activities will not alter significantly during the period of analysis.
3. The transportation system will not be changed during the analysis period.

The first assumption is critical. From a modelling point of view it means that trip generation can be determined exogenously to the model. It simplifies the process greatly. Briefly, the model takes current trip distribution tables for auto and transit and computes the equilibrium state given the current level of service conditions. This allows the analyst to check whether the model accurately predicts observed data. A change is then made in a service attribute such as a change in parking charges. The model then computes the new equilibrium transit-auto split and outputs the service levels arising from the new split. It does not alter the total demand for travel. The following discusses the validity of this assumption.

Total demand for travel may be altered in two ways.

1. The socio-economic activities in a region may increase due to growth in population and employment opportunities. Hence, the total demand for travel increases.
2. Latent demand may be induced to use the system through increased service levels (i.e. lower travelling costs).

The assumption that socio-economic activities do not change significantly over one or two years is valid provided the growth rate in the region is not excessive and no new major housing or employment developments commence during the period of analysis. An extension of this assumption beyond the two year period would require judgement in accepting its validity.

Latent demand is defined as trips that[1]:

1. are desired and can be met by existing transportation systems but are not attempted for reasons other than poor level of service.
2. are desired at a particular time but cannot be met by the existing system.
3. are not now desired but may be desired in the future and can be

met by existing systems.

4. are not now desired and cannot be met by the existing system.

It would appear that latent demand unsatisfied by existing transportation systems for work trips might have some significance to this model. It would also appear that changes in total demand for work trips are insensitive to changes in level of service. In the case of automobile-restraint measures for work trips, Heggie makes this statement[2]:

"Work journeys cannot be easily terminated (except for temporary or part time work) and travellers can usually be forced to use public transit."

This suggests that lowering or raising the service levels would not greatly influence latent demand over a short period. It must be noted however that this assumption loses validity over time as people can make adjustments in their place of residence or place of employment.

One of the remaining assumptions has already been discussed. That is, total demand is a function of socio-economic activities. To be consistent with the fixed demand function it is necessary that the socio-economic activities remain unaltered as well.

The assumption that the transportation system remains unchanged during the analysis period is valid provided that no infrastructure becomes operational during that period.

These assumptions alter the form of Figure 3 from a family of intersecting curves to a single vertical line.

Equation 1 transforms from

$$V = f(L,A) \qquad \text{----------} \qquad 1$$

to

$$V = Z \qquad \text{----------} \qquad 4$$

where Z is a constant.

Since V, and T of equation 2 are constants but the aggregate level of service can fluctuate, equation 2 transforms from

$$C = f(L) = f(V,T) \quad \text{----------} \quad 2$$

to

$$C = f(L) = f(V_T,V_A) \quad \text{----------} \quad 5$$

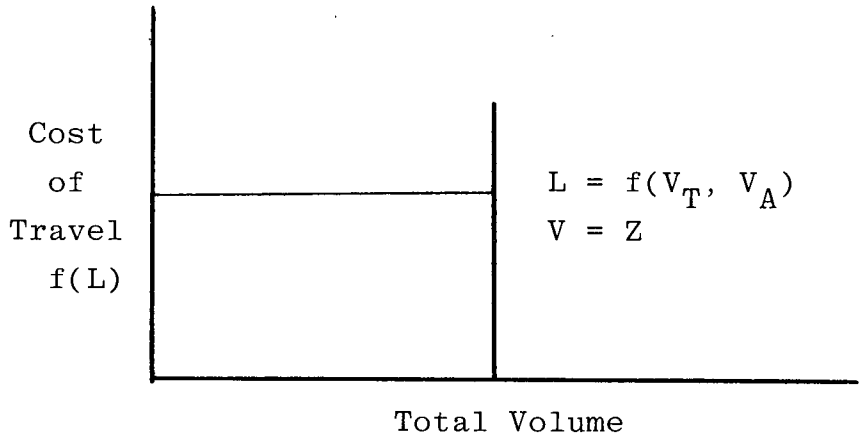
where T and A are subscripts denoting the transit and auto modes. V is the volume of traffic on each mode.

It is hypothesized that by altering the split between the auto and transit modes the aggregate level of service can be altered.

The equilibrium state of the system is a point defined by Equation 4 on the line V = Z ; refer to Figure 5.

FIGURE 5

A GENERAL EQUILIBRIUM MODEL UNDER SHORT RUN ASSUMPTIONS



Maximization of the aggregate level of service may not be the goal of the city planner or engineer. From the point of view of society, there may be factors outside the level of service function or factors which are improperly represented in it. Such examples are energy consumption, pollution or noise problems. The benefits to society at large however, must be balanced

against the aggregate cost to the trip makers due to the reduced level of service.

Returning to the main topic, in the system sense then, the equilibrium solution is redundant. It is simply the sum of all level of service factors plotted on the straight line in Figure 5. The problem lies in determining those level of service factors for both modes in equilibrium. The general equation for the level of service is:

$$L = f(V_T, V_A) \qquad \text{----------} \qquad 6$$

$$\text{where } L = L_T + L_A \qquad \text{----------} \qquad 7$$

The level of service for each mode in equation 7 are functions of the volumes or demands on both the mode networks.

$$L_T = f_1(V_T, V_A) \qquad \text{----------} \qquad 8$$

$$L_A = f_2(V_T, V_A) \qquad \text{----------} \qquad 9$$

The demands on both the networks in turn are dependent on the level of service on both the networks.

$$V_A = f_3(L_T, L_A) \qquad \text{----------} \qquad 10$$

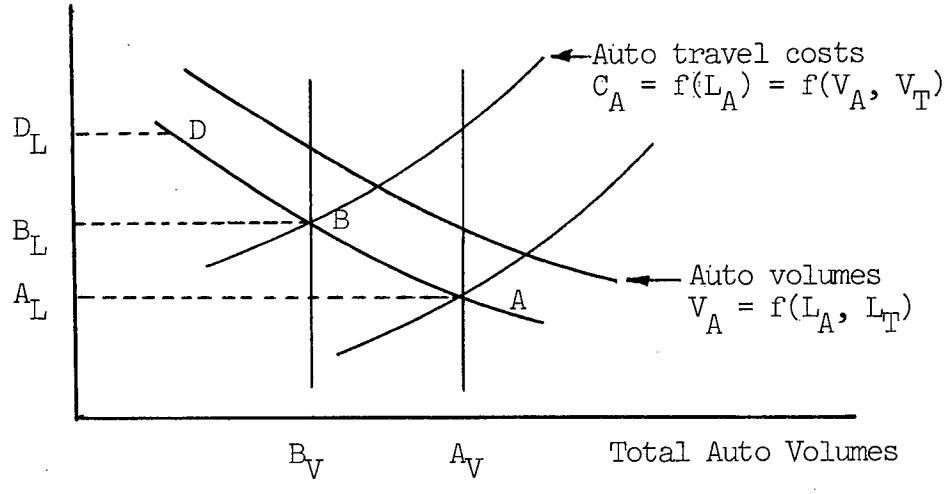
$$V_T = f_4(L_T, L_A) \qquad \text{----------} \qquad 11$$

These equations are similar in form to those presented for the general case. Figure 6 is a pictorial representation of the equilibrium state for the automobile mode only. A similar graph could be developed for the transit mode in equilibrium.

There is a family of curves describing the auto demand V_A for every given level of service of transit L_T. Similarly, there is a family of vertical lines describing the level of service of the auto L_A for every given demand of transit V_T.

FIGURE 6

AN EQUILIBRIUM MODEL OF THE AUTO MODE



The transit and automobile modes are at equilibrium at point A. The level of service for autos is reduced by adding a parking charge. The immediate result is an increase in the costs of driving from A_L to D_L. However, after the system users have had a chance to react to the new prices the system settles into equilibrium at point B. The new demand for auto travel is represented by B_V, the difference between B_V and A_V being the shift to transit.

The process described above is precisely the problem which is being addressed in this paper. Stated briefly, the problem is as follows.

Given the current equilibrium state of the transit and auto modes, what will be the new equilibrium conditions when a change is made in the level of service of either mode? Once the new equilibrium solution has been found, its operational differences and cost benefits over the previous state may be determined.

3.1 Approach to Equilibrium Solutions

An equilibrium model may be structured in two ways. According to Manhiem[3] the equilibrium state may be obtained through a direct or indirect approach. The direct approach utilizes a single modelling step while the indirect approach utilizes several sub-models. An econometric model which estimates the trip generation, trip distribution, mode split and assignment in one step is a direct approach. The Urban Transportation Model System (UTMS) estimates each of the above segments of the problem in four different sub-models and it is an indirect approach. Although UTMS has been very widely used and accepted, it has many short-comings. Its problems and limitations with respect to equilibrium criteria are discussed by Manhiem[4].

It is generally recognized however, that the indirect approach has many advantages. It allows the analyst to calibrate the parameters of each of the sub-models and run the models separately. This means that the process can be stopped at any time and examined. If the results are unreasonable, alterations can be made or the erroneous sub-model may be recalibrated and the process may continue without necessarily starting from the beginning again.

Although direct models are theoretically the best at satisfying equilibrium conditions, there are problems associated with them. Button[5] discusses a number of direct approaches and came to the following general conclusions:

1. the creation of a workable model has eluded the analyst;
2. to date, results have shown wide divergences in the parameters obtained; a consequence partly resulting from the assumptions employed.
3. no satisfactory method has been devised to ensure that the

predictions supplied by explicit models fall within the bounds of what is thought intuitively possible.

Given the state of the art, it appears that the sequential indirect approach is the better method to use if a practical modelling system is being developed.

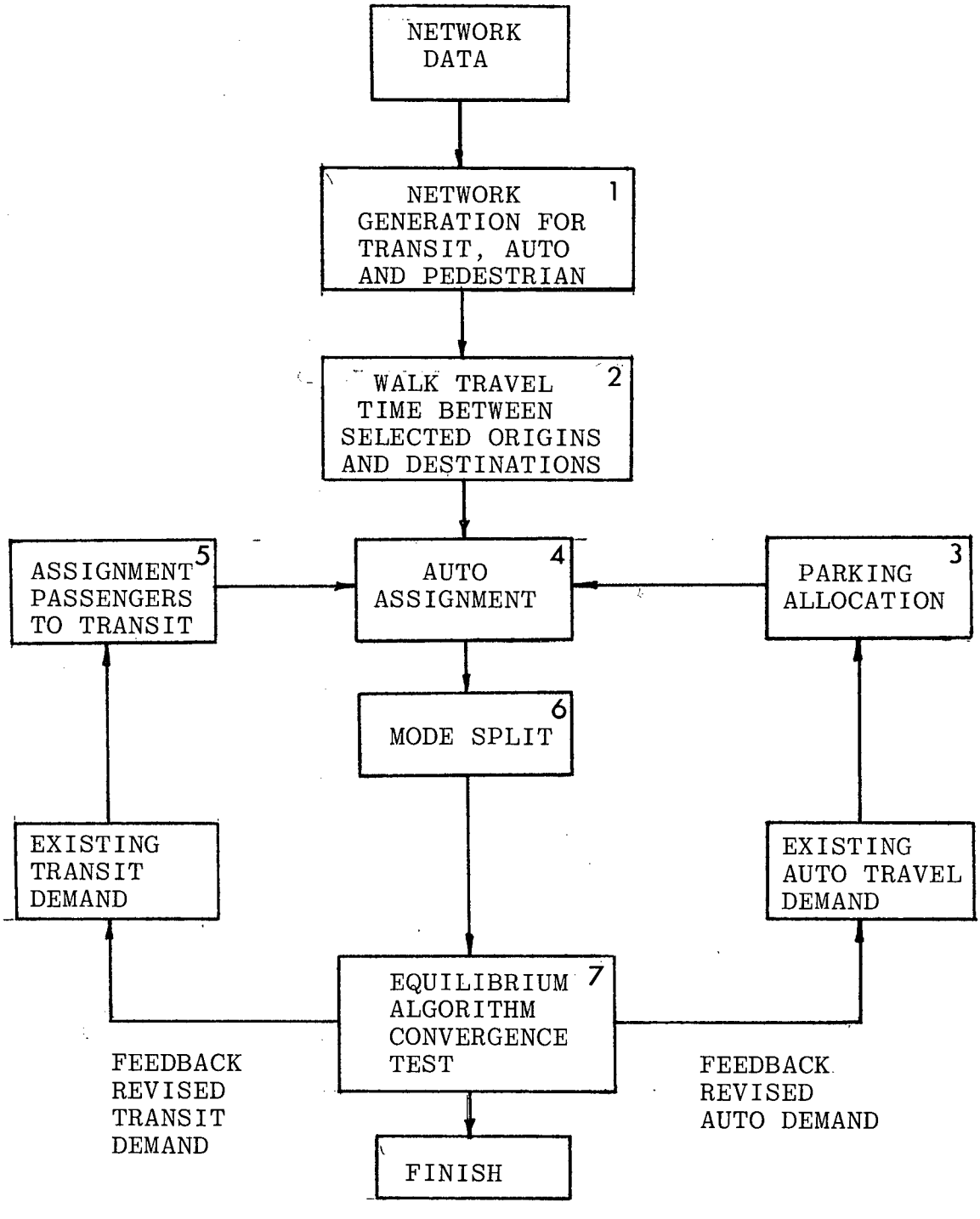
Other advantages are offered by the indirect approach. Figure 7 illustrates the sequence of steps embodied within the framework developed. This sequence of steps allows changes to be introduced at any point in the system. For example: if the parking prices are changed, then those changes would be introduced to the parking allocation step. The system then proceeds through the sequence of steps iterating until equilibrium is attained. The nature of the indirect approach implies that the parking allocation will initially be made without knowing the congestion levels arising out of any changes in congestion. Similarly, the mode choice will initially be made without knowledge of the congestion levels arising out of price changes and subsequent mode shifts.

It was hypothesized that the commuter makes decisions based on prices and levels of congestion experienced, not those anticipated. It is unlikely that price increases would be advertised and also , the commuter would not think of or be capable of estimating the equilibrium congestion level after a price change. The initial decision will be based on the new parking charge and the old congestion levels. Because of the lag in change of congestion levels behind price changes the system may not proceed to equilibrium in one step but must proceed through several steps.

This same concept involving a change in the transportation system and the user's response over time is discussed by Hutchinson[6]. The context of the discussion in his paper is different than the context presented here.

FIGURE 7

FLOW CHART OF A SHORT RUN ANALYTICAL FRAMEWORK



It deals with the problem of controlling the response of commuters during the transition period to the installation of new facilities. Its significance to this paper is:

1. it recognizes that there is a transitory period and;
2. that decisions which lead to travel patterns are based on congestion levels during the transitory period.

A model which proceeds through several steps to attain a state of equilibrium may in actual fact be approximating the real situation. It must be noted here that this model does not attempt to pin down the mechanism which operates during the transitory period nor develop a function which accurately describes the approach to equilibrium. The purpose of this discussion is simply to show that the indirect approach to equilibrium may be close to the process which the system goes through to attain equilibrium.

3.2 The Modelling Framework

An indirect approach was utilized for the equilibrium model developed in this paper. The framework includes the following seven steps:

1. Generate pedestrian, automobile and transit networks.
2. Determine walking times between selected origins and destinations.
3. Allocate automobiles to parking spaces so that walking and parking charges are traded off and the availability of space is constrained.
4. A multipath probability assignment of auto traffic to a network which interacts with the bus traffic.
5. An all-or-nothing assignment of transit users to a bus network which interacts with the automobile traffic.
6. Determine the demand for each mode through a logit model.

7. An application of an equilibrium algorithm for fixed demand and a convergence test.

The details and assumptions embodied in these steps will be discussed later. System equilibrium is achieved through the iteration of steps 2 through 7 and is controlled by step 7. System equilibrium conditions are met by the feedback of the appropriate service and demand levels. Steps 4 and 5 are computations of equilibrium for the single class user of auto and transit respectively.

Each of the steps 2 through 5 provide data to the mode split in step 6. Computation of walk travel times was excluded from the iterative process because it was thought that walk times would not be affected by changes in the level of traffic. Figure 7 illustrates the flow through the seven steps. This flow chart was not designed to illustrate the computer programs and their linkages but to show the theoretical form of the system.

Table 2 demonstrates more clearly the utilization of demand and supply data by the models in the system. The supply side is divided into service attributes and level of service factors. The service attributes are parking charges, bus fares and frequency of bus service. The level of service factors are auto walk times, auto invehicle times, bus walk and wait times, and bus invehicle times. The models in the table are listed in the order of execution. By referring to Table 2 and Figure 7 it is easy to trace through the process and determine where the data is computed and utilized.

The exogenous demand data provided to the system is in the form of origin-destination trips by car and by transit. The parking allocation model uses parking charges and auto walk times to transform the person O-D trips by auto into vehicle O-D trips. The process moves along to the vehicle assignment model utilizing the vehicle origin-destination (O-D) trips to compute the auto invehicle travel times and perform the vehicle assignment.

TABLE 2 SYSTEM SUB-MODELS VERSUS LEVEL OF SERVICE AND SERVICE ATTRIBUTES

MODEL	DEMANDS	SERVICE ATTRIBUTES			LEVEL OF SERVICE			
		PARKING CHARGES	BUS FARES	FREQUENCY OF SERVICE	AUTO WALK TIMES	AUTO INVEHICLE TIMES	BUS WALK & WAIT TIMES	BUS INVEHICLE TIMES
parking allocation	person trips by auto	X			X			
vehicle assignment	vehicle O-D trips					X		
transit assignment	person O-D trips by transit			X		X	X	X
mode split	person trips by auto and transit	X	X		X	X	X	X

The vehicle travel times are translated into average speeds on the links which set the maximum speed for the buses. The transit assignment model utilizes these maximum speeds, the frequency of bus service and the transit origin-destination demand to compute bus walk, wait and invehicle times in order to perform the transit assignment. The mode split model is the pivot point of the system. It is through the mode split that the service levels computed by the previous iteration are translated into new demands for the next iteration. In this manner also, all service levels are implicitly represented throughout the system by the revised demands.

Within the iterative portion of the framework, the commuter is allowed the following choices: (i) transit or auto mode; (ii) any number of paths in either mode; (iii) within the auto mode a trade off between parking costs and walking times . The inclusion of a parking allocation model offers more detailed information on the trade off between walking and parking charges. This trade off has implications on both the assignment of auto trips in the congested C.B.D. and the choice between transit and auto. Increased parking charges generally induce a shift to parking lots further from the place of work[7]. This shift may have the effect of reducing traffic flows in the vicinity of the zone where the increases were made. The parking allocation model also has an input to the choice process between auto and transit. In this case it is included in the generalized cost of auto travel (in-vehicle time, marginal operating costs, parking costs and walking time) and compared with the generalized cost of transit (invehicle time, bus fare, walking, waiting and transfer times). If the generalized cost of auto travel (including trade-offs) which the driver may choose to make is too high, then he will choose transit. In summary, this framework allows for a shift of drivers to different parking lots or a shift to transit.

FOOTNOTES

1. L. A. Hoel. et al, "Latent Damand For Urban Transportation", Transportation Research Institute, Carnegie-Mellon, University of Pittsgurgh, Pennsylvania, 1968, p. 215.

2. I. G. Heggie, "Consumer Respeonse to Public Transport Improvements and Car Restraint: Some Practical Finding. Working Paper No. 2 (revised)", Transport Studies Unit/ University of Oxford, 1976, p. 29.

3. M. L. Manhiem, "Practical Implications of Some Fundamental Properties of Travel Demand Models", Highway Research Record, 422., 1973, pp. 21 - 38.

4. Ibid., pp. 23 - 24.

5. K. J. Button, "The Use of Economics in Urban Travel Demand Modelling: A Survey", Socio-Economic Planning Science, Vol. 10, 1975, p. 65.

6. B. G. Hutchinson, "A Framework For Short-Run Urban Transport Policy Responses", A paper written for presentation at the Annual Meeting of the Roads and Transportation Association of Canada, Vancouver B.C., 1977, pp. 165 - 171.

7. D. W. Gillen, "Effects of Changes in Parking Prices and Urban Restrictions on Urban Transport Demands and Congestion Levels", University of Toronto - York University Joint Program in Transportation, 1975, p. 20.

CHAPTER 4

4.0 THE COMPUTER SYSTEM AND COMPONENTS

Up to this point in the paper the discussion has dealt with the theoretical aspects of equilibrium, its application to short-run policy questions, the approach to modelling a transportation system in equilibrium and the general structure of that modelling system. The following discussion deals with the actual construction of the modelling system and relates the choice of the models and functions imbedded in the system back to the theory.

Two options were open in the development of the computer system. The whole system could have been developed from scratch or a system which fulfilled part of, or all of the requirements of the study could have been utilized. If a partial system was available it could be modified and adapted where necessary.

A transportation planning model for detailed traffic analysis had been developed by the University of British Columbia and the City of Vancouver[1]. The model was designed to study the operational problems of peak hour vehicular commuter traffic. It is most appropriately applied to areas of high traffic activity such as the central business district of a metropolitan area or arterial streets of a region-wide network during peak demand. The framework consists of a parking allocation model and a multipath probabilistic assignment model which considers the physical interaction of auto and transit traffic. This methodology partially fulfills the requirements of this paper. It does not consider the transit side of trip-making nor the choice process between the auto and transit modes. To meet the requirements of this paper, a transit assignment model, mode split model and equilibrium algorithm would have to be added to the U.B.C. framework.

Short range policies and traffic management programs are directed at, and generally affect only the operational service levels of automobile and transit networks. The U.B.C. framework addresses the auto side of this problem. It has been used by the City of Vancouver for traffic analysis in the C.B.D.. To develop a methodology from scratch would have been a duplication of the U.B.C. work. It was decided then, to enlarge upon the existing framework by adding the three missing components mentioned above.

The following is a description of the U.B.C. framework. Each of its components is described in detail and the suitability in an equilibrium context is discussed. The modifications to this framework and the additional components are discussed as well.

4.1 Features and Components of The U.B.C. Framework

The transportation model was developed for the purpose of providing detailed analyses of traffic movements over localized traffic networks. In order to accurately model vehicle delays, the transit and pedestrian traffic and their interaction with auto traffic was modelled as well. The framework was designed to be applied in an area of high traffic activity such as the central business district or the arterial streets of a region-wide network during peak hours.

The framework was set up so that it would fulfill the following criteria:

1. Reproduce observed traffic patterns.
2. Forecast new traffic movements after changes in the road network, parking system or office concentration.
3. Be inexpensive and quick to use.
4. The output should be in a form which is easy to use and understand by a traffic engineer.

The degree to which the models meet these criteria is discussed by Navin[2].

The model was put together as a group of programs, each program designed to work independently or interactively with the others. Figure 8 shows a flow chart of the programs. The processing commences with the pedestrian and vehicle network builders which are contained in the program DEBUG. It searches for logical errors in the network and produces a plot of the vehicle network. It also outputs pedestrian travel times. The program TRANSIT performs a similar function in that it sets and produces a plot of the transit network. These two network programs provide data to both the parking allocaiton model TRANS and the vehicle assignment model STOCH.

4.2 Components of The U.B.C. Model

As already stated, the program DEBUG generates the vehicle and pedestrian networks, checks for errors and produces a plot of the vehicle network. It also computes the pedestrian walking times from parking lots to places of work and walk times to and from bus stops. The TRANSIT takes as input bus route information and the headways. It generates a transit network and computes the volume of buses on the links which are supplied to the vehicle assignment model STOCH.

The purpose and theoretical aspects of the parking allocation model TRANS and the traffic assignment model STOCH will be discussed in greater detail.

4.2.1 Addressing The Parking Problem

Generally transportation studies which included the choice of two or more modes parking costs have been lumped with automobile costs to create a single total cost variable. Parking services however, are a distinct

FIGURE 8 FLOW CHART OF THE U.B.C. COMPUTER FRAMEWORK.

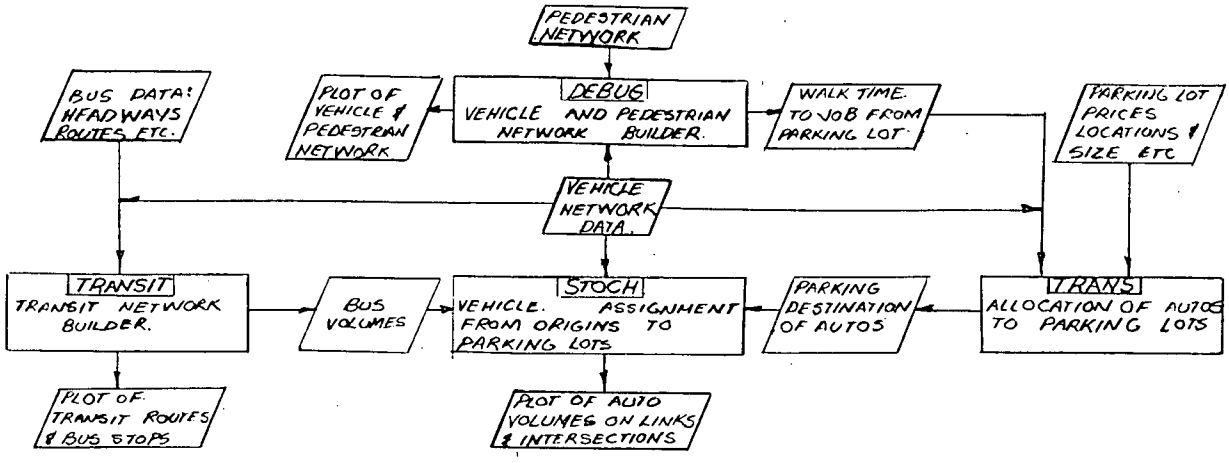
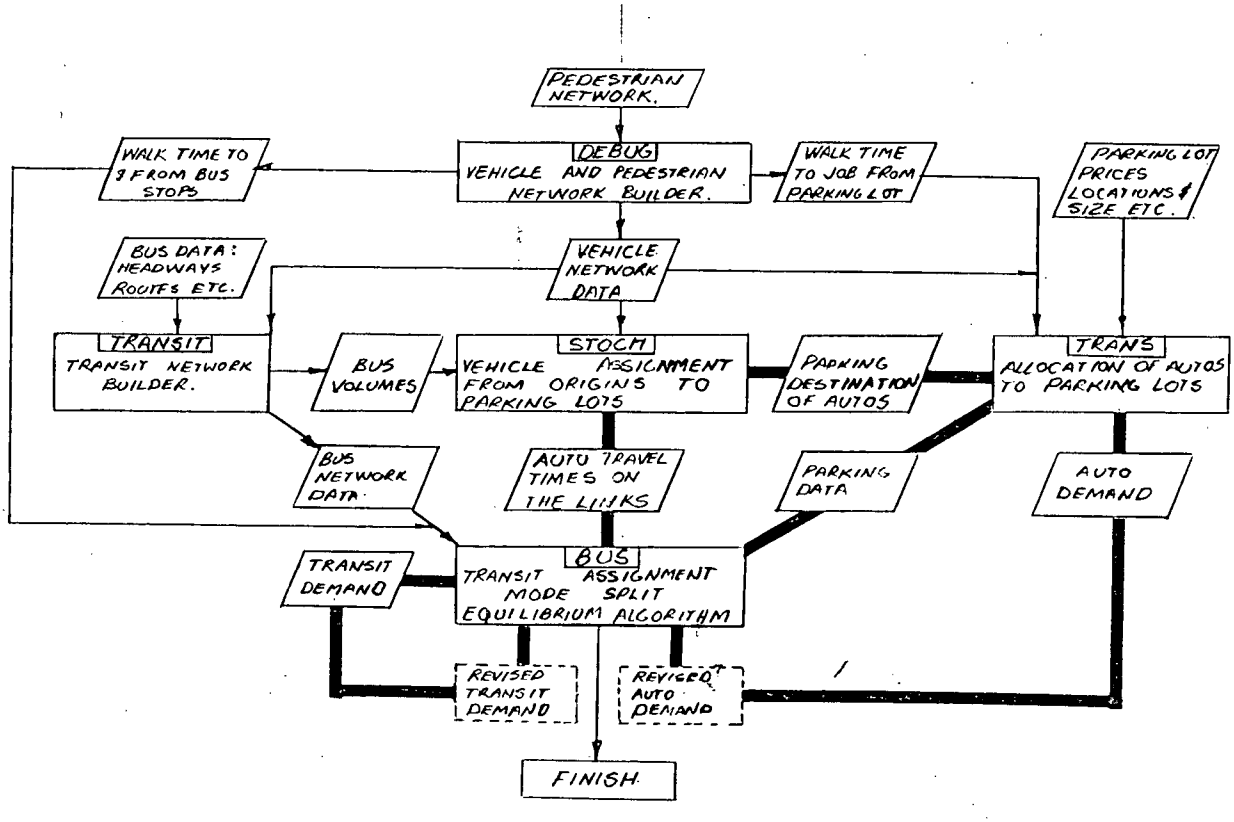


FIGURE 9 FLOW CHART OF THE MODIFIED FRAMEWORK



LEGEND:

INDICATES PATH OF ITERATION

DATA

PROCESSING

NOTE: ON THE FIRST ITERATION THE EXISTING AUTO AND TRANSIT DEMANDS ARE USED. ON SUBSEQUENT ITERATIONS THESE DEMANDS ARE REVISED AUTOMATICALLY BY THE MODE SPLIT AND EQUILIBRIUM ALGORITHM.

product or factor input from transportation services and are complementary to auto use[3].

Work that Gillen has done suggests that drivers will capitalize on guaranteed parking spots, spread costs by carrying passengers, and trade off parking costs and walking costs.[4] Other methods of avoidance of increased parking charges are: taking a taxi, relying on family members for a chauffeured lift to work, parking illegally, and employee reimbursements .

It can be seen that determining where drivers park is a complex problem with many variables. In the light of these avoidance methods enumerated above, the old assumption that automobile costs rise in equal proportion to the increased parking costs is false. These reduced real parking costs would have a significant effect on mode split calculations. Also as mentioned in Chapter 3 section 3.2 these avoidance techniques have effects on the assignment of vehicles to the network. These effects are felt in the most congested part of the city, the C.B.D..

From the discussion it would appear then that to be consistent with equilibrium concepts it is necessary to include a model which would attempt to describe the processes above. In effect, its purpose would be to contribute a better description of the service levels for the auto mode and a better description of demand levels on the links in the C.B.D..

4.2.2. The Parking Allocation Model TRANS

It would be difficult to model all of the avoidance techniques mentioned. Some can be accounted for in existing parking models while others cannot. Shifting to taxi mode, being chauffeured and parking illegally cannot be modelled. There is not sufficient empirical data available to formulate descriptions of the mechanisms involved in these types of behaviour. Within a parking allocation framework, guaranteed parking spots, employee reimburse-

ments and the trade off of parking charges and walking times can be addressed. Within the larger framework of the paper the problem of carrying passengers can be addressed through the logit model.

The parking allocation model used was designed with a two-fold purpose in mind. Firstly, it may be used to determine the redistribution of parking after alterations in the organization, pricing and structure of the downtown parking system. Secondly, it provides origin and destination data for the traffic assignment program.

Given that the final destination of the commuter is known the model uses a linear programming approach and optimally assigns vehicles to parking lots on an uncongested network.

Optimal location as defined by the model theory is the set of locations which minimizes the total cost for the system of commuters given the contraint of parking lot capacities[5]. The costs to be minimized are the cost of parking and that of walking. The value placed on walking is determined by the socio-economic status of the worker. A provision is included in the model which takes into account workers with high incomes or workers who have their parking fees subsidized or guaranteed. They are lumped into an inelastic component of the demand.

The function to be minimized is:

$$C = \sum_{i,g,k,l} (O(i,g,k,l) \times (W(g,k,l) + C(l)) \quad \text{---------} \quad 12$$

where $O(i,g,k,l)$ = the number of trips in group g from traffic source i, with final destination in zone k and parking in zone l.

$W(g,k,l)$ = cost of walking time for group g from zone l to k.

$C(l)$ = parking charges in zone l.

The constraints imposed on the system are:

$$\sum_{i,l} O(i,g,k,l) = T(g,k) \quad \text{----------} \quad 13$$

$$\sum_{i,k,g} O(i,g,k,l) \quad S(l) \quad \text{----------} \quad 14$$

where T(g,k) is the number of trips in group g whose final destination is zone k, and

S(l) is the parking capacity in zone l.

The output from TRANS consists of vehicle origin/ destination information which is used in the traffic assignment program, and parking and walking costs which are used in the logit model.

There are several drawbacks with this model. As noted previously it does not take into account all of the behaviour associated with drivers and parking costs, and it performs the allocation based on an uncongested network.

The allocation of "parkers" to facilities is based on the overall optimizing criteria rather than that of actual driver behaviour. It would seem that a behavioural model which allocates parkers to facilities based on optimizing their individual benefits would be more reasonable. The data requirements and a more complex calibration of the parameters is required in the behavioural models. The model used in this framework was selected because it was readily available and it is an adequate and accepted tool for determining parking allocation.

4.2.3 An Equilibrium Model for Vehicle Traffic

A traffic assignment model is a method of determining the equilibrium flows of vehicles on a road network. There is a hierarchy to the application

of equilibrium models. At the beginning of this paper such a model was described which considered the interaction of variable socio-economic activities over a multimodal transportation network with associated variable demand levels and resulting levels of service. For the overall short run thesis of this paper this general model was constrained to one of fixed demands, fixed socio-economic activities and a fixed multimodal transportation network. The level of service is variable and the equilibrium model consists of the interaction of the demand levels and service levels of the auto and transit modes. In order to determine the demand levels and service levels of the two modes an equilibrium model is needed which describes the interaction of the demand and service levels on the paths in the network for each mode.

There are numerous approaches available for solving single-mode equilibrium problems. Traffic assignment mathematical programming, algorithmic approaches with fixed demands, and algorithmic approaches with varying demands are available[6]. The traffic assignment classes of solution have by far predominated the other classes in actual application and in number of variants. The following deficiences have been noted in these approaches in solving network equilibrium problems[7]:

1. Link travel times have often been kept constant, thereby ignoring the existence of link supply functions.
2. Origin-destination trips have often been kept constant thereby ignoring the existence of travel demand functions.
3. The number of paths travelled between each origin and destination have often been limited to one, making it impossible, normally, to satisfy Wardrop's first principle.
4. The accuracy of the approaches as approximations of equilibrium

has not been determined. (This includes both their convergence properties (if they involve iterations), and their expected errors upon completion.)

The Dial Stochastic Assignment used in the framework presented in this paper avoids all except the last of the deficiencies mentioned above. The link travel times are a function of the demand on the links. The origin-destination trips are variable through the logit model, (i.e. auto drivers can switch to the transit mode) and more than one path is considered.

Criticisms have been leveled at the Dial model from other sources however, when assembling a modelling framework more than theoretical considerations must be taken into account[8,9]. Probably no matter what modelling methodology was selected it would be subject to theoretical criticism. Models will always be somewhat less than reality. The model selection must be made within a set of time and resource constraints and must perform adequately the necessary functions in order to solve the problem. The Dial model is significantly better than all-or-nothing assignment techniques[10]. Conversely, it is not the best technique available. It performs the functions which are needed to solve the problem being addressed. It has been used by the Traffic Engineering Department of the City of Vancouver for operational traffic analysis. Whether it produces results sufficiently accurate for the requirements of this paper is something which will have to be determined.

4.2.4 The Stochastic Vehicular Assignment Model

The vehicle network is loaded with traffic using the probabilistic multipath approach developed by Dial[11]. Trips are assigned to efficient paths between origin and destination pairs utilizing an algorithm which

precludes the necessity of enumerating the paths.

The Dial method has the following five basic specifications:

1. All reasonable paths between a given origin and destination have a non-zero probability of use.
2. All reasonable paths of equal length should have equal probability of use.
3. When there are two or more reasonable paths of unequal length the shorter should have higher probability of use.
4. The model's user should have some control over the path diversion probabilities.
5. The assignment algorithm should not explicitly enumerate all paths.

An efficient path is defined as one which proceeds in the direction of the destination and does not "back-track".

The distribution of trips along routes with different travel times is assumed to be determined according to the decreasing exponential function:

$$\exp(\theta\, t^{p}_{ij}) \qquad \text{----------} \qquad 15$$

where t^{p}_{ij} = the travel time along an efficient path

θ is a model parameter which determines the dispersion of trips along paths of different lengths.

4.2.5 Vehicle Delay

There are two components to vehicle delay: the delay of acceleration and deceleration due to the random encounter of traffic signals, and volume delay caused by interaction with other streams of traffic. Delay due to the interaction of the flow of traffic between intersections is considered to be minor compared to the delay at intersections. In general the intersection

constitutes the region of minimum capacity of the link[12]. It was assumed that only volume delays due to the interaction of traffic at intersections are considered in the model. The interaction of transit and pedestrian traffic with vehiclar traffic is considered as well. The problem of capacity restraint is addressed by utilizing an incremental approach to assignment. The program allows the analyst to break the assignment period into a number of smaller assignment periods. It also allows him to assign any combination of proportion of the vehicular load to the set of smaller assignment periods.

For the first assignment period, it assumes travel times due to free flow conditions and for each subsequent assingnment it uses travel times computed by the previous iteration.

FOOTNOTES

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2. F. P. D.Navin, C. Fisk, "A Downtown Traffic Management System", Prepared for the Canadian Transportation Research Form Annual Meeting, St. Andrews, New Brunswick, 1977, p.13.

3. D. W. Gillen, "The Effects of Parking Costs on Mode Choice", Resaerch Paper No. 23, The Department of Economics, The University of Alberta, 1975, pp. 2 - 3.

4. D. W. Gillen, "Effects of Changes in Parking Prices and Urban Restriction on Urban Transport Demands and Congestion Levels", University of Toronto-York University, Joint Program in Transportation, 1975, pp. 20 - 25.

5. C. Fisk, op. cit., pp. 11 - 13.

6. E. R. Ruiter, "Implementation of Operational Network Equilibrium Procedures", Transportation Research Board, 491., 1974, p. 43.

7. Ibid.

8. J. D. Murchland, M. A. Florian (ed.), "The Structure of Model Research", Traffic Equilibrium Methods, Proceedings of the International Symposium at the University of Montreal, Springer-Verlag, New York 1976, p. 8.

9. J. E. Burrell, M. A. Florian (ed.), "Multiple Route Assignment: A Comparison of Two Methods", Traffic Equilibrium Methods, Proceedings of the International Symposium at the University of Montreal, Springer-Verlag, New York, 1976.

10. R. B. Dial, "A Probabilistic Multipath Traffic Assingment Model Which Obviates Path Enumeration", Transportation Research Vol. 5, 1970, pp. 84 - 85.

11. Ibid., pp.89 - 110.

12. C. Fisk, op. cit., pp. 18 - 19.

CHAPTER 5

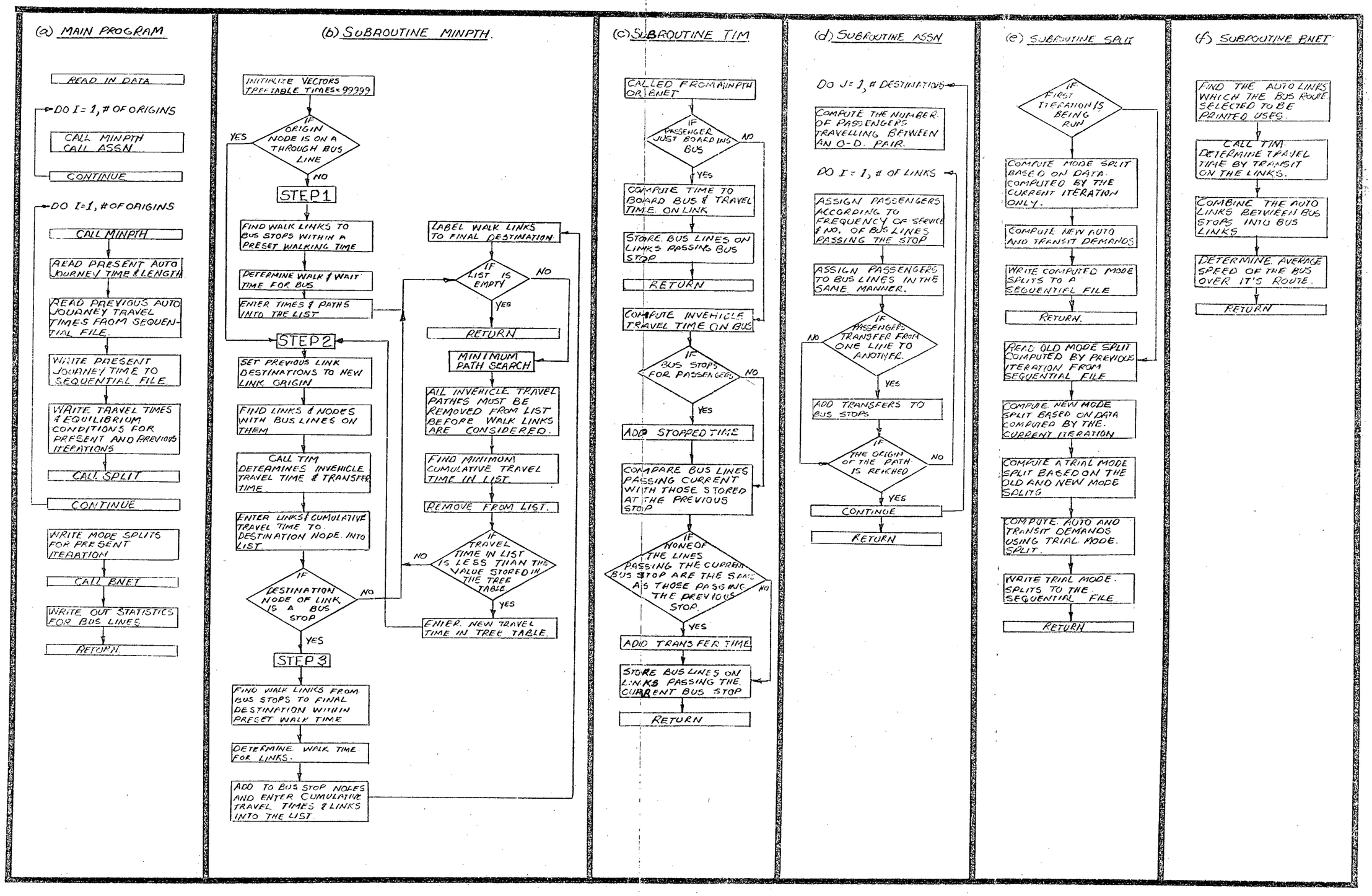
5.0 THE U.B.C. FRAMEWORK MODIFIED

In Chapter 4 a choice was made to utilize the computer modelling system developed at U.B.C.. It partially satisfied the theoretical requirements outlined in Chapters 2 and 3. The addition of a transit assignment model, mode split model and an equilibrium algorithm complete those requirements. This chapter deals with the functions, details and assumptions imbedded in the additional work.

The three new models are all contained in the program called BUS. It is executed after the vehicle assignment program; refer to Figure 10. There follows a brief description of the functions of the program. The theoretical basis of these functions are described in greater detail later in this chapter. The transit assignment model assigns transit trip makers to bus routes. Walking, waiting and transfer times are considered. The in-vehicle bus times are a function of the number of stops the bus makes, the number of persons loading and off-loading and the average speed of the stream of traffic. The traffic speeds are computed by the vehicle assignment model and are supplied to the transit program. The mode split model takes the service levels computed by the parking allocation model, vehicle assignment model and transit assignment model and computes an estimated mode split. The equilibrium algorithm computes a trial mode split based on the mode split form the previous iteration and the one just calculated. A new set of origins and destinations for both modes are computed using the mode split probabilities. The new auto O/D is input back into the parking allocation model and the transit O/D back into the transit assignment model. Before the iterative process is begun again with the parking allocation model, a test is made to determine the change in travel times

Figure 10

FLOW CHART OF PROGRAM BUS



between iterations. If the change is below a predetermined level then the process is stopped.

5.1 An Equilibrium Model For Transit

Before proceeding to the discussion of the theory behind the transit assignment it may be useful to discuss the term itself. When one speaks of vehicle assignment one thinks of the assignment of automobiles to a vehicle network. However, in this paper the term "transit assignment" refers to the assignment of transit passengers not only to the transit network but to walking links to and from the network.

Transit passengers are assigned to paths on an all-or-nothing basis without a capacity restraint function. Travel times are determined on the loaded network for use in the logit model. These congested travel times are not used to affect the assignment of people to routes in the transit network.

The use of an all-or-nothing assignment technique may be questioned from an equilibrium point of view. Similarly, the lack of a capacity restraint function may also be questioned. Herein appears a discussion on why this may be acceptable from a theoretical point of view. Its validity can only fully be accepted when these ideas are tested.

A theoretical equilibrium assignment can be described as a convex type of function. The solution is located at the minimum point of the function. No user can reduce his generalized travelling costs by altering his route. This solution has the characteristic that each path which is used between any pair of points has a cost which is no greater than any other path between those points.

When dealing with automobile assignment the nature of the road network allows for a choice between multiple paths which have similar costs between a given O-D pair. All-or-nothing assignment of auto trips assigns all the

trips to paths which may be only a few seconds shorter than parallel paths. In certain applications this leads to unrealistic assignments.

The transit network differs from the automobile network. The service is provided on a coarser grid and hence there are fewer parallel paths with similar costs. The possibility of multiple path use between any given O-D pair is reduced due to the likelihood of greater differences in costs between parallel paths. Similarly, because there are greater differences in costs between parallel paths the consideration of capacity restraint is not likely to have a significant effect on route choice in transit. Congestion is likely to increase travel times but is not likely to significantly alter the advantages of one route over another. Where the congestion effects may have more impact is in the mode choice. It is for this reason that travel times on the fully loaded transit network are computed.

More important in this paper is the description of transit travel times. The generalized costs of transit travel are more complex than auto travel. Whereas the auto driver attempts to minimize invehicle travel time the transit rider deals with minimization of walk times, waiting, transferring and invehicle times. It is widely accepted that the commuter values all of these components differently. Also, the calculation of travel times relies on different delay functions. The problem in transit equilibrium solutions is one of accurately describing the generalized costs of transit travel. An attempt has been made in this paper to address that problem.

5.2 The All-Or-Nothing Assignment Model

This section deals with a description of the computer model developed for this paper. Figure 10 is a descriptive flow chart of the functions performed by the program. There is a main program and five subprograms.

The general functions of the subprograms are:

MINPTH: Determines the minimum path

ASSN: Assigns passengers to the minimum paths

SPLIT: Performs the mode split and some of the equilibrium functions

TIM: Computes the transit travel time on the links

BNET: Preparation of vectors for print-out of selected bus lines.

The purpose of this is to illustrate the organization of the program. However, within this organization five important functions are performed. They are: (1) minimum path search; (2) transit travel time computations; (3) assignment of passengers to the minimum path; (4) mode split computation and (5) equilibrium computations. Each of these functions will be addressed with references to the flow chart.

The main program reads data, controls the subroutines and writes out the final results; refer to Figure 10(a). The following equilibrium statistics are also written out:

- The average of the current and previous travel times from each origin to all destinations by car and bus.
- The number of people travelling from each origin to all destinations by each mode and the split.
- The average change in mode split between iterations.
- The statistics of bus usage such as numbers of passengers on the bus, numbers at the stop and the average speed of the bus.

5.3 Minimum Path Algorithm

This algorithm finds a minimum path from the traveller's origin to his destination. This includes walking to, and waiting for the bus, riding the bus, any transferring necessary, and the final walk to the destination. The algorithm has two basic functions: a path generator which generates

paths and stores them in a list, and a minimum path finder which removes the minimum paths from the list and stores them in a tree table. Figure 10 (b) illustrates the flow of the processing in the subroutine MINPTH. The path generation process is broken into three segments:

1. the walk to, and wait at the bus stop;
2. the trip on the bus, including transfers and
3. the walk to the destination.

The first segment utilizes the walk links and travel times computed by the program DEBUG and the origins and destinations associated with those links. A set of pedestrian origins and destinations and a maximum walk time are designated by the analyst. The program DEBUG finds destination nodes which are within the maximum walking time from the origins. The path generator selects destination nodes which are bus stops and calls the subroutine TIM to compute the wait time for the bus. The total time to the bus stops and the nodes at the bus stop are stored in a list.

The minimum path finder selects the path to the bus stop with the minimum travel time, stores it in a minimum path tree table and removes it from the list. The paths to other bus stops remain in the list to be used later on. A fuller explanation of the minimum path finder will be given later.

The second segment of the path generator uses the bus stop node found by the minimum path search as an origin for links proceeding away from it. The link considered must have bus lines on them. In this path generating process, the program takes transit network data from the program TRANSIT and superimposes it upon the vehicle network data from program STOCH. In adding links to the list it is not important which bus line is available, it is only important that there is a bus line along that link. Delays due

to transferring and travel times along the links are computed in subroutine TIM. The passenger is allowed to make as many transfers as necessary to reach his destination. However, once on the bus he must remain on it until he reaches his final bus stop destination. He cannot get off, walk and reboard the bus. If the destination of the new link in segment 2 is a bus stop then the program control moves into the third segment.

The function of the third segment of the path generator is much the same as the first. In this case destination nodes and the cumulative travel times including walking are added to the list. Again only those destinations which are within a maximum walking time from the bus stop are considered.

At this point, control of the program moves to the minimum path finder. Control can move to the minimum path finder after the second segment if none of the destinations of the new links are bus stops. Control always moves to the path finder after the first and third segments. The function of the path generator is to add new links to the paths and store the destination nodes of those links along with the cumulative travel time to the nodes in the list. In general, there are three steps to the minimum path finder function. The first step is to find the node with the minimum cumulative travel time in the list and remove it from the list. The second step is to compare that travel time with what is already stored for that node in the tree table. (The tree table initially is set to a very large number.) If the time from the list is less than that already stored then the old travel time is replaced by the new value. The final step is to return control of the program to the second segment of the path generator. Here the destination node of the tree table becomes the origin node for the generation of new links. If the time from the list is larger than what is already stored in the tree table then control goes back to step one of

the minimum path finder. The process is complete when no more links can be added to the paths and when the list is emptied. In order to prevent walk links from becoming intermediate links, all nodes which are part of the bus network must be removed from the list first.

5.4 Transit Travel Time Computation

All components of transit travel time are computed in subroutine TIM except the walk times to and from the bus lines. The total transit travel time is described mathematically in this manner:

$$TT = f(WT) + f(W) + f(IV) + f(TF) + f(WF) \quad \text{----------} \quad 16$$

where TT = total transit travel time

WT = walk time to the bus

W = wait time and time to load

IV = invehicle time

TF = transfer time

WF = walk time from the bus stop

The first link is a walk from the origin to any number of bus stops which are within a maximum walk time set by the analyst. These walk times (as already mentioned) are inputs from the program DEBUG.

Another portion of the walk link is the wait time and this is comprised of waiting for the bus to arrive and waiting for the bus to load and get under way.

The amount of time spent waiting for the bus is given by the following equation.

$$W = 0.13\mu + 2.8 \quad \text{----------} \quad 17$$

where W = wait time

μ = mean headway (in this program the official headway is used)

This equation was developed by Jolliffe and Hutchinson[1] from data collected by Lynam and Everall[2]. It relates average observed waiting time to headway during peak traffic periods. It was noted that the equation broke down at low headways[3]. For this reason, wait times of bus lines with headways less than 7 minutes were assumed to be half the headway. Where there is more than one bus line available going in the desired direction the headway is assumed to be the average of the lines available.

The loading time is given by the number of persons times a per person boarding time set by the analyst. Off-loading is assumed to take half as long as loading. If there are more than twice as many persons off-loading as loading, then off-loading time determines the stopped time.

When the walk paths to the available bus stops have been determined, invehicle travel times on the bus are computed. The bus routes are fixed on the road network and the headways are predetermined. The basic coding for the two networks is the same. Bus traffic flows over road links designated for use by the transit network program TRANSIT. The bus lines which travel on the links are used for headway calculations for transfers and so that utilization of particular lines may be tabulated. Invehicle travel time on any link is given by the set of equations:

$$IV = ST + ADT + RT \qquad \text{----------} \qquad 18$$

where

IV = invehicle time

ST = stopped time

ADT = acceleration deceleration time

RT = running time at average velocity

Stopped time is given by the number of stops to pick up passengers and the number of passengers boarding the bus. The acceleration/deceleration

time is as follows:

$$ADT = (V / ACC + V / DEC) \times N \qquad (19)$$

where

V = average velocity of the stream of traffic

ACC, DEC = acceleration/deceleration of the bus

N = number of bus stops along the link

The average velocity is an input from the automobile assignment program STOCH. The acceleration/deceleration parameters of the bus are set by the analyst. The running time at average velocity is the time taken to cover the distance of the link not covered by accelerating or decelerating. The STOCH program considers intersection delay, cornering velocities, acceleration and deceleration of the vehicles from stops. The time to traverse a link is given by the above mentioned components. Rather than breaking them down into their separate components for the transit computations, the average velocity is simply taken to be the distance of the link divided by the travel time on that link. The transfer time is half the average of the headways of the bus lines going in the desired direction up to a maximum of 5 minutes. This assumption was made on the basis that during rush-hour, buses with headways greater than 10 minutes will meet at transfer points so that the maximum wait time is 10 minutes and the average wait time is 5 minutes. There did not appear to be much work done in the field of studies of transfer time. However, these assumptions seem to be reasonable for rush-hour conditions. As there are usually a number of bus lines travelling along the same route it is not possible to determine exactly which bus line the passenger is on. The only way that the program knows that a passenger has transferred is when none of the bus lines on the present link are the same as on the previous link. When this occurs the transfer

travel time function is activated.

The minimum transit paths are computed twice. This is done so that the loading of the system with passengers can be taken into account. The program computes the minimum paths from origins to all destinations and assigns passengers to the paths sequentially. It is not a simultaneous process whereby all minimum paths are computed and the passengers are loaded on to the system at once. Because passengers from more than one origin share parts of the same path, the paths computed first and assigned first are under-loaded and hence have low travel times. To overcome this problem the minimum paths are computed once again with the system fully loaded. In order to reflect the delays to passengers due to overloaded buses the wait times are considered to be double the headway if the bus is full.

To recapitulate the travel times for transit are comprised of walk times, wait times, transfer times and invehicle times. The invehicle times are sensitive to the number of automobiles sharing the same links and the number of people using the bus system.

5.5 Assignment of Passengers to the Network

The subroutine ASSN assigns the passengers to the minimum paths computed by MINPTH. Two assignments are carried out. Transit users are assigned to the bus stops as well as to the buses. Therefore, it is possible to determine the number of people waiting at the stops and the number of persons on the bus. This data is used in the second execution of MINPTH (see Figure 10(a)) to account for the delay due to people boarding and exiting the bus. The instantaneous demand on a minimum path is given by the equation:

$$ID = D \times H / (P \times NB) \qquad (20)$$

where

ID = instantaneous demand along the entire route

H = headway of the bus

D = total demand over the assignment period

P = the length of the period

NB = number of bus lines on link

Instantaneous demand is the average number of people at a bus stop waiting for one bus line or one bus at any instant throughout the assignment period. This is computed for each of the minimum paths. Where these paths share the same bus lines, stops and transfer points, the instantaneous demands for the individual paths are added together to produce the total instantaneous demand on the system. One of the difficulties encountered in the assignment process is that where there is more than one bus line serving a bus stop or a route it is not possible to determine which one the passenger will use. To overcome this, where a number of bus lines are available the passengers are loaded equally among them. Similarly, the average of the headways of the buses are used to compute wait times.

5.6 The Mode Choice Model

The subprogram SPLIT containing the logit model is set up so that with some alterations any calibrated logit model may be used. The generalized cost components made available to the mode split model are the: invehicle travel times for both modes, the walking time for the auto mode, the parking costs, the distance travelled by car, and the out of vehicle travel time for bus users. The out-of-bus travel times include walking, waiting and transfer times.

A logit model already developed and calibrated by D. W. Gillen was

selected and put into the program for demonstration purposes[5]. If a study was being done it would be necessary to collect data and calibrate a logit model to the particular city being studied. In the model given below G(x) is a function of the choice variable and P_c is the probability of choosing the auto mode. The form of the model is:

$$G(x) = -1.57 + 1.27TT/TC + .095FT/FC + .391\ AGE - .81SEX + .233\ SS + .129\ Y - .615\ EPC \quad \text{----------} \quad 21$$

$$P_c = e^{G(x)} / (1 + e^{G(x)}) \quad \text{----------} \quad 22$$

where

TT/TC = ratio of door to door travel times for transit and car respectively

FT/FC = ratio of modal running costs

AGE = the age variable; AGE = 1 if the user is between 20 and 55, otherwise AGE = 0

SEX = the sex variable, male = 0 , female = 1

SS = social status variable, SS = 1 if the individual is a middle manager or higher, otherwise SS = 0

Y = gross income of the individual in thousands of dollars

EPC = the inclusive parking price associated with choosing the auto mode for a given trip

P_c = probability of taking the car

Since the demonstration network and all of the input data were fabricated, the variables of the logit model were reduced to those levels of service factors and service attributes produced by the modelling system. If a full scale study were being performed more social factors could be included in the analysis. The following simplifying assumptions were made about the input data to the logit model. The modal cost of transit was

assumed to be 35 cents and that of auto to be 10 cents per mile driven (1964 dollars). Although the program has the capability of handling three different socio-economic groups, only one was used. All persons travelling to work were assumed to be between 20 and 55. Fifty percent of the population was assumed to be male, the other fifty percent female. Similarly, fifty percent of all C.B.D. employees were considered to be middle managers or higher and the remaining fifty percent were considered to be other types of workers. The average gross income of C.B.D. employees was assumed to be $5,000 (1964 dollars). Given these assumptions Gillen's equation then becomes:

$$G(x) = -.83 + 1.27\ TT/TC + .095(.35/MILES \times .08) - .615EPC \quad --- \ 23$$

It should be noted that this model was developed using data from the Metropolitan Toronto Regional Transportation Study (MARTS) done in 1964. The parameters of the model are most appropriate to that year and place. It is thought however, that for the purposes of demonstration the above equation will yield results which are responsive to changes in travel times and parking costs.

5.7 A System Equilibrium Algorithm

The transportation model presented in this paper embodies three equilibrium models; one for each of the two modes and one for the two modes combined. The equilibrium of the two modes by themselves is determined through assignment methods. The validity and assumptions of these methods have been discussed. The global equilibrium of the system (both modes combined) is solved using an equilibrium algorithm. A general equilibrium algorithm for the single mode was suggested by Ruiter[5]. The equilibrium model here follows the procedural framework outlined in his paper and is set out as follows:

1. Develop an initial network solution S.
2. Determine the best direction in which to proceed to obtain a new trial solution.
3. Develop a trial solution.
4. Obtain a new solution.
5. Determine whether S is a satisfactory final solution. If it is not return to step 2.

The initialization consists of executing all of the steps shown in Figure 9. This serves a four fold purpose: (1) It performs the initialization and produces an initial network solution. (2) It allows the analyst to determine whether the model is accurate in predicting the current situation. (3) Rather than starting off the process with free flow service levels corresponding to zero flow conditions, the network is already loaded. This reduces the number of iterations needed to approach equilibrium at the new parking costs. (4) It tabulates and stores the cost benefit factors such as travel times, total distance travelled etc. for comparison with the conditions of the transportation system under the new policy.

After the initialization process is complete the direction for the trial solution and a new solution is developed. The initialization computes the mode split for the existing situation and stores it in a file for later use; refer to Figure 10(e). The new parking charges are introduced at the parking allocation step. The vehicle and transit assignment steps are executed and then the mode split step is executed. The sign of the difference between the old mode split and the new mode split calculations indicates the direction of the new solution.

The trial solution is determined as a function of the old solution, the direction of the new mode split, and the difference between the new and old mode splits. It is not possible to use the new mode split as the trial

solution for the next iteration because in congested systems it tends to overestimate the solution (i.e. on subsequent iterations, the direction of the solution reverses direction). The trial solution is obtained in this manner:

When $M_O \geq .5$

$$M_T = M_O + M_O (M_N - M_O) \quad \text{----------} \quad 24$$

When $M_O \leq .5$

$$M_T = M_O + (1 - M_O) (M_N - M_O) \quad \text{---------} \quad 25$$

where M = the auto mode split computed by equation 22 and

the subscripts N = new

O = old

T = trial

The trial mode split is used to determine the transit and auto demands in the next iteration. The level of service resulting from these demands is used to determine a new mode split (step 4) and the trial mode split on the previous iteration becomes the old mode split. The old mode split was chosen as the moderator because it was found that it worked well. Appendix A documents the work done to determine this finding.

The process continues until the system converges. The convergence test (step 5) simply indicates the percent change in travel times from one iteration to the next. Since the iterative process is in the control of the analyst it can be halted according to the judgement of the analyst.

In summary, the effects of a policy change in the transportation system are determined by executing the computer models in the following manner. The programs are run first with current data and policies. The reason for this is outlined above. The analyst then alters the policy variable in the appropriate program and commences the iterative process.

If changes in parking charges were being examined, then the analyst would alter the parking costs in the parking allocation model and run that program. Next, the vehicle assignment program, and the ensueing programs in the iterative process would be executed until the convergence criteria were met.

FOOTNOTES

1. J. K. Jolliffe and T. P. Hutchinson, "A Behavioural Explanation of the Association Between Bus and Passenger Arrivals at a Bus Stop", Transportation Science No. 3 Vol. 9, 1975, p. 280.

2. D. A. Lynam and P. F. Everall, "Public Transport Journey Times in London", Transport and Road Research Laboratory, LR. 413, 1971.

3. Jolliffe and Hutchinson, op. cit. pp. 279 - 280.

4. D. W. Gillen, "Effects of Changes in Parking Prices and Urban Restriction on Urban Transport Demands and Congestion Levels", University of Toronto - York University, Joint Program in Transportation, 1975 pp. 28 - 35.

5. E. R. Ruiter, "Implementation of Operational Network Equilibrium Procedures", Transportation Research Board 491, 1974, pp. 45 - 48.

CHAPTER 6

6.0 AN APPLICATION OF THE MODELLING SYSTEM

The previous chapters discussed the theoretical aspects of an equilibrium model and the approach to constructing the model.

The following sections delve into five topics. The first discusses the network used for the demonstration. The second enumerates the capabilities of the transit program. The third traces an example through the modelling process to obtain equilibrium. The fourth section is concerned with the problems and anomalies encountered in the example problem. The fifth and final topic deals with an example of how the system could be used for analyzing a short run policy question.

Throughout this analysis the reasonableness of the results will be discussed. "Reasonable" in this case implies: (1) any changes in service levels or parking costs will result in shifts of demand in the appropriate direction and (2) that the changes in demand will be in proportion to the change in level of service and vice versa.

6.1 A Demonstration Using A Small Network

In the development of a computer modelling framework, it is important to determine whether it produces reasonable results before an application of the model is made to a real world problem. After the model has been shown to meet these criteria there follows a stage where it must be shown to be practical, reliable and economical[1]. These criteria are important in satisfying the users' needs and must be defined by the potential user. The purpose of this demonstration is to determine whether the model produces reasonable results. The task of determining reliability and costs will be left to others.

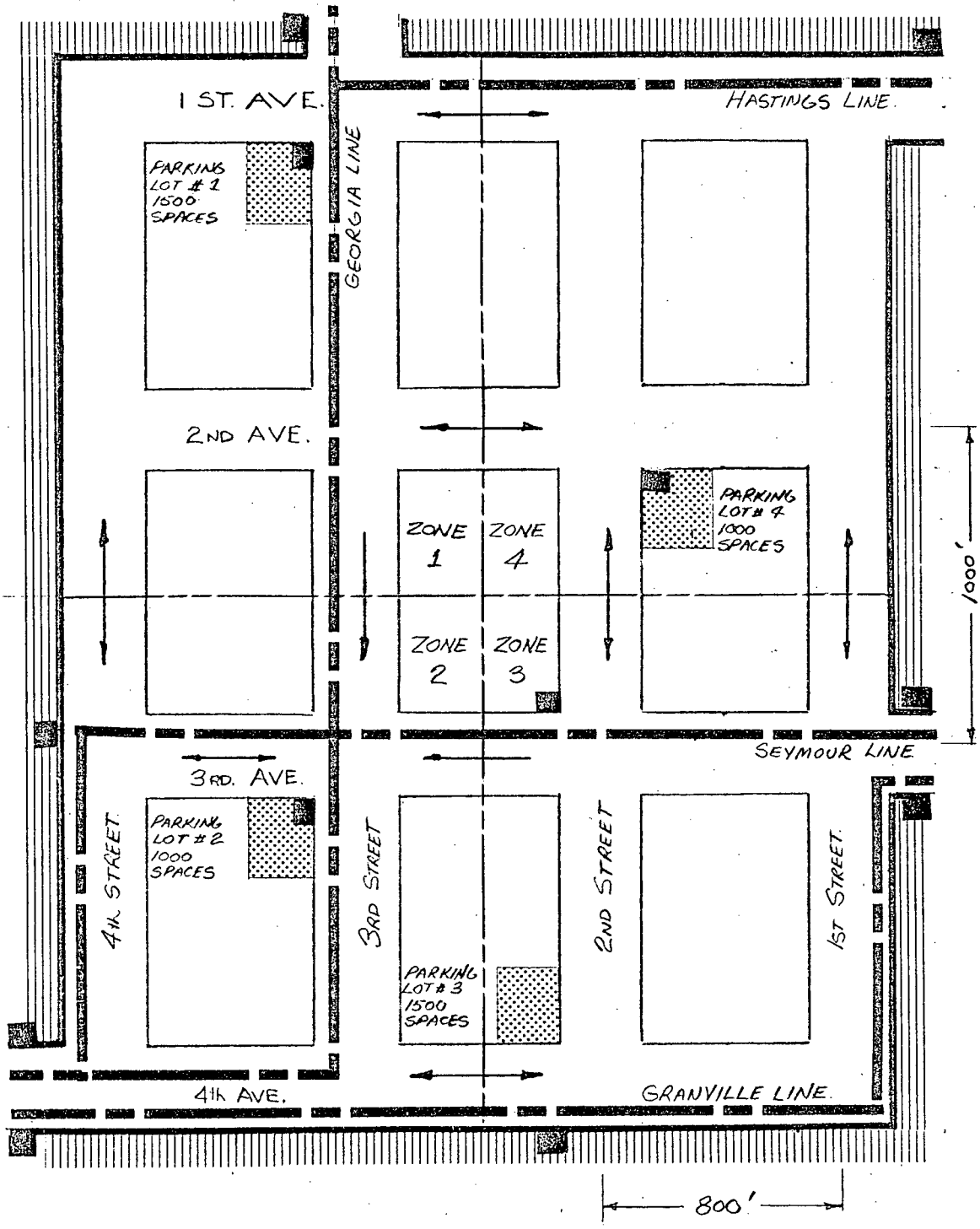


FIGURE 11 A DEMONSTRATION NETWORK

LEGEND:

BUS STOPS

BUS LINES

PARKING LOTS

ZONE DIVISION

TRAFFIC DIRECTION

A small network was developed for the purposes of demonstration in which (see Figure 11) there are 4 parking lots, 4 bus lines, and 8 different streets laid out on a grid. The east-west streets are 800 feet apart and the north-south streets 1000 feet apart. The network is divided into 4 zones with a parking lot and entrance to the network in each zone. The network is intended to represent a C.B.D. with a restricted number of access points.

Due to the fact that it is such a small network some modifications were made to the mode split model to make the input parameters more consistent with the choice situation faced by the downtown commuter. It was assumed that car drivers had already driven an average of 5.6 miles to arrive at the C.B.D. and had spent 20 minutes in their cars. Similarly it was assumed that the bus passenger had already spent 26 minutes on the bus. The travel times and distances computed by the programs for each mode in the C.B.D. would be added to these figures and input to the mode split model. In determining the acceptability of the results, the assumptions listed above and the size of the network should be kept in mind.

Some unrealistically large delays were obtained at the entry points and the parking lots. It was thought that this was due to the size of, and configuration of the network. The effect of the large delays on the results will be discussed later. The stochastic assignment model has been applied to the C.B.D. of Vancouver and produced reasonable results[2].

An origin-destination matrix for each of the modes - auto and transit - was generated by trial and error so that the network would be congested. Several steps were involved in the trial and error process:

(1) Headways for the bus routes were selected.

(2) The capacity of the parking lots and the prices charged were selected.

(3) The demand levels for auto and transit were selected.

(4) The framework was run until the system had reached equilibrium.

(5) The average speed for the automobiles on the network was used as an indicator of a congested network.

(6) Steps one to five were repeated until a reasonable level of congestion was attained (average automobile speeds less than 10 mph).

The demonstration was divided into three parts: (1) an illustration of the capabilities of the transit program, (2) an illustration of the equilibrium process and (3) an analysis of a short run policy question. In the first two, the differences induced in the system by specific price changes were examined. For example when demonstrating the capabilities of the transit program, the effects on detailed aspects of the transportation system were examined when a uniform increase of $1.00 was applied to all parking lots. Similarly the equilibrium process was examined by increasing the prices on three lots by 25¢ and the final lot by 50¢. This differential increase served to highlight important points in the iterative process of obtaining equilibrium. Finally the analysis of a short run policy question entailed determining the aggregate effects on the transportation system due to incremental price increases on one parking lot only and incremental price increases on all parking lots.

All of these price changes mentioned above are referred to as policies. They are considered to fall into two categories: (1) specific changes of prices on parking lots which occur once only, and (2) incremental changes of prices on parking lots which are applied several times. The former are referred to with alphabetic notation such as policy A, B, C, etc. and the latter with numeric notation such as policy 1, 2, etc.

6.2 Capabilities of The Transit Program

The features and capabilities of the parking allocation model and the vehicle stochastic assignment model are well documented by Fisk[3]. The assignment model is backed up with an extensive graphical presentation system and may be used with the modified framework for analysis.

The expanded portion of this framework which now includes the transit side of travel can be operated in two modes. It is possible to analytically examine the operation of the existing transit system in a limited interaction with the automobile network. On the other hand, it is possible to examine short-run planning questions where the analysis involves a full interaction of both the automobile network and the transit network. Limited interaction implies utilizing average vehicle speeds on the roads to determine the maximum speed of the buses. An operational examination might entail determining the loading of the buses, finding out where people get on and off the bus, determining the paths passengers follow through the transit system etc.. No iteration of the modelling system would be necessary to perform this type of study.

Full interaction implies the inclusion of both the effects of the physical interaction of the two modes and the interaction of the demand for the two modes. A short-run planning examination might include determining the effect of increased bus frequencies or parking charges on transit ridership and general congestion. It would be necessary to put the framework through several iterations for this type of analysis.

It is possible to obtain the following information from the transit model:

(1) The minimum transit path from any transit origin to any destination. This includes the invehicle travel time, excess travel time, the number of passengers on the bus at any point in the path, the bus lines taken and transfer points.

(2) Equilibrium data which includes the auto invehicle travel time for the previous and current iteration, the invehicle travel time for the bus for the current iteration, and the mode split from each origin to all destinations.

(3) The bus line statistics which include the number of persons on the bus and waiting at the stops, the time to travel from bus stop to bus stop which includes stopped time, the total time to run the route (one way) and the average speed over the route.

Two parking policies were tested in order to show the capabilities of the transit program. They are policies A and B and are shown in Table 2(a). The price difference between these policies is $1.00 on all parking lots.

TABLE 2(a) PARKING POLICIES USED TO ILLUSTRATE THE PROGRAM CAPABILITIES AND THE EQUILIBRIUM PROCESS

PARKING ZONE		1	2	3	4
POLICY	A	2.00	2.00	2.50	1.50
	B	3.00	3.00	3.50	2.50
	C	1.50	1.50	1.25	1.00
	D	1.75	1.75	2.25	1.25
	E	1.25	1.25	1.50	.75
	F	1.50	1.50	1.75	1.00

ALL VALUES ARE IN DOLLARS

Tables 3, 4, and 5 show the data output for the test. The minimum path print-out allows the analyst to trace the path of a transit user through any part of the system. The effects of any changes in the system on a particular origin-destination pair can be easily detected. Table 3(a) shows a minimum path print-out from the 3rd Street entrance to 4th Avenue. This particular minimum path is associated with parking pricing policy A. The total travel time is 671 seconds or 11.1 minutes with ½ minute taken to transfer. Since in this case the destination point is at a bus stop and the bus line is a through line (the people are already on the bus before it enters the study area), the out-of-vehicle travel time is low. As the bus enters the study area at 3rd Street there are 17 persons on the bus. At the stop at 1st Avenue and 3rd Street the passengers change from bus line 3 to bus line 1. Also at that bus stop passengers transferred from bus line 1 to bus line 3 to set the total departing on bus line 3 at 41 passengers. The total on bus line 1 departing from the same bus stop is 20.

Table 3(b) shows the same minimum path print-out under policy B which is $1.00 greater on all lots than under policy A. This has a profound effect on the transit travel time on this particular path. It is now 388 seconds or 6.4 minutes almost half of the time under policy A. The price increase also has the effect of increasing the number of riders on the bus to a maximum of 49.

Table 4(a) and 4(b) show average travel times from the given intersections to all destinations for both the automobile and bus mode. Note this is different from Tables 3(a) and 3(b) which give the travel time for an individual using the bus between a specific origin and destination. A comparison of Table 4(a) and 4(b) show that in general the average travel times are reduced by half between policy A and B. Both modes are effected in the same manner indicating that the bus speeds are tied to the general level of congestion.

MINIMUM TRANSIT PATH DATA

TABLE 3 (a) PARKING PRICE POLICY A

total travel time (secs) 671.
transfer, wait and walk time (secs) 30.

INTERSECTION		PERSONS ON THE BUS	BUS LINES AT THE NODE	
4th AVENUE		0.	1	4
4th AVENUE	4th STREET	11.	1	
4th AVENUE	3rd STREET	7.	1	
3rd AVENUE	3rd STREET	7.	1	
2nd AVENUE	3rd STREET	20.	1	
1st AVENUE	3rd STREET	41.	3	
	3rd STREET	17.	3	

TABLE 3 (b) PARKING PRICE POLICY B

total travel time (secs) 388.
transfer, wait and walk time (secs) 30.

INTERSECTION		PERSONS ON THE BUS	BUS LINES AT THE NODE	
4th AVENUE		0.	1	4
4th AVENUE	4th STREET	13.	1	
4th AVENUE	3rd STREET	8.	1	
3rd AVENUE	3rd STREET	8.	1	
2nd AVENUE	3rd STREET	24.	1	
1st AVENUE	3rd STREET	49.	3	
	3rd STREET	20.	3	

NOTE: Policy B is a $1.00 increase in parking prices on all parking lots

Page 69 omitted in numbering

TRAVEL TIMES FROM THE GIVEN INTERSECTION TO ALL DESTINATIONS

TABLE 4(a) PARKING PRICING POLICY A

INTERSECTION	AUTO CURRENT TRAVEL TIME	AUTO PREVIOUS TRAVEL TIME	BUS IN VEHICLE TRAVEL TIME	BUS EXCESS TRAVEL TIME
3rd STREET	4.5	4.5	9.2	0.7
4th AVENUE	4.4	4.4	4.4	3.9
1st AVENUE	3.6	3.7	6.1	0.7
3rd AVENUE	3.4	3.6	3.0	2.6

TABLE 4(b) PARKING POLICY B

INTERSECTION	AUTO CURRENT TRAVEL TIME	AUTO PREVIOUS TRAVEL TIME	BUS IN VEHICLE TRAVEL TIME	BUS EXCESS TRAVEL TIME
3rd STREET	2.1	2.3	4.5	0.7
4th AVENUE	3.3	3.7	4.2	3.9
1st AVENUE	2.6	2.6	5.8	0.7
3rd AVENUE	2.3	2.1	3.1	2.6

NOTE: Policy B is a $1.00 increase in parking prices on all parking lots

CAR AND BUS SPLITS FOR THE GIVEN INTERSECTION TO ALL DESTINATIONS

TABLE 5(a) PARKING POLICY A

INTERSECTION	PERSONS BY CAR	PERSONS BY BUS	AUTO SPLIT*
3rd STREET	947.	1126.	.457
4th AVENUE	1038.	1084.	.489
1st AVENUE	986.	1285.	.434
3rd AVENUE	918.	1102.	.454

TABLE 5(b) PARKING POLICY B

INTERSECTION	PERSONS BY CAR	PERSONS BY BUS	AUTO SPLIT
3rd STREET	677.	1396.	.327
4th AVENUE	828.	1294.	.390
1st AVENUE	744.	1527.	.328
3rd AVENUE	726.	1294.	.359

* Auto split is the proportion of tripmakers travelling by car

NOTE: Policy B is a $1.00 increase in parking prices on all parking lots

These results are not unreasonable given the nature of the network being used for demonstration. The magnitude of the results, however, cannot be construed as general indications of what might occur in a city where all parking prices were raised $1.00.

Looking at Table 4(a), it can be seen that normally travel by bus takes longer than by car. Also, there was little change in the travel time between the current iteration and the previous iteration. This is used as quick check to determine whether the equilibrium process has converged or not. Since the number of iterations is controlled manually, judgement is used to decide whether to terminate the process. In this case the differences were considered insufficient to warrant any further iterations.

The bus line statistics shown in Table 6(a) and 6(b) allow the analyst to determine the effects of any changes on any particular bus line. It is possible to determine where the maximum load point is, the load profile, the links of greatest delay and the average speed of the bus. The $1.00 increase in parking data also has an effect on bus operation. For example, the average speed of the bus almost doubles from 5.6 mph to 10.2 mph and the maximum number of people on the bus increases from 41 to 49.

To reiterate, the program provides information about the passenger's trip through the system, equilibrium statistics which are indicators of the general state of the system and detailed information about the bus routes through the system.

6.3 An Illustration of the Equilibrium Process

The following is an example illustrating the process whereby equilibrium of the system is obtained after a change in parking prices. The purposes of this test is to show that a change in parking allocation has an effect on the outcome of the equilibrium state, and also, to trace the process through

to equilibrium. The change in pricing is as shown in Table 2(a) under policies C and D. In policy D, all prices are raised 25¢ except zone 3 which is raised 50¢. The differential increase in parking prices was chosen for demonstration because when the prices are uniformly increased there are no significant changes in the allocation of cars to parking lots. The only changes that occur are in the mode split and the vehicular assignment. Differential price increases result in substantial changes in parking allocation in the case chosen.

Before going straight into the example, the theory behind the equilibrium algorithm given in Chapter 5 section 5.7 will be restated and the example will be explained with references to the theory. The theoretical framework for equilibrium is set out as follows.

1. Develop an initial network solution S.
2. Determine the best direction in which to proceed to obtain a new trial solution.
3. Develop a trial solution.
4. Obtain a new solution.
5. Determine whether S is a satisfactory final solution. If it is not, return to step 2.

Recall that there are several iterations required to obtain equilibrium after a parking price change is made. Recall also that several programs make up one iteration. After the initial network solution has been developed subsequent iterations consist of the execution of the parking allocation model (TRANS), vehicular assignment model (STOCH), and the transit assignment-mode split-equilibrium algorithm model (BUS).

BUS STATISTICS FOR BUSLINE NUMBER 3

TABLE 6(a) PARKING PRICING POLICY NUMBER A

headway = 1. minute
busline number = 3
busline name = Georgia
the average speed of the bus is 5.6 mph.

BUS STOP INTERSECTION		PEOPLE ON THE BUS	PEOPLE AT THE STOP	LINK, TIME & TOTAL TIME	BUS LINES AT THE STOP	
	3rd STREET	17.	17.	6.2	0	3
1st AVENUE	3rd STREET	41.	18.	2.3	3	
2nd AVENUE	2nd STREET	11.	0.	1.6	3	
3rd AVENUE	1st STREET	13.	0.	0.7	3	
3rd AVENUE		0.	0.	10.7	2	3

NOTE: TIMES ARE IN MINUTES

TABLE 6(b) PARKING PRICING POLICY NUMBER

headway = 1. minute
busline number = 3
busline name = Georgia
the average speed of the bus is 10.2 mph.

BUS STOP INTERSECTION		PEOPLE ON THE BUS	PEOPLE AT THE STOP	LINK, TIME & TOTAL TIME	BUS LINES AT THE STOP	
	3rd STREET	20.	20.	1.3	0	3
1st AVENUE	3rd STREET	49.	22.	2.4	3	
2nd AVENUE	2nd STREET	12.	0.	1.5	3	
3rd AVENUE	1st STREET	15.	0.	0.7	3	
3rd AVENUE		0.	0.	5.9	2	3

NOTE: Policy B is a $1.00 increase on all parking lots

TABLE 7 (a) AVERAGE TRAVEL TIMES FROM GIVEN INTERSECTIONS TO ALL DESTINATIONS FOR EACH ITERATION BETWEEN POLICY C AND D

NOTE: The price increase is 50¢ on parking lot 3, 25¢ on all others

ITERATION NO. / INTER-SECTION	1st MIN.	2nd MIN.	3rd MIN.	4th MIN.	5th MIN.
3rd STREET	8.3	7.1	5.0	6.5	6.0
4th AVENUE	6.1	5.9	5.6	5.9	4.7
1st AVENUE	6.1	5.0	4.4	4.5	4.5
3rd AVENUE	4.7	4.8	4.0	4.0	3.8

TABLE 7 (b) AVERAGE AUTO MODE SPLIT FROM GIVEN INTERSECTIONS TO ALL DESTINATIONS FOR EACH ITERATION BETWEEN POLICY C AND D

ITERATION NO. / INTER-SECTION	1st	2nd	3rd	4th	5th
3rd STREET	.492	.478	.487	.481	.480
4th AVENUE	.566	.539	.515	.503	.513
1st AVENUE	.496	.483	.475	.475	.476
3rd AVENUE	.506	.478	.477	.477	.480

* TIMES ARE IN MINUTES

TABLE 8 TRANSITION PARKING ALLOCATIONS FOR EACH ITERATION BETWEEN POLICY C AND D

NOTE: The price increase is 50¢ on parking lots, 25¢ on all others.

(a) first iteration

work zone \ parking zone	1	2	3	4
1	1315*			
2		1250	207	
3			1243	
4			191	1250

(b) second iteration

work zone \ parking zone	1	2	3	4
1	1312			
2		1250	206	
3			1252	
4	188			1250

* Persons arriving at the parking lot

TABLE 8 (cont'd) TRANSITION PARKING ALLOCATIONS FOR EACH ITERATION BETWEEN POLICY C AND D

(c) third iteration

work zone \ parking zone	1	2	3	4
1	1213			
2		1250	166	
3			1192	
4	175			1250

(d) fourth iteration

work zone \ parking zone	1	2	3	4
1	1211			
2		1250	137	
3			1172	
4	158			1250

TABLE 8 (cont'd) TRANSITION PARKING ALLOCATIONS FOR EACH ITERATION BETWEEN POLICY C AND D

(e) fifth iteration

work zone \ parking zone	1	2	3	4
1	1192			
2		1250	127	
3			1171	
4	145			1250

The program BUS is the last program of the iteration to be executed. The output of BUS is examined to determine whether another iteration should be undertaken or not. If the changes in the auto travel times, or changes in the auto mode split between iterations are small, then an equilibrium solution has been obtained and the iterative process is stopped. Table 7(a) and 7(b) show the travel times and auto mode splits for the iterations between policies C and D.

The first iteration travel times and mode splits shown in Tables 7(a) and 7(b) are the conditions associated with the equilibrium state of policy C. (see Table 2(a)). Table 8(a) shows the parking allocation associated with the same policy. The first iteration is the initial network solution S. The second iteration commences when the parking price changes are made and the parking allocation model produces the parking configuration shown in Table 8(b). The vehicle assignment model is run and then the transit assignment mode split model is run. The second iteration results of these two models are shown in Tables 7(a) and 7(b). The running of the three models in this order correspond with the process of determining the best direction in which to proceed to obtain a new trial solution, the second step in the framework set out above. The third step is imbedded in the transit mode split program, BUS. It takes the initial network solution S (the mode splits associated with that solution), compares them to the one just found and develops a trial solution using equations 24 or 25 from Chapter 5 section 5.7. The trial mode split is used to compute auto and transit demands for the next iteration. The average travel time and mode split displayed in Tables 7(a) and 7(b) is used to determine whether the solution is satisfactory or not. If it is not (and generally it is not

satisfactory after the second iteration), the process returns to step 2. The newly computed auto and transit demands are used in the next iteration of the models. The same steps are followed through without changing the parking prices. This allows the mode split, travel times and parking configurations to converge. The final and intermediate iterations to equilibrium are shown in Tables 7(a) and 7(b) and 8(b) to 8(e).

The previous discussion traced the modelling process with references to the theory. The following discussion touches on some of the changes in demands and travel times which took place during the process.

The prices for all zones were increased by 25¢ except for zone 3 which was increased by 50¢. The 50¢ increase in zone 3 results in a shift of 188 auto users (150 cars) from the parking lot in zone 3 to the lot in zone 1. Tables 8(a) and 8(b) show this. This change results in a reduction of auto travel time as shown in Table 7(a) between the first and second iterations. The auto mode split for iteration #2 is shown in Table 7(b) second iteration. Although the travel times for the automobile were reduced due to the parking shift, the added increase in parking costs and walking costs offset this gain and the auto split is smaller. The mode split of the second iteration is used to compute the origin-destination matrices of the third iteration. The change in the mode split between the first and second iteration is reflected in the reduced numbers of auto users in the third iteration (Table 7(b)). The reduction in auto drivers results in further reductions in auto travel times (Table 7(a) third iteration). The mode split for the third iteration is computed based on these travel times. All changes in the mode split are in the same direction except the one for 3rd Street. The reason for its reversal in direction will be discussed later. The others behave in a manner as predicted by the equilibrium theory, see Chapter 5 section 5.7 and Appendix A. There are anomalies in the travel times and the

mode split of the fourth and fifth iterations of the 3rd Street and 4th Avenue origins. These will also be addressed later. The travel times and mode splits for 1st Avenue and 3rd Avenue show an asymptotic approach to the equilibrium state.

6.3.1 Problems and Anomalies

Several problems were noted upon examination of the convergence process. The first problem was located in the parking allocation model. The 25¢ increase in zone 3 over the other zones resulted in drastic changes in the allocation of automobiles to parking lots. It can be seen that of those persons parking in zone 3 and walking to zone 4 almost all (188) shift to parking in zone 1 and walking to zone 4. This does not seem realistic. In the case where one parking zone was made 25¢ more expensive than all others, one would expect some shift but not a complete shift. The reason for this drastic change is that the parking allocation algorithm optimizes the trade-off between parking costs and walking time for the whole system (i.e. all users), not the individual. Another possible problem was noted with this model. Invehicle travel time was not considered to be important in the choice of parking lot. The choice was thought to be dictated by the parking cost and walking time. In this small demonstration network some links are heavily congested; so much so that walking is faster than driving. This condition may occur occasionally in the real world and the driver may choose to park further away from his destination and walk because walking is faster. In a heavily congested network a few extra vehicles added to the links significantly alter travel times and become important in determining the equilibrium state.

It appears that a parking allocation model which optimizes the individual's trade-off between parking costs and walking would be better. Some work should be done to determine whether invehicle travel time should be considered in the trade-off.

When a parking price increase resulted in a shift of the allocation of parked cars as well as shifts in the mode split the system did not converge to equilibrium in the fashion expected. It converged by oscillating about a value. When the price increase resulted in a shift of the mode split only, the system converged asymptotically as expected. Figures 12(a) and 12(b) show the convergence patterns for travel time and mode split for the former case and Figure 13(a) and 13(b) show the patterns for the latter case. These figures illustrate in graphical form the values of travel times and the mode splits produced by the iterations between the equilibrium states of each policy. Figure 12 is the result of a price increase of 50¢ on parking lot 3 and 25¢ on all other lots. The initial policy is C and the final is D; refer to figure 2(a). Figure 13 is the result of a price increase of 25¢ on all parking lots where the initial policy is E and the final is F.

According to the theory the system should have approached the equilibrium state asymptotically; refer to Chapter 5, section 5.7 and appendix A. Figure 12 illustrates that this was not the case.

Several reasons were postulated for the problem. The size, configuration and travel demands on the network produced some links with low volumes and low travel times and produced others with high volumes and unrealistically high delays (over 20 minutes per automobile in one case). The number of models and the manner in which they interact caused problems. The method of feedback of automobile travel time to the mode split model coupled with the small size of the network also caused difficulties.

FIGURE 12(a)

TRANSITION TRAVEL TIMES POLICY C TO D

NOTE: The price increase is 50¢ on parking lot 3, 25¢ on all others

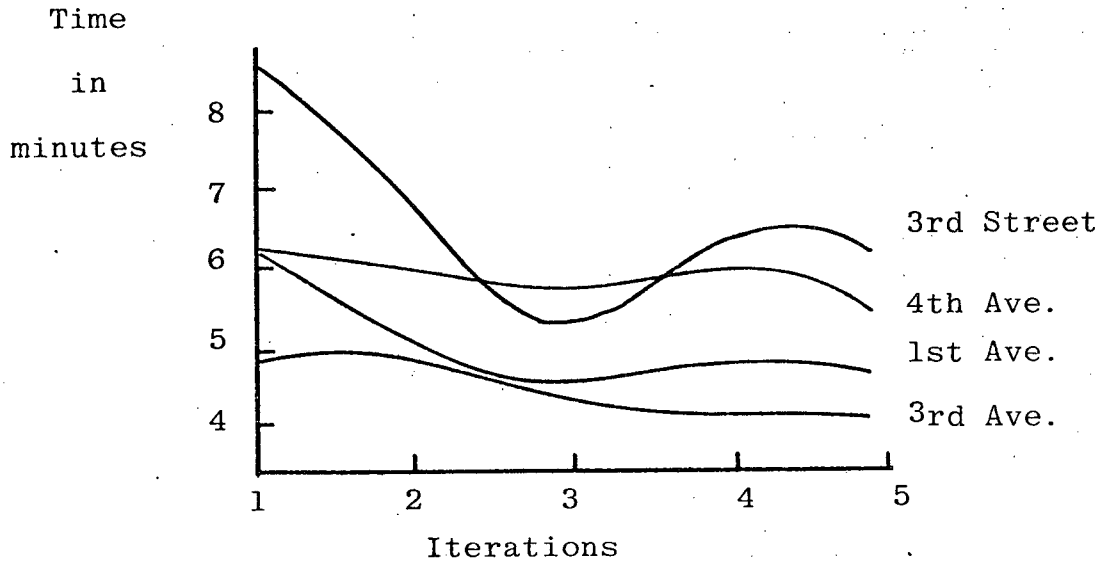


FIGURE 12(b)

TRANSITION MODE SPLIT POLICY C TO D

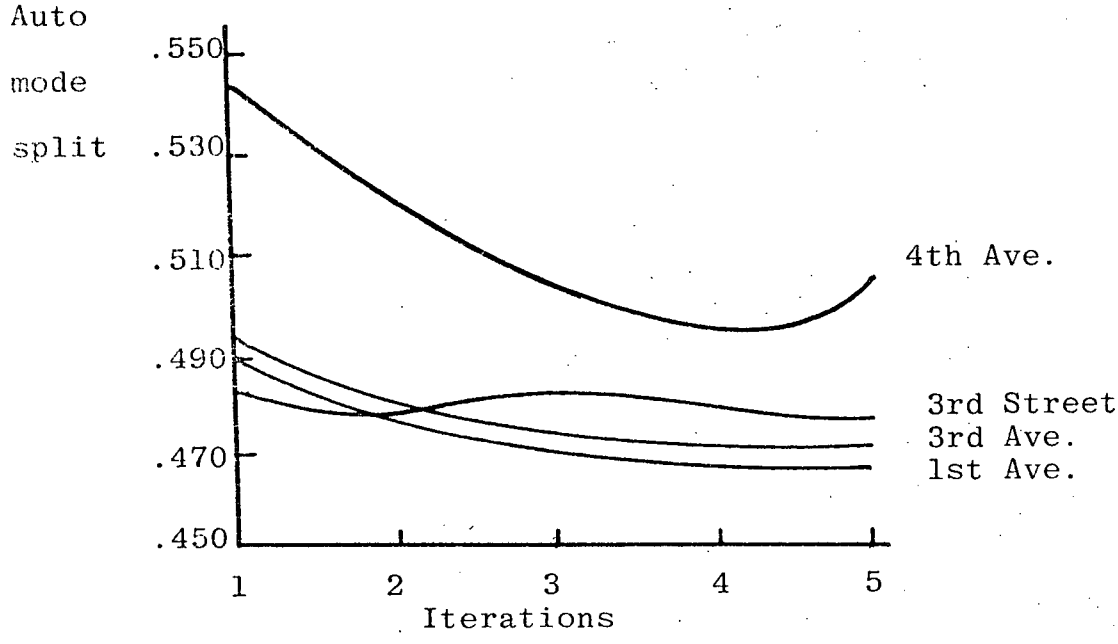


FIGURE 13(a)

TRANSITION TRAVEL TIMES POLICY E TO F

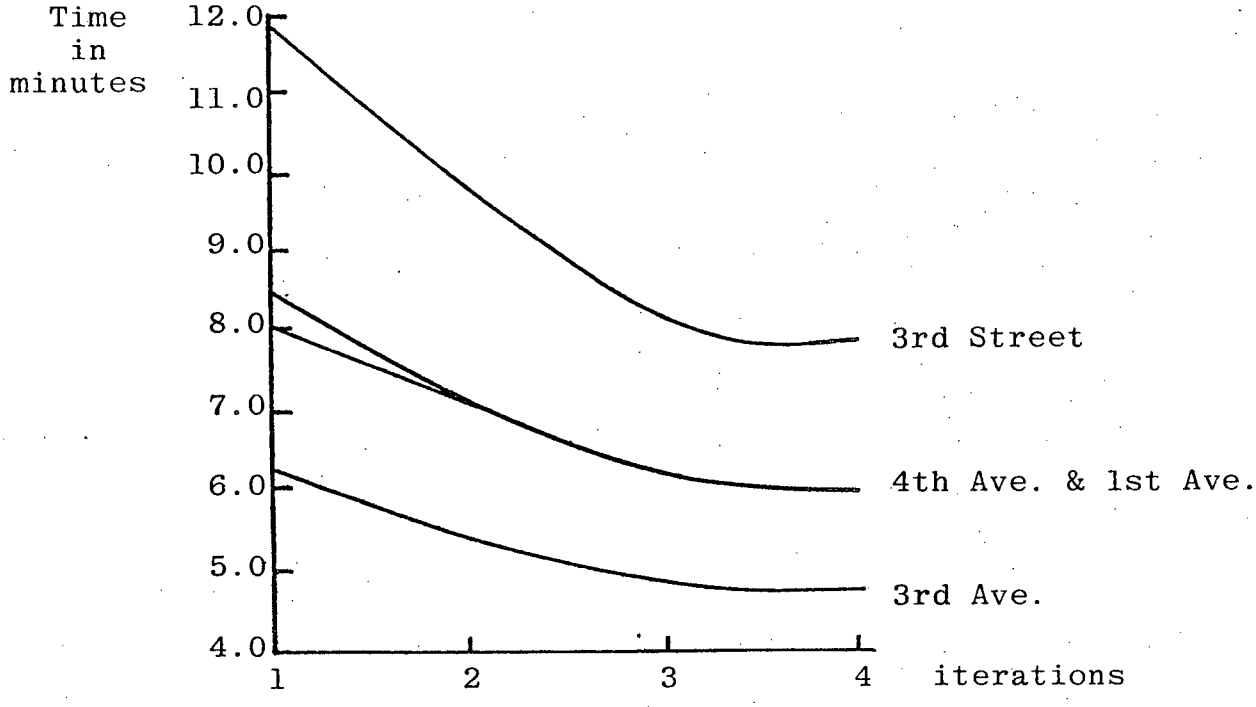
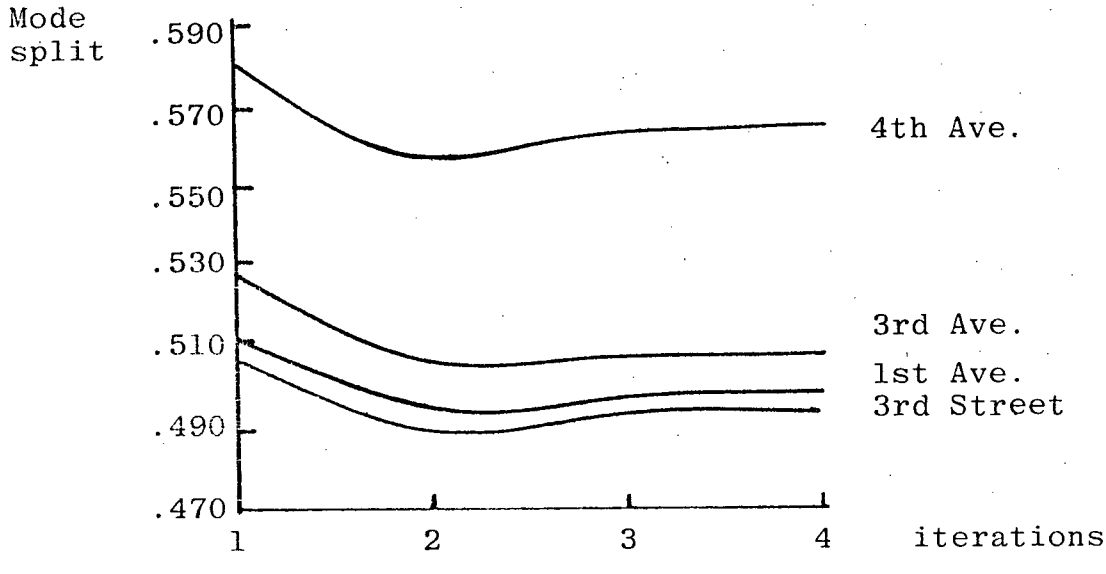


FIGURE 13 (b)

TRANSITION MODE SPLIT POLICY E TO F



NOTE: The price increase is 25¢ for all parking lots

Figure 12 shows the configuration of the network. There are four entrances and four parking lots. Delay and congestion is concentrated on the links around these points. The volumes on the links not directly connected to them are such that travel times are generally at slightly greater than free flow conditions. One would expect delays at entrances to the C.B.D., such as the bridges to Vancouver and at parking lots where vehicles converge. However, one would also expect the delays throughout the network to be of the same magnitude as those at the more heavily congested points. In the example, network travel times on most of the links range between 25 and 100 seconds while those at the congested areas range between 300 and 1000 seconds. This clearly is not realistic. Some work was done in order to alleviate this problem by adjusting the network and the location of the parking lots. However, adjustments had to be made through a trial-and-error approach and proved to be time-consuming and costly in computing costs. After several adjustments and some improvement it was decided to go ahead with the example runs. The difficulty encountered on the example runs then, was large changes in travel times with small changes in volumes on heavily congested links. This phenomenon of having a few unrealistically congested links and the remainder being lightly congested had repercussions on the results throughout the analysis.

Perhaps one of the advantages of the problem mentioned above is that it highlighted the weaknesses in the logic of the system and made it much easier to locate faults and make recommendations.

The second difficulty was found to have its source in the nature of the modelling system. Within the overall system there are three sub-systems which can alter demands on the vehicular and transit network. They are: the parking allocation, the vehicle assignment and mode split models. In the example chosen for demonstration all three make changes to the demand.

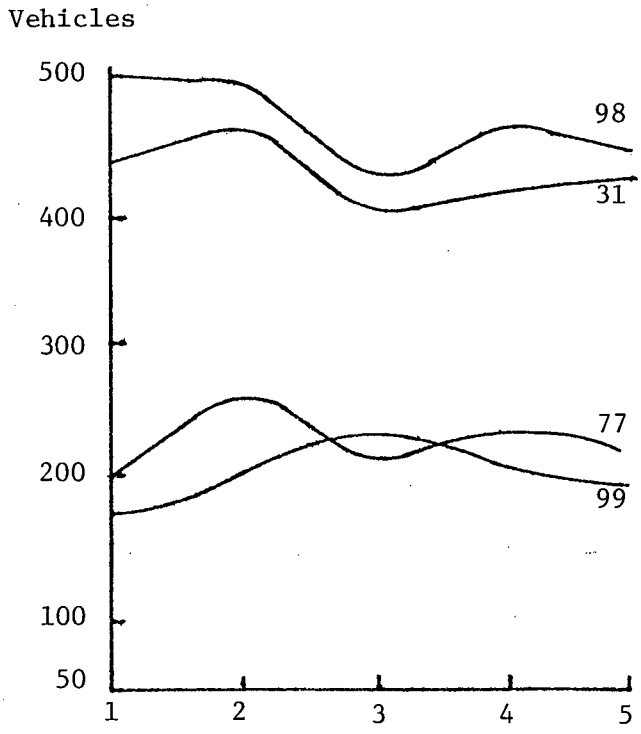
When parking prices are uniformly increased only the mode split and the vehicle assignment model make changes to the demand. The reason for this is that none of the parking lots gain an advantage over the others in terms of walking and parking costs. The approach to equilibrium is faster in this case. When prices are increased differentially all three sub-systems interact and the approach takes longer.

The problem was seen to be two-fold. It appears that firstly, the number of systems interacting has a significant effect on the approach to equilibrium and secondly, the degree of interaction or independence of the systems from one another. Each of the models operates independently in time and the models interact by passing aggregated demand data between one another. This is a sequential process and the difficulty with it lies in the fact that each sub-system -- except the mode split model -- perform their functions without any consideration of what has happened in the other sub-systems or in the previous iteration.

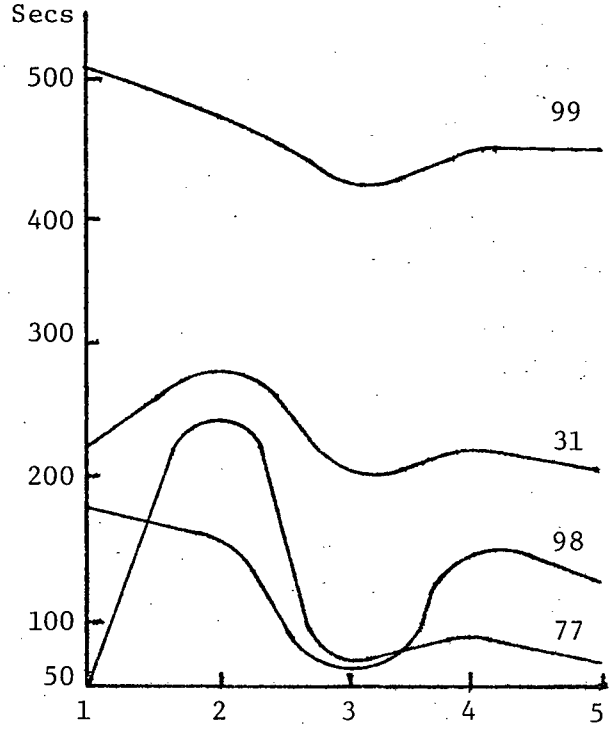
To illustrate this, the intersection of 3rd Street and 1st Avenue will be examined more closely. Figure 14(c) shows the intersection in detail with the location of parking lot #1. Only the links which are important to this analysis are shown. Figures 13(a) and 13(b) show the travel times and the volumes on congested links at this intersection for each of the iterations. This intersection is a good illustration of the interaction of the three models through the iterative process. The impact of the parking allocation model is noticed in the second iteration. The parking price increase reallocates cars from parking lot #3 to parking lot #1 and an increase in volumes on links 99, 31 and 77 are seen. These links enter the parking lot. Correspondingly there is a decrease of traffic on link 98 which feeds all the other parking lots.

FIGURE 14: TRANSITION TRAVEL TIMES AND VOLUMES ON LINKS INTO PARKING LOT I POLICY 2 INCREMENT 2 TO 3.

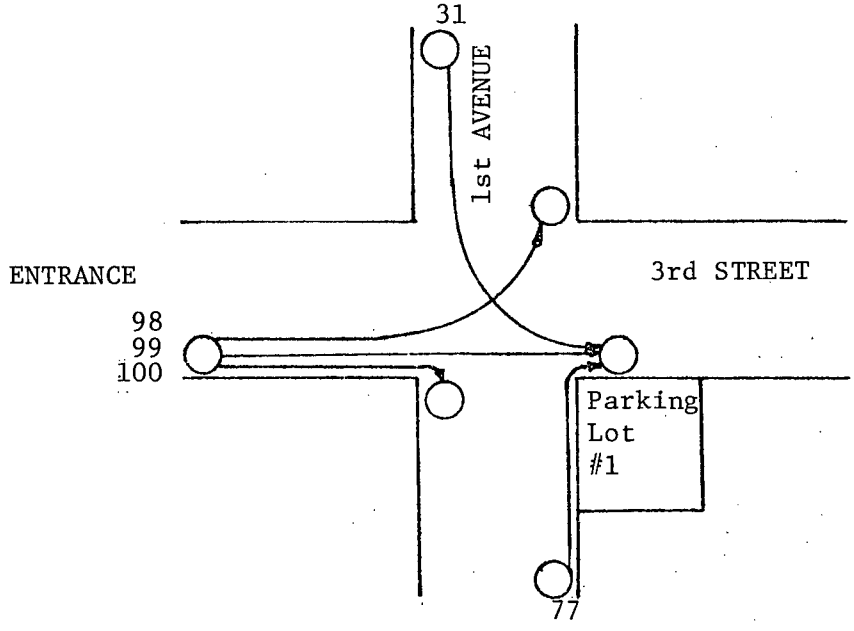
(a) Vehicles Vs Iterations



(b) Time Vs Iterations



(c) Intersection showing Parking Lot #1



The effect of the assignment model is seen in the computation of the travel time. The travel times on links 31 and 77 increase while on links 99 and 98 they decrease. One would expect there to be less travel time on link 98 because there are fewer vehicles turning left. However, on link 99 the travel time is also less although there are more vehicles on that link. This is due to the reduced interference with cars turning left on link 98.

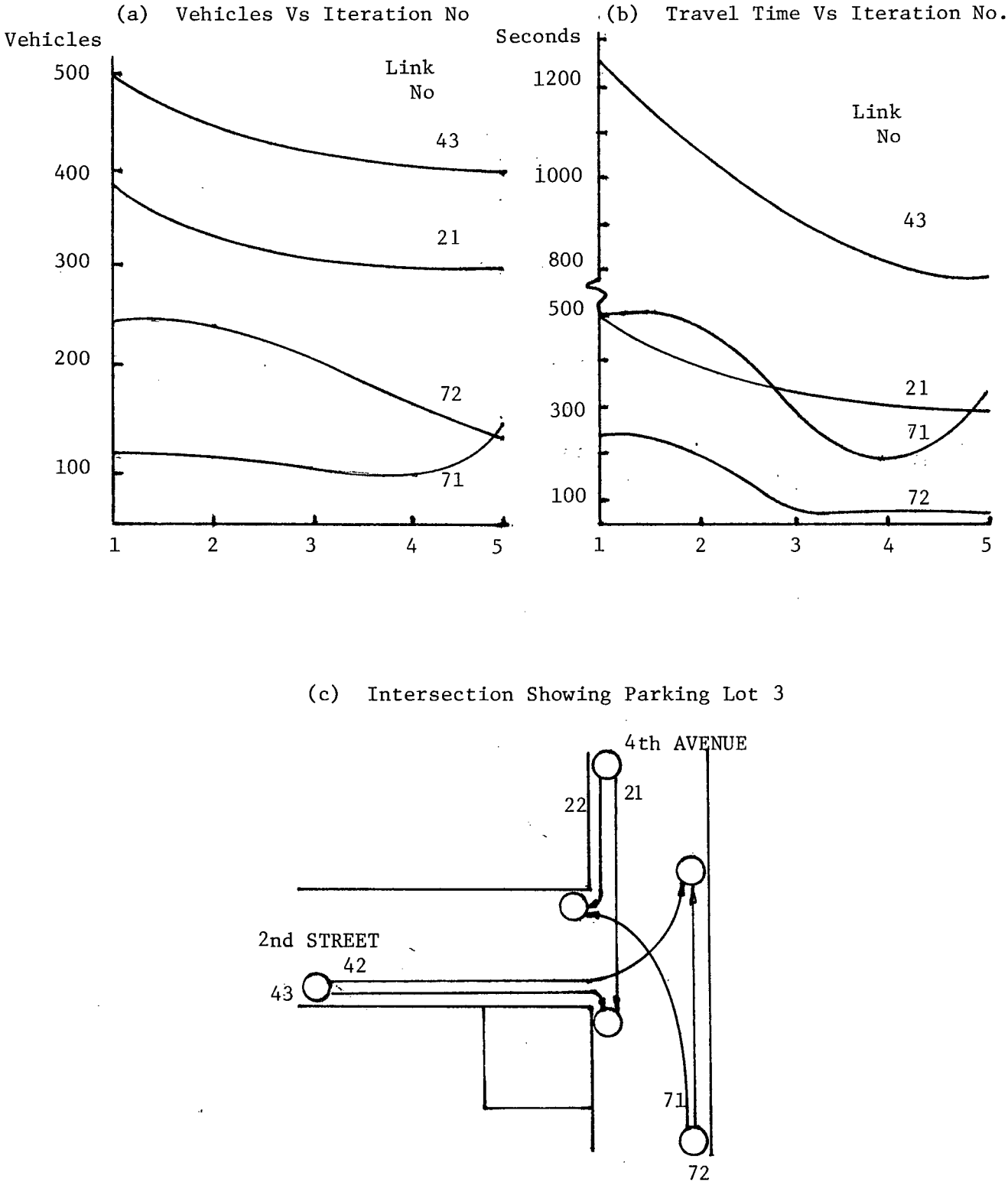
On the third iteration the impact of the mode split model is seen in the change of volume of vehicles on the links. It must be remembered that the mode split is based on the whole journey time and is influenced by travel time and parking costs. The mode split takes the parking prices and the travel times computed as a result of the parking allocation, and the assignment of vehicles, and computes the aggregate demands for the next iteration. In this case it is the third iteration. This is the first time that the effects of the price changes and travel time changes are passed on to the mode split. On links 31, 98 and 77 there are reductions in volumes and there is an increase in volumes in link 99. The combination of increased travel time, increased parking charges and increased average walking times due to the reallocation of parked cars caused the mode split to reduce the number of cars travelling to parking lot 1 via link 77 and 31. Link 98 carries traffic to all other parking lots from the entrance at 3rd Street and probably lost vehicles because of increased parking charges in other lots. Link 100 is not important because it carries only 14 to 20 cars. Link 99, on the other hand, gained auto traffic. Most of the traffic on this link goes directly to parking lot 1, so the reduction in travel time on this link between interation 1 and 2 was sufficient to offset the parking charge increase and induce more transit riders to take the car for this trip.

The process continues in this manner through the third, fourth and fifth iterations. It can be seen from the discussion above that the process is quite complex. When all three models are making changes simultaneously, the amplitude of the oscillations in travel time and vehicular volumes is quite large. In the third, fourth and fifth iterations where only two models interact, the system settles down. It appears that this may be one of the drawbacks of using an indirect approach to equilibrium. However, the approach does converge and does produce reasonable results (as defined at the beginning of Chapter 5); refer to Chapter 3, section 3.1 for a discussion on direct and indirect approaches. The more independent the models are in the sequential process, and the greater the number of models or systems interacting, the greater the number of iterations required to reach equilibrium. Since it is not possible to reduce the number of models and be consistent with the theory set out previously, perhaps work should be done to reduce the independent of the models. This could be achieved by modifying the equilibrium algorithm (refer to Chapter 5, section 5.7) so that it would allow smaller incremental changes in the mode split when large changes in travel time between iterations were detected. There may also be other methods which could be examined.

It must be emphasized that before any of these changes can be considered, the system should be tested on a more realistic network. The problems noted here may simply be a result of the network used.

The final problem noted was the computation of the automobile travel time which is used to compute the mode split. The stochastic assignment model did not compute the cumulative travel time from origin to destination. It was necessary to add a function to the assignment model which would extract this information. It was thought that a minimum path search applied after the vehicular assignments had been completed, and the travel times associated with that assignment had been computed would be adequate. It was expected that there would not be a significant difference in travel time between a set of possible routes connecting an origin and a destination. Further, it was thought that the majority of vehicles would travel the route of shorter time and hence, this method of computing automobile travel would be a good approximation of the journey time. It must be pointed out again that the assignment on this network produced travel times on most of the links under 100 seconds and on the remainder over 300 seconds. To reiterate: the links with high travel times are heavily loaded, they are directly connected to the entrances of the network or the parking lots, and they differ greatly within the range of 300 to 1300 seconds. For example: links 43 and 21 entering the parking lot in zone 3 have travel times of 1300 and 500 seconds respectively on the first iteration; refer to Figure 15(b) and 15(c). The links connecting these links have travel times under 100 seconds, with the exception of one case which is 830 seconds and that is due to the traffic entering the network at 3rd Avenue. The minimum path search can avoid the link with the travel time of 1300 seconds by taking a circuitous route through the network and compute journey times which are considerably less than the average.

FIGURE 15: TRANSITION TRAVEL TIMES AND VOLUMES ON LINKS INTO PARKING LOT 3 POLICY 2 INCREMENT 3.



If the network was representative of real world conditions, and delays on all links were of the same magnitude, this problem would not be significant. It is recommended, however, that the sensitivity of the results to the use of the minimum path search to obtain auto journey times be examined using a realistic network.

6.4 An Analysis of A Short Run Policy Question

The small network was used to perform the analysis. The results from this analysis will be very general indications of the effects of parking price increases on congestion. As already noted, there are some unrealistically congested links in the network. Two short run policy questions were posed. The first was: what would be the effect of raising the cost of parking in parking lot #3 by increments of 25¢ three times with a final increase of $1.00. The second entailed determining the effect of increasing parking prices on all parking lots in the same manner as above. There was one exception in this case where the prices of parking lot #3 were increased 50¢ on the second increment. This is the scenario which was analysed in detail previously. Table 9 shows the price increase for the two policies in each parking lot. The reason that the two different policies were selected for analysis was because municipalities generally control only a fraction of the parking spaces in the C.B.D. The first policy approximates the case where the municipality decides to increase the rates in its own parking lots. The second policy approximates the case where the government is able to levy a tax on all parking lots.

With the data output from the programs, it is possible to examine the policies at several levels. Total hours of travel time versus total travel costs can be examined. The shift in the mode split for each of the different policies can be looked at. Usage and statistics on particular bus lines can

TABLE 9 PARKING PRICE POLICIES

PARKING ZONES	1	2	3	4
ORIGINAL POLICY	1.25	1.25	1.50	.75
POLICY #1				
increment #1	1.25	1.25	1.75	.75
#2	1.25	1.25	2.00	.75
#3	1.25	1.25	2.25	.75
#4	1.25	1.25	3.25	.75
POLICY #2				
increment #1	1.50	1.50	1.75	1.00
#2	1.75	1.75	2.25	1.25
#3	2.00	2.00	2.50	1.50
#4	3.00	3.00	3.50	2.50

All Prices are in Dollars

NOTE: Policy #1 is an Incremental Increase of the Parking Price in Parking Lot 3 only.

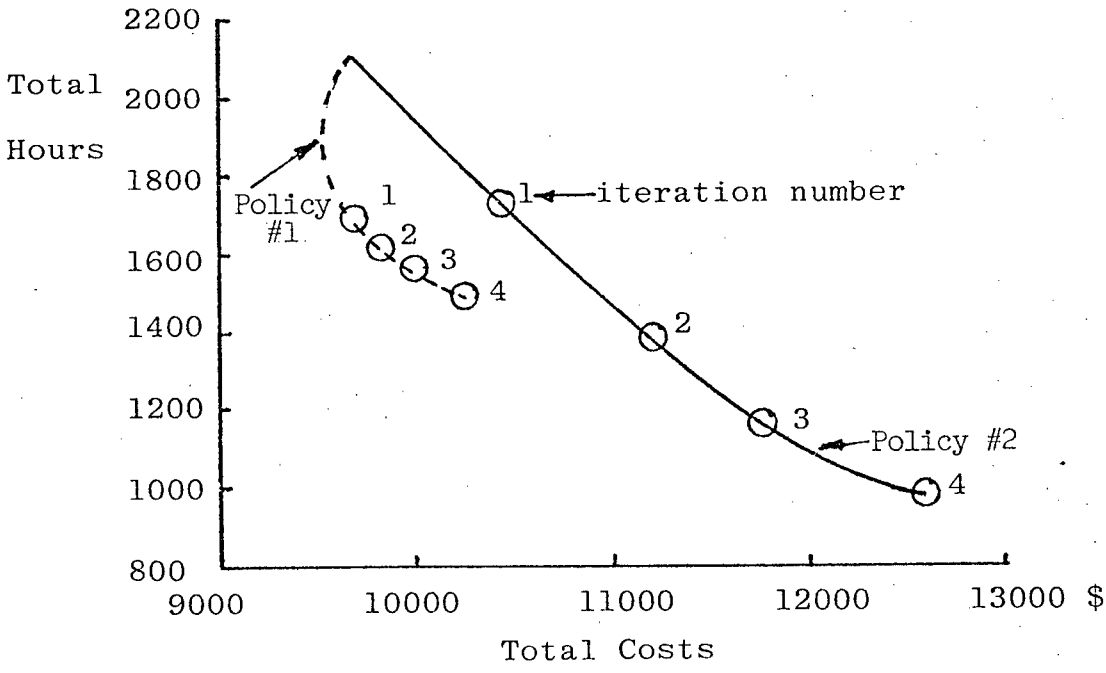
Policy #2 is an Incremental Increase of the Parking Price on all Parking Lots

be examined. The effect of the changes on the individual's transit trip can be traced.

Generally, the purpose of increasing parking prices in the C.B.D. is to induce more efficient use of the auto and better utilization of public transit for the purpose of reducing road congestion. The effectiveness of these policies is generally measured in the number of hours of travel time saved. Figure 16 is a plot of the total hours travelled versus the travel costs for each policy. The total hours travelled include walking time and

FIGURE 16

TOTAL HOURS VERSUS TOTAL TRAVEL COSTS



invehicle time for both modes. The travel costs include; parking charges, bus fares, and the marginal cost of driving the car. The marginal cost of driving was approximated by assuming that the average trip was 6 miles and the gasoline costs were 10¢ per mile (1964 dollars).

The first price increase in policy 1 results in a significant reduction in total numbers of hours travelled and a slight reduction in the total cost

of travel. This result can partly be attributed to the unrealistically congested links and may not be valid. One would expect an increase in total travel time with a reallocation of parked cars due to a price increase. A price increase on one lot should result in either a shift to another lot which is further from the final destination and therefore a longer walk, or a shift to transit which is usually slower than the automobile. This is a case of the parking allocation model not taking into account the fact that there may be a trade-off between walking and driving when driving is the more time consuming. The remaining results appear more realistic. Policy 2 is much more effective in reducing congestion. However, the costs to society are much greater. If one were to raise the parking prices to the highest level shown for policy 2, the cost to society would be $2,669 and the total time savings are 906 hours. The value of time would have to be no less than $2.90 per hour to justify this course of action. On the other hand, if one were to raise the prices to the highest level shown in policy 2, the cost to society would be $473 and the time savings 437 hours. The value of time in order to justify this course of action would have to be at least $1.08. In terms of unit cost to society, policy 1 is better. However, it is not as successful at reducing congestion as policy 2. It should be noted that there are other costs or savings which were not taken into account here. For example: noise, pollution, and the costs or savings to the bus operator were not included. By developing and applying the proper functions, all of these factors could be obtained from the models.

TABLE 10 AGGREGATE STATISTICS OF THE SYSTEM FOR THE FINAL STATE OF EACH POLICY

STATISTIC \ POLICY	ORIGINAL POLICY	POLICY #1 INCREMENT #4	POLICY #2 INCREMENT #4
Average transit Share of the Demand	46.9%	48.4%	65%
Average Speed of the Bus	7.27 MPH	7.88 MPH	10.43 MPH
Average Speed of the Car	4.15 MPH	6.18 MPH	16.22 MPH
*Average Speed of the Car with High Link Delays Adjusted	7.5 MPH	9.15 MPH	———

*NOTE: The average speed of the car is lower than the bus in the first two policies because the bus does not travel over some of the heavily travelled links. There were 6 links with travel times greater than 300 seconds (5 min or less than 2.3 mph.). In order to demonstrate the distortion created by these large delays, the average speeds were recalculated by reducing the travel times on these particular links to 200 seconds.

Table 10 shows the aggregate transit statistics for the different parking policies. Policy 1 results in very little change in the average speed of the buses and little change in the numbers of people using the bus. Policy 2, on the other hand, shows considerable improvement in both the transit ridership and the average speed of the buses. The benefits of policy 1 are due to a slight reduction in congestion only. The benefits of policy 2 are a result of a considerable reduction in congestion, increased ridership of transit, increased speed fo the buses and reduced pollution and noise due to the fewer number of cars on the road. Although generalized conclusions should not be drawn from this analysis because of the problems with the network, it appears that the analysis confirms the

experience with parking price increases. That is, that where the municipality attempts to increase the prices of parking lots under its control, little is gained in the way of reduced congestion or increased transit ridership. It suggests that for parking policies to be effective in reducing congestion and increasing transit ridership, it is necessary to control all parking - which includes illegal parking, off-street parking, street parking and parking provided free by employers.

The modelling system developed for this paper is capable of analysing changes in the bus system and auto network as well as the parking system. Bus lines may be dropped or added; the frequencies may be changed or bus stops may be relocated and the effect of exclusive bus lanes may be tested. The street network may be changed, new links may be added or dropped, the direction of flow on the streets may be changed and traffic lights and intersection design may be changed. Before any new analysis should be done, the modelling system should be tested on a more realistic network.

FOOTNOTES

1. F.P.D. Navin, C. Fisk, "A Downtown Traffic Management System", Prepared for the Canadian Transportation Research Form Annual Meeting, St. Andrews, New Brunswick, 1977, p.9.

2. Ibid., pp. 13-14.

3. C. Fisk, "A Transportation Planning Model for Detailed Traffic Analysis", Transportation Research Series Report No. 11, The University of British Columbia, Department of Civil Engineering, 1977.

CHAPTER 7

7.0 CONCLUSIONS

The purpose of this paper was to develop an analytical framework to answer short range policy questions. This type of framework is needed because until recently most models dealt with long range capital investment decisions while many urban transportation problems may be solved through short range policies.

First, the theoretical considerations of the short range planning framework were examined. The literature indicated that in order for the framework to be responsive to policy changes it must be sensitive to changes in attributes of transportation alternatives that would result from policies being analysed[1]. Also it must be structured in such a way that it reflects the choice process of an individual deciding between the alternate transportation modes. Changes in parking prices in the demonstration network resulted in changes in travel times and mode splits. The modelling system developed has been shown to be responsive to changes in service levels of the different modes and reflect the choice process. The accuracy of the model's predictions cannot be obtained until a full scale network is tested.

Several conditions enumerated by Manhiem were deemed as being necessary to ensure consistency in this type of a model. The equilibrium conditions are as follows:

(1) The level of service must enter at each stage in the sequence unless it is explicitly found to be superfluous.

(2) The same attributes of service should enter at each step unless the data indicates otherwise.

(3) The same values of the level of service should influence each sub-model.

(4) The level of service provided by each mode should influence the demand to some degree.

The degree to which the modelling system meets these requirements will be addressed in the same order as they are listed above.

(1) The system developed in this paper computes four level of service factors. They are the auto and transit in-vehicle and out of vehicle travel times. Table 2 shows each of the models in the system and indicates whether the listed levels of service are considered in the models.

The models in the table are listed in the order in which they are executed. It is easy to trace through the process and determine where each of the levels of service are utilized. It begins with the parking allocation model which, using the parking charges and auto walk times, transforms the person O-D trips by auto into vehicle O-D trips. The person O-D trips are in the form of ultimate origin and destination while the vehicle O-D trips are in the form of ultimate origin and parking lot destination. It was suggested in Chapter 6 section 6.4 that the inclusion of the auto in-vehicle travel times might improve the allocation. The remaining two transit levels of service are unnecessary in the parking allocation model because they are irrelevant to a decision which considers a trade-off between parking costs and walking time.

The process moves along to the vehicle assignment model utilizing the vehicle origin-destination trips and the auto in-vehicle travel times to compute the vehicle assignment. Chapter 4 section 4.2.5 discusses how travel times are incorporated in the assignment model. The vehicle travel times are translated into average speeds on the links which set the maximum speed for the buses in the transit assignment. The computation of bus in-vehicle travel times and walk-wait times is described in Chapter 5 section

TABLE 2 SYSTEM SUB-MODELS VERSUS LEVEL OF SERVICE AND SERVICE ATTRIBUTES

MODEL	DEMANDS	SERVICE ATTRIBUTES			LEVEL OF SERVICE			
		PARKING CHARGES	BUS FARES	FREQUENCY OF SERVICE	AUTO WALK TIMES	AUTO INVEHICLE TIMES	BUS WALK & WAIT TIMES	BUS INVEHICLE TIMES
parking allocation	person trips by auto	X			X			
vehicle assignment	vehicle O-D trips					X		
transit assignment	person O-D trips by transit			X		X	X	X
mode split	person trips by auto and transit	X	X		X	X	X	X

5.4.

The mode split model is the pivot point of the system. All service levels are represented. It is through the mode split that the service levels computed by the previous iteration are translated into new demands for the next iteration. In this manner also, all service levels are implicitly represented through out the system by the revised demands.

(2) The attributes of service are the parking charges, bus fares and frequency of bus service. These enter the sub-models where they have a direct impact. As is the case with the level of service factors, they are indirectly represented in all systems through the mode split.

(3) Where the level of service factors are repeated in the different sub-systems they are the same value throughout any given iteration. It is after the mode split and when a new iteration begins that the level of service factors are changes.

(4) The level of service provided by each mode influences the demand for travel by the two modes through the mode split model.

From a theoretical point of view all of the equilibrium conditions set out by Manhiem have been met, however, an examination of the impact of including the auto travel times in the parking allocation model has been recommended.

The modelling system was tested using a small network. Several recommendations and conclusions arose out of this test procedure. The purpose of testing was to show that the system produced reasonable results. It was defined that to be "reasonable" the results should meet the following criteria:

(1) any changes in service levels or parking charges would result in shifts of demand in the appropriate direction;

(2) that the changes in demand will be proportionate to the change in level of service and vice versa.

The size and configuration of the demonstration network produced delays on some links which were not representative of delays on a real network. It was concluded that although these results served to highlight the weakness of the system, a more realistic network should be developed with the test network the system of models produced results which were reasonable. The first criteria was satisfied in that when travel times of a mode were reduced the use of that mode increased and when the parking costs increased the use of the automobile dropped. It appeared also, that all changes in levels of service were proportionate to changes in demand and vice versa except in the case of the parking allocation model. In this case a large change in the parking allocation occurred due to a small change in price. It was thought that this occurred because the parking model optimized the trade-off between parking costs and walking time for the whole system, not the individual user.

Some problems were noted in the equilibrium algorithm. The system did not converge asymptotically as expected. It converged by osillating with decreasing amplitude about a value. The problem was seen to be two-fold. It appeared that the number of systems interacting and the independence of the sub-systems from one another caused the problem. It was thought that the independence of the sub-models could be reduced by modifying the equilibrium algorithm so that it would allow smaller incremental changes in the mode split when large changes in travel time between iterations were detected.

It was noted that the computation of the automobile journey times for the mode split using a minimum path algorithm produced low travel times for

the auto mode. This was largely attributed to the fact that the delays on the links on this particular network varied from tens of seconds to thousands of seconds. It was thought that in a realistic network such variations would not occur and the minimum path algorithm would compute travel times representative of real times.

Despite the problems with the network, the analysis of the two parking policies tested generally confirmed the experience with parking price increases. The results suggests that for parking policies to be effective in reducing congestion and increasing transit ridership, it is necessary to control all parking.

At the beginning of this demonstration it was noted that a model must be shown to be practical, reliable and economical. The objective of the demonstration was to show that the model was practical and produced reasonable results. The remaining criteria mentioned above could be addressed by others. The demonstration was successful in showing the reasonableness and practicality of the results. It is not possible at this point to state that the model is accurate. It is possible to say that in general it produces results as expected, given the testing network. The demonstration did succeed in pinpointing several weaknesses and providing insights into how the system behaves.

FOOTNOTES

1. T. J. Atherton, J. H. Suhrbier, and W. A. Jessiman, "Use of Disaggregate Travel Demand Models to Analyse Car Pooling Policy Incentives", Transportation Research Board, 599., 1976, p.35.

CHAPTER 8

8.0 RECOMMENDATIONS

A set of recommendations arose out of the analysis of the test network.

Before any of the following suggestions are carried out it is recommended that an unmodified version of the modelling system developed in this paper be tested on a more realistic network. This may result in the clarification of the doubts which gave rise to some of the following recommendations.

Two deficiencies were noted in the parking allocation model. The model considers a trade-off between parking costs and walking time in representing the decision made by the commuter. It was thought that the model would be improved if the invehicle travel times on a congested network were also considered in the model. This suggestion was made because the choice of a parking lot not only affects walking time and parking costs but on a heavily congested road system in the C.B.D. the choice could have a significant effect on invehicle travel time.

It was thought that there may be a problem in the way the parking allocation modelled the trade-off between the two variables. The model minimizes the sum of the parking costs and walking costs for all users. This resulted in large shifts in parking demand due to small changes in parking prices. It was thought that this behaviour was not realistic. However, a conclusive statement cannot be made due to the lack of empirical data concerning parking behaviour. A model which optimizes the trade-offs for the individual rather than all of the drivers would represent the choice process better. It is recommended that research be undertaken in order to more fully understand the behaviour of commuter parking in the C.B.D.. With this knowledge the model may be modified so that it accurately reflects that behaviour.

Appendix A illustrates the reasoning behind the choice of a modifier for the mode split in the equilibrium algorithm. The mode split itself was selected as a modifier because it was the most efficient in bringing the system to convergence. Under a test model and network in Appendix A the system reached convergence through an asymptotic approach in three or four iterations. The results produced by the larger framework were different. Equilibrium was obtained by osillating with decreasing amplitude about a value and four to five iterations were required for convergence. Two factors were seen to contribute to the difference. First there are four sub-models in the larger system whereas there were only three in the test system of Appendix A. Secondly, the sub-systems operate relatively independently from one another. One recommendation has already been made to include invehicle travel time in the parking allocation. This would serve to reduce the independence between the parking allocation and vehicle assignment models. It is also recommended that the influence of the modifier in the equilibrium algorithm be examined more thoroughly. The testing should be done on the full size modelling system. Research in this area may provide a better understanding of the mechanisms involved in the convergence to equilibrium and lead to improvements in the modifier.

The automobile journey time for the mode split model is computed by a minimum path algorithm after the network has been loaded. Due to the large variations of travel times on the links (from tens of seconds to thousands of seconds) the minimum path algorithm computed low journey times (i.e. it selected links with low volumes and small delays). It is recommended that the sensitivity of the results to the use of a minimum path algorithm to obtain auto journey times be examined using a realistic network.

The mode split model used was developed and calibrated in 1964 for a

study in Toronto[1]. It was satisfactory for the purposes of testing and demonstration in this paper. However, it is recommended that if a study is to be undertaken on a real network, the logit model should be calibrated to the conditions of the area being studied.

The development of a modelling system proceeds in several stages. The theory and a modelling system have been developed. The system has been tested on a small network and has been shown to produce reasonable results. It has been recommended that a more realistic network be used for further testing. Subject to the outcome of those tests a set of refinements and sensitivity tests were recommended. Once these have been completed the final task is to show that the system is practical, reliable and economical. Upon satisfactory completion of the recommendations above the system would be ready for a practical application.

FOOTNOTES

1. D. W. Gillen, "Effects of Changes in Parking Prices and Urban Restriction on Urban Transport Demands and Congestion Levels", University of Toronto-York University, Joint Program in Transportation, 1975, pp. 28 - 35.

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APPENDIX A

DEVELOPMENT OF A MODE SPLIT MODIFIER

APPENDIX A

The following is a discussion on the development of a modifier of the mode split. The computation of the trial mode split is the pivotal point of the methodology set out in the main text. The trial mode split computes the new transit-auto demands for the next iteration. Theoretically the trial mode split can range from the old mode split to the new mode split. The old mode split in fact is the trial split of the previous iteration. The new mode split is computed based on the level of service and service attributes of the present iteration. It was found that the value of the trial mode split within this range had a significant influence on the convergence of the solution. Figures 17 a to b illustrate the effect of different modifiers on the convergence of the solution. The purpose of this appendix was to develop a modifier of the new mode split such that the trial mode split would produce a swift convergence to the solution.

It was not possible to develop such a modifier mathematically and accurately predict its effects. This was due to the indirect nature of obtaining the equilibrium solution; see Chapter 3 section 3.1. It was necessary to determine the function of the modifier empirically. Two approaches could have been taken in order to solve this problem. The full set of computer programs could have been written and run using different functions to compute the modifier. The second approach would have been to isolate the essential functions in the larger framework and build them into a small system which replicates the larger system. It was decided to take the second approach because it was thought to be more flexible and amenable to experimentation. It was also less costly and time consuming than the first approach. The draw-back of the second approach would be the loss of an understanding of the exact behaviour of the larger system.

FIGURE 17

PARKING PRICE INCREASE FROM $1.50 TO $2.50

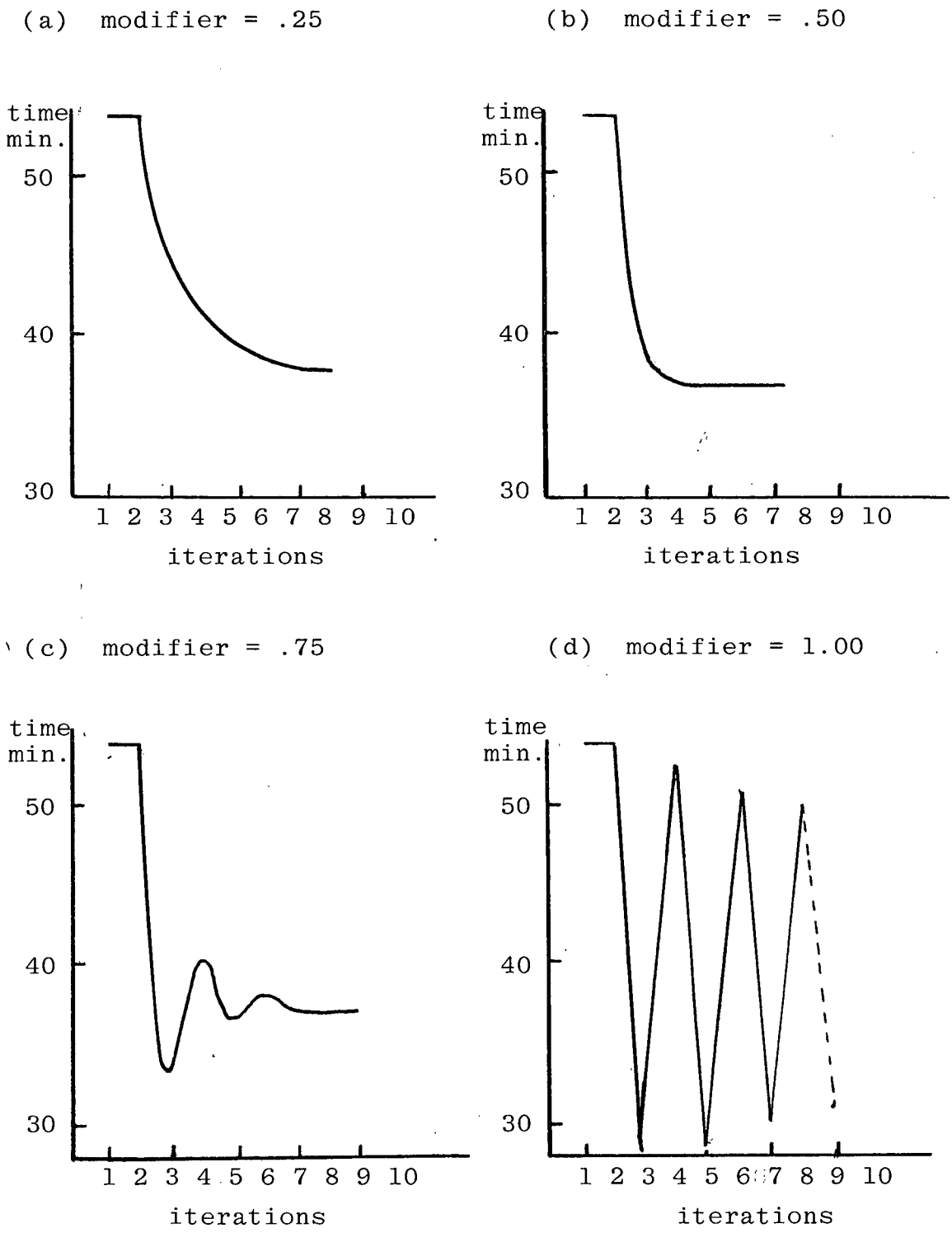
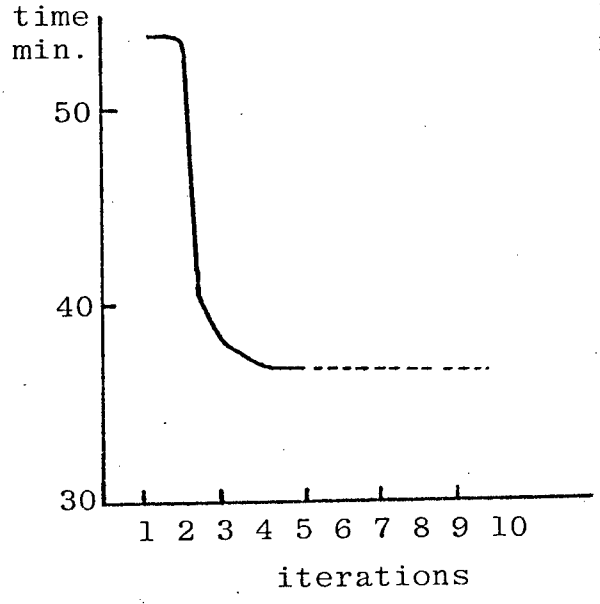


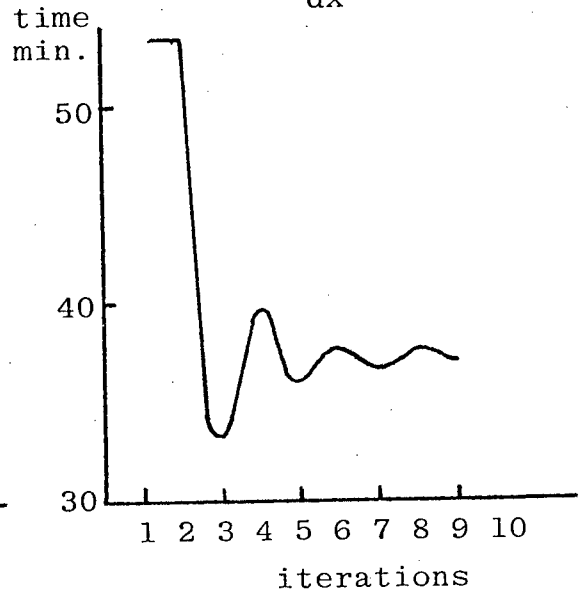
FIGURE 18

AUTO TRAVEL TIME VERSUS NUMBER OF ITERATIONS

(a) modifier=f(logit function)

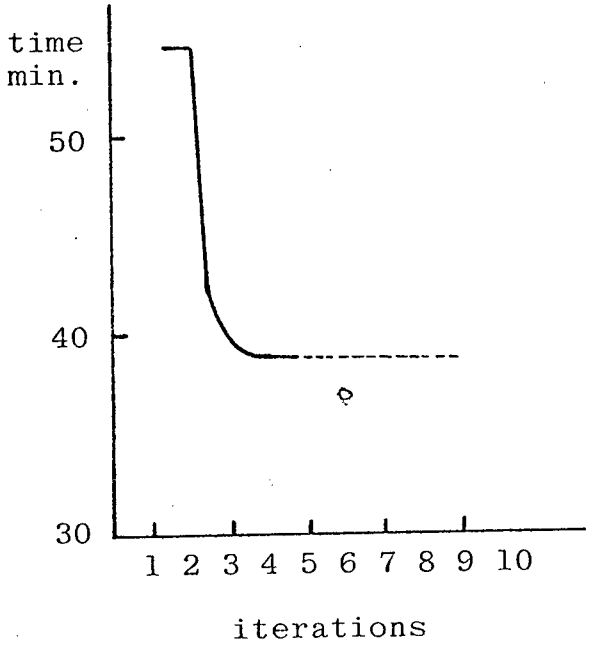


(b) modifier = $1 - f\frac{dy}{dx}$(logit function)

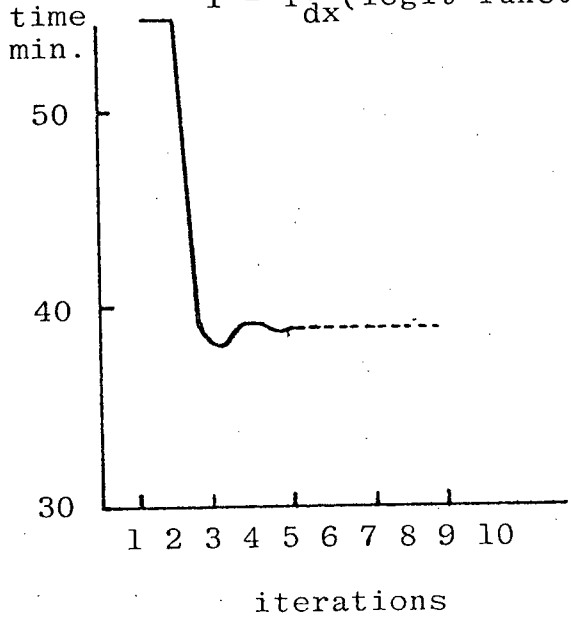


ORIGINAL PARKING CHARGE = $1.50
INCREASE PARKING CHARGE TO $2.50

(c) modifier=f(logit function)



(b) modifier = $1 - f\frac{dy}{dx}$(logit function)



ORIGINAL PARKING CHARGE = $0.00
INCREASE PARKING CHARGE TO $1.00

The composition of the test framework was dictated by the inputs required by the logit model and the criteria that it should resemble the larger framework as much as possible. The essential elements of the larger system are the parking allocation, auto assignment, transit passenger assignment, mode split models and equilibrium algorithm; refer to Figure 7, Chapter 3 section 3.2. The inputs to the logit model are, the transit travel time, auto travel time, number of miles travelled by auto and the parking costs; refer to Chapter 5 section 5.6 equation 23.

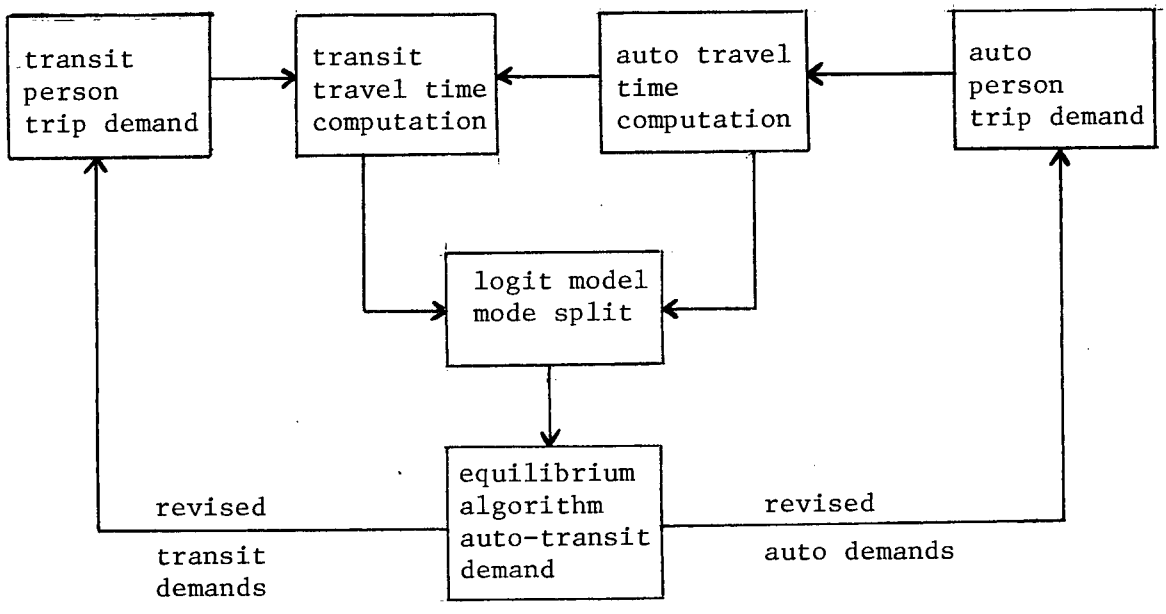
The parking allocation model was not included in the test framework for the following reasons:

(1) It did not have direct input to the logit model; refer to Figure 7.

(2) The network to be run on the test framework was such that it would not be affected by the parking allocation model.

The test system is shown in Figure 19 below; refer to Figure 7 for a comparison with the full scale system.

FIGURE 19 MODE SPLIT MODIFIER TEST SYSTEM



The important aspect to be considered in the choice or development of the functions to compute transit and auto travel times was not that they be exact or extremely accurate; they must be responsive to changes in demand and representative of the subsystems being modelled. The test network was simply a 6 mile long road with a free flow velocity of 25 mph. It was assumed to carry buses as well as cars. One end of the link was assumed to originate in the suburbs and the other in the C.B.D.. It was assumed that there was a parking lot in the C.B.D. which would accomodate any size demand. The demand for both bus and auto travel was assumed to be distributed uniformly over the length of the link.

The functions for each of the stops in the test framework are given below:

1. Auto Travel Time

$$K = PD / (AO \times M) \qquad (26)$$

$$V = VF\,(1-K/KJ)^{1.8} \qquad (27)$$

$$T = V / M \qquad (28)$$

where:

V = velocity

VF = free flow velocity

K = density of cars on the road

KJ = the jam density

M = the number of miles

PD = person trip demand by auto

AO = auto occupancy

Equation 27 was developed by May - Keller [1] and computes the average velocity on a link as a function of the free flow velocity, jam density (200 cars per mile) and actual density. The actual density is a function of the demand for travel by car. In order to compute the average velocity the auto person trip demand was translated into vehicle demand by assuming

there were 1.2 persons per car. This demand was then assigned to the route as a uniform density over the length of the link. This density is then used in equation 27 to determine the average velocity and equation 28 computes the actual auto travel time over the link.

2. Bus Travel Time

$$BT = AT \times 1.15 + BP \times LT \quad \text{----------} \quad 29$$

where: BT = the bus travel time over the route

AT = the total auto travel time over the route

BP = the number of bus passengers

LT = the loading time per passenger

The bus travel time is computed as a function of the auto travel time and the number of passengers using the bus. The 1.15 factor accounts for the slower average speed of the bus due to slowing down for bus stops. The number of passengers and loading time per passenger account for the stopped time of the bus.

3. The Logit Model

The logit model is the same as defined in equation 24 and 25 in the main report and are repeated here for clarity sake.

$$P_c = e^{G(x)} / (1 + e^{G(x)}) \quad \text{----------} \quad 24$$

$$G_x = -.83 + 1.27 TT / TC + .095 (.35 / MILES \times .08) - .615\ EPC \quad \text{----------} \quad 25$$

where: P_c = the probability of using the car

TT = transit travel time including out of vehicle time

TC = auto travel time including out of vehicle time

MILES = length of trip in miles

EPC = the cost of parking the car

The Development of the Modifier Function

As noted earlier the value of the modifier function must lie between the values zero and one. Also as noted earlier the trial mode split is a function of the old mode split, new mode split and the modifier. Equation 30 shows this function.

$$M_T = M_O + x(M_N - M_O) \quad \text{----------} \quad 30$$

where: x = the modifier

M = the mode split and the subscripts

N = new

O = old

T = trial

A two step approach was taken in defining the modifier. First an optimal range of the function was defined. Theoretically it was known that the value lied between zero and one but it was hoped to narrow the range by testing the system with different values in that interval. The second step after an optimal interval was defined was the testing of several functions which produced values within the optimal range.

Four values were selected for the initial test. They were .25, .5, .75, and 1.0. A heavily congested network and mode split values between .4 and .6 were used for this experiment. These conditions were selected because

(1) the travel times on a heavily congested network are sensitive to small changes in demand and

(2) the slope of the logit function is at its greatest within the values defined above and hence is also most sensitive to changes in input parameters.

The convergence of the system can be determined by examining any of the following values: the auto travel time, the transit travel time and the

auto-transit travel demands. When the difference between any one of these values from one iteration to the next is equal to zero or is small then the system is said to have converged to a solution. The auto travel time was selected as the parameter to be used to test for convergence.

Figures 18 (a) (b) (c) (d) show the auto travel time versus the number of iterations for each modifier. Table 10 shows the values for all of the parameters through the iterative process for each of the modifiers. It can be seen that the system converges to a solution fastest when the modifier is equal to 0.50. It appears then, that the optimal range for the modifiers when the mode split is between .4 and .6 is the interval from .25 to .75. Further, it appears that in this case it would not be possible to improve upon the results produced by the .5 modifier. Table 11(b) shows that a solution was reached in 3 to 4 iterations. If this was reduced to 2 to 3 iterations then that would be close to achieving a direct solution. The first iteration is really the conditions associated with the $1.50 parking price. The ultimate then would be to achieve convergence in the third, possibly the fourth iteration.

The logit function ranged between .54 and .46 for these experiments and the modifier selected was .5, approximately the value of the logit function. It was thought that the logit function itself could be used as a modifier. In other words when the mode split of the previous iteration is .8 and the mode split of the current iteration is .7 the modifier would be equal to .8. Theoretically this was thought to make sense because the slope of the logit function approaches zero as its value approaches the limits of zero and one. Greater changes are allowed where the function is less sensitive to changes. The trial mode split then is computed as follows:

when $M_0 \geqslant .5$

$$M_T = M_O + M_O (M_N - M_O)$$

when $M_O \leqslant .5$

$$M_T = M_O + (1 - M_O) (M_N - M_O)$$

The variables and subscripts are as defined earlier.

A second modifier function was developed for comparison purposes. This function was based on the slope of the mode split. The derivative of the logit function was taken and is shown below:

$$S = e^{x} / (1 + 2 e^{x} + e^{2x}) \quad \text{----------} \quad 31$$

where S = the slope of the logit function

x = generalized cost difference between modes

$S_{MAX} = .25 \quad @ \quad x = 0$

$S_{MIN} = 0 \quad @ \quad x = \pm \infty$

The maximum value of the slope occurs when the generalized cost difference between the two modes equals zero and is equal to .25. The minimum occurs when the generalized cost difference is positive or negative infinity and is equal to zero. The purpose of the modifier is to reduce shifts in the trial mode split. It is not possible to use the slope directly for this purpose but the residual function, (1 - S) suffices. The value of this function when the generalized cost difference is zero is equal to .75. The trial mode split using the slope residual is computed as follows:

$$M_T = M_O + (1 - S) (M_N - M_O) \quad \text{----------} 32$$

All variables are defined previously.

Four scenarios were tested in order to determine the performance of the modifier functions. These scenarios were divided into two groupings. The first entailed parking pricing changes on a heavily loaded network when the mode split was in the range of .4 to .6. The second was performed on a heavily loaded network when the mode split was in the range of .7 to .8.

One parking price increase of $1.00 was considered. The base parking price for the mode split range of .4 to .6 was $1.50 and for the .6 to .75 range was $0.00. At these base prices the average auto speed on the route was approximately 7 miles per hour. After the price increases it was approximately 9 miles per hour. The demand at the $1.50 base price was 1081 persons by car and 918 by transit and at the $0.00 base price was 1083 by car and 446 by transit. The auto demand was maintained approximately equal in both cases so that the tests would be performed on the routes with the same level of congestion.

The test showed that the logit function modifier was superior to the derivative of the logit function. In fact in each test case the equilibrium solution is attained after 4 iterations and is very close at the third iteration when the logit function modifier is used. Figure 18 shows the graphs of the auto travel times versus the number of iterations. Table 12 illustrates all of the parameters in detail. Several more tests were conducted with the logit modifier under different conditions. In all situations a solution was attained after 3 to 4 iterations. Table 13 shows the results of these tests. It was decided at this point that the logit modifier would be used.

TABLE 11 THE ITERATIVE PROCESS USING FOUR CONSTANT MODIFIERS
PARKING PRICE INCREASE FROM $1.50 TO $2.50

(a) modifier = .25

ITERATION NO.	AUTO TIME	BUS TIME	NEW MODE SPLIT	TRIAL MODE SPLIT	AUTO DEMAND	BUS DEMAND
1	54	79	.54	.54	1081	918
2	54	79	.39	.50	1005	994
3	45	70	.42	.48	962	1037
4	41	66	.43	.47	938	1061
5	39	64	.44	.46	926	1073
6	38	63	.45	.46	920	1079
7	38	63	.45	.46	917	1082
8	38	63	.46	.46	915	1084

(b) modifier = .50

1	54	79	.54	.54	1081	918
2	54	79	.39	.46	916	1082
3	38	63	.46	.46	913	1086
4	37	63	.46	.46	913	1086
5	37	63	.46	.46	913	1086

(c) modifier = .75

1	54	79	.54	.54	1081	918
2	54	79	.39	.43	853	1145
3	33	58	.49	.47	945	1053
4	40	65	.44	.45	899	1100
5	36	62	.46	.46	920	1078
6	38	63	.45	.46	909	1089
7	37	62	.46	.46	915	1083
8	37	63	.46	.46	913	1086

(d) modifier = 1.0

1	54	79	.54	.54	1081	918
2	54	79	.39	.39	778	1221
3	28	55	.53	.53	1066	933
4	53	77	.39	.39	787	1211
5	29	55	.53	.53	1054	944
6	51	76	.40	.40	796	1203
7	30	56	.52	.52	1044	956
8	50	75	.40	.40	802	1196

ALL TIMES ARE IN MINUTES
DEMANDS ARE IN PERSONS

TABLE 12 THE ITERATIVE PROCESS USING TWO MODIFIER FUNCTIONS

(a) PARKING INCREASE $1.50 to $2.50 modifier = f(logit function)

ITERATION NO.	AUTO TIME	BUS TIME	NEW MODE SPLIT	TRIAL MODE SPLIT	AUTO DEMAND	BUS DEMAND
1	54	79	.54	.54	1081	918
2	54	79	.39	.46	916	1082
3	38	63	.46	.46	914	1085
4	37	63	.46	.46	913	1085
5	37	63	.46	.46	913	1085

(b) PARKING INCREASE $1.50 to $2.50 modifier = $1 - f \frac{dy}{dx}$ (logit function)

1	54	79	.54	.54	1081	918
2	54	79	.39	.42	849	1150
3	33	59	.49	.47	947	1052
4	40	65	.44	.45	897	1102
5	36	61	.46	.46	921	1078
6	38	63	.45	.45	909	1090
7	37	62	.46	.46	919	1080
8	38	63	.45	.46	910	1088

(c) PARKING INCREASE $0.00 to $1.00 modifier = f(logit function)

1	55	71	.71	.71	1083	446
2	55	71	.57	.61	930	598
3	39	55	.61	.61	929	599
4	39	55	.61	.61	929	599
5	39	55	.61	.61	929	599

(d) PARKING INCREASE $0.00 to $1.00 modifier = $1- f\frac{dy}{dx}$ (logit function)

1	55	71	.71	.71	1083	446
2	55	71	.57	.60	920	608
3	38	55	.61	.61	931	598
4	39	55	.61	.61	930	599
5	39	55	.61	.61	930	599

TIMES ARE IN MINUTES
DEMANDS ARE IN PERSONS

TABLE 13 VARIOUS PARKING INCREASES AND CONGESTION LEVELS USING THE LOGIT FUNCTION MODIFIER

(a) PARKING PRICE INCREASE $2.50 to $2.75 MODERATELY CONGESTED

ITERATION NO.	AUTO TIME	BUS TIME	NEW MODE SPLIT	TRIAL MODE SPLIT	AUTO DEMAND	BUS DEMAND
1	37	63	.46	.46	914	1086
2	37	63	.42	.44	879	1120
3	35	60	.44	.44	876	1123
4	34	60	.44	.44	876	1123

(b) PARKING PRICE INCREASE $2.50 to $2.75 LIGHTLY CONGESTED

1	17	29	.47	.47	471	528
2	17	29	.43	.45	453	546
3	16	28	.45	.45	449	551
4	16	28	.45	.45	449	551

(c) PARKING PRICE INCREASE $2.50 to $3.50 MODERATELY CONGESTED

1	37	63	.46	.46	914	1086
2	37	63	.31	.39	782	1218
3	29	55	.38	.39	773	1227
4	28	55	.39	.39	772	1228

(d) PARKING PRICE INCREASE $2.50 to $3.50 LIGHTLY CONGESTED

1	17	29	.47	.47	471	528
2	17	29	.33	.40	402	597
3	15	28	.37	.39	389	609
4	14	28	.38	.39	386	612
5	14	28	.38	.38	386	612

TIMES ARE IN MINUTES
DEMANDS ARE IN PERSONS

FOOTNOTES

1. A.D. May, H.E. Keller., "Non-Integer Car Following Models," Highway Research Record, 199, 1967, pp. 19-32.

APPENDIX B

THE COMPUTER PROGRAM BUS

```
      DIMENSION DIS(250),NAME(1000,20),MTTD(250),MTTO(250)
      DIMENSION MATO(250),MATD(250),DUM(250),ATRAV(150)
     +,NOB(100),NBSTP(100),BTM(100),NTHRU(30),NOPTB(100)
     +,NTT(1500),NTR(1500,28),NS(2100,4),EW(2100,4),NU(400)
     +,CNTT(150),BTAV(150),NOPTD(50)
      COMMON/MEIN/ TTO(1500,50),NBL(1500),NUMDEP(1500),
     +       LINKDP(1500,10),TLINK(2100),TRAV(1500),NT(1500,50)
     +       ,IKT(1500),NLINK,LAST,NNODE,ND(2100),NBT(2100),
     +       NBUS(2100,30),DIST(2100),NO(2100),ECES(1500)
      COMMON/TME/HEAD(1000),PERSON(1500),NNN(1500,5),DEC,ACC
     +,BOARD,LLINE
     +,PERSOF(1500),FREFLO
      COMMON /ASS/ IPELO(3500),NN(1500),ITAC(1500)
      COMMON/PARK/ OIN(100,100),O(3,100,100),JS(15),MR(15)
     +,LZONE(30),ETAV(250),TAV(250),ADIS(250),NVSINK(250)
     +,ATAV(250),W(150,150),MZONE(30),C(150),TOD(3,100,100)
     +,WP(150,150),NC(15),NPSINK(400),P(100)
      DEFINE FILE 4(240,800,L,IST)
C*************************************************************
C
C       READ IN PROGRAM PARAMETERS
C
C*************************************************************
C
      READ(18)NZONE,NGROUP,NEXT,INELAS,TM
      READ(13)LLINE
      READ(12) FREFLO,PERIOD, LAST,NLINK,NNODE,NORIGN,NDEST
      READ(5,1) DEC,ACC,BOARD,NTSCE,NTSK,NSTOP,NTHR,IGD,IOPT
     +,NOPB,NOPD
      WRITE(6,25) LLINE,NSTOP,BOARD,DEC,ACC,NTSCE,NTSK,NORIGN,
     +NDEST,NLINK,NEXT,NZONE,NGROUP,TM,PERIOD,IGD,IOPT,NOPD,NOPB
      IF(NTSCE.NE.NORIGN) GO TO 9997
C
C*************************************************************
C
C           IGD= THE ITERATION INDEX 0=1ST ITERATION 1=2ND AND
C           SUBSEQUENT ITERATIONS
C           IOPT= THE ORIGIN OF THE MINIMUM PATH TO BE PRINTED
C           NOPD= THE NO. OF MINIMUM PATHS TO BE PRINTED WITH
C           IOPT AS THE ORIGIN
C           NOPTD= THE DESTINATION NODES OF THE MINIMUM PATHS
C           NBSP= THE NO. OF BUS LINES TO BE PRINTED OUT
C           NBSTP= THE NODE AT WHICH A BUS LINE STARTS WHICH IS
C           BEING PRINTED OUT
C           NTHR= THE NO OF NODES WHERE BUS LINES ENTER THE
C           STUDY AREA
C           NTHRU= THE NODES WHERE BUS LINES ENTER THE CITY
C
C*************************************************************
      DIFF=0.0
      TMOD=0.0
      IXT=2*NZONE
      IZT=0
C*************************************************************
C
C       READ IN AUTO AND TRANSIT ORIGINS AN DESTINATIONS
C
C*************************************************************
      READ(5,5) (NBSTP(I),I=1,NOPB)
      READ(5,5)(NTHRU(I),I=1,NTHR)
```

```
      READ(5,5)  (NOPTB(I),I=1,NOPB)
      READ(5,5)  (NOPTD(I),I=1,NOPD)
      READ(5,2)  (MTTO(I),I=1,NTSCE)
      READ(5,6)  (MTTD(I),NPSINK(I),I=1,NTSK)
      WRITE(6,30)
      READ(15,2)  (MATO(I),I=1,NORIGN)
      READ(15,6)  (MATD(I),NVSINK(I),I=1,NDEST)
      WRITE(6,31)
C*************************************************************
C
C       READ IN WALK TIMES TO AND FROM BUS STOPS
C
C*************************************************************
      DO 100 I=1,3000
      READ(11,END=140)  IK,KK,(NT(KK,N),N=1,IK)
      IKT(KK)=IK
      READ(11,ERR=9999)  (TTO(KK,N),N=1,IK)
100   CONTINUE
C*************************************************************
C
C       READ IN O-D NODES,LINKS AND BUS LINES ON LINKS
C
C*************************************************************
140   WRITE(6,32)
      DO 115 I=1,LAST
      NUMDEP(I)=0
      NBL(I)=0
      PERSON(I)=0.0
      PERSOF(I)=0.0
      NBT(I)=0
      NN(I)=0
      NTT(I)=0
115   CONTINUE
C
C           Read bus stops
C
      DO 130 I=1,NSTOP
      READ(17,2)  MM
      NBL(MM)=1
130   CONTINUE
C
C           Read bus lines and headways
C
      DO 125 I=1,LLINE
      READ(13)  NM,IHEAD,(NAME(NM,K),K=1,18)
      HEAD(NM)=IHEAD
      NU(I)=NM
125   CONTINUE
      WRITE(6,33)
C
C           Read street names, link travel times & lengths
C
      DO 120 I=1,NLINK
      READ(13)  IX,(NBUS(I,K),K=1,IX)
      NBT(I)=IX
      READ(12)  MN,N,DIST(I),TLINK(I),(NS(MN,M),M=1,3)
     +,(NS(N,M),M=1,3),(EW(MN,M),M=1,3),(EW(N,M),M=1,3)
      ND(I)=N
      NC(I)=MN
      NUMDEP(MN)=NUMDEP(MN)+1
```

```
      JJ=NUMDEP(MN)
      LINKDP(MN,JJ)=I
120   CONTINUE
      WRITE(6,34)
C
C           Read inelastic auto demand
C
      IF(INELAS.NE.1) GO TO 155
      DO 150 I=1,NORIGN
      READ(19,7) (OIN(I,K),K=1,NZONE)
150   CONTINUE
C
C          Read elastic auto demand
C
155   DO 160 M=1,NGROUP
      DO 160 I=1,NORIGN
      READ(19,7) (O(M,I,K),K=1,NZONE)
160   CONTINUE
      WRITE(6,35)
      IF(NEXT.EQ.0) GO TO 164
      DO 161 I=1,NORIGN
161   READ(19,4) F
C
C           Read transit demand
C
164   DO 165 M=1,NGROUP
      DO 165 I=1,NORIGN
      READ(19,7) (TOD(M,I,K),K=1,NZONE)
165   CONTINUE
      WRITE(6,36)
C
C           Read parking data
C
      DO 170 K=1,NZONE
      READ(18) JS(K),MR(K),LZONE(K),MZONE(K),C(K)
170   CONTINUE
      WRITE(6,37)
C
C           Read walk travel times
C
      READ(18) ((W(L,K),L=1,NZONE),K=1,NZONE)
      READ(18) ((WP(L,K),L=1,NZONE),K=1,NZONE)
      WRITE(6,38)
C
C
      DO 180 I=1,NZONE
      NC(I)=0
180   CONTINUE
      DO 190 M=1,NTSK
      LL=NPSINK(M)
      L=MZONE(LL)
      NC(I)=NC(L)+1
190   CONTINUE
C
C           First execution of minpth witout passenger loading
C           Assignment of passengers to bus lines and stops
C
      DO 300 I=1,NTSCE
      NHOME=MTTO(I)
      CALL MINPTH(NHOME,MTTD,NTSK,O,NS,EW,NTHR,NTHRU,NOPTD,NOPD)
```

```
      CALL ASSN(MTTD,NHOME,NTSK,NZONE,NGROUP,I,TOD,NC,NPSINK
     +,MZCNE,PERIOD)
300   CCNTINUE
C
C          Initialize scalars for management of sequential file
C
      IL=NEXT+1
      IXT=2*NZONE+3
      IXXT=NZCNE+1
      IZT=0
C
C          Read total trip time and length from unit 12
C
      WRITE(6,19)
      DC 400 I=1,NTSCE
      NHOME=MTTO(I)
      READ(12)  (DIS(J),J=1,NDEST)
      READ(12)  (ATRAV(J),J=1,NDEST)
C
C          Second execution cf minpth with passenger loading
C
      CALL MINPTH(NHOME,MTTD,NTSK,IOPT,NS,EW,NTHR,NTHRU,NOPTD,NOPD)
C
C          Initialization of vectors in preparation for
C          subroutine SPLIT
C
      DC 470 L=1,NZONE
      TAV(L)=0.0
      ETAV(L)=0.0
      ADIS(L)=0.0
      ATAV(L)=0.0
      CNTI(L)=0.0
      IF(NC(L).EQ.0) TAV(L)=999999.
      IF(JS(L).EQ.0) ADIS(L)=999999.
470   CCNTINUE
C
C          Aggregate data from node level to zone level for SPLIT
C
      DO 480 M=IL,NDEST
      LL=NVSINK(M)
      L=MZCNE(LL)
      IF(JS(L).EQ.0) GO TO 480
      ADIS(L)=ADIS(L)+DIS(M)/FLOAT(JS(L))
      ATAV(L)=ATAV(L)+ATRAV(M)/FLOAT(JS(L))
480   CCNTINUE
C
C          Read write auto travel times to sequential file
C
      IF(IGD.EQ.0) GO TO 320
      GO TO 340
320   IZT=IZT+1
      IST=IZT
C
C          First iteration write to sequential file
C
      WRITE(4'IST) (ATAV(J),J=1,NZCNE)
      IXXT=IXXT+1
      IST=IXXT
      WRITE(4'IST) (ATAV(J),J=1,NZCNE)
340   IF(IGD.GE.1) GO TO 350
```

```
      GO TO 360
350   IXXT=IXXT+1
      IST=IXXT
C
C           2nd 3rd 4th ... iteration read of previous travel time
C
      READ(4'IST)(BTAV(J),J=1,NZONE)
      IST=IXXT
C
C           2nd 3rd 4th ... iteration write of current travel time
C
      WRITE(4'IST)  (ATAV(J),J=1,NZONE)
C
C           Preparation of data for write of equilibrium statistics
C
360   TOTALT=0.0
      TOTALE=0.0
      TOTALA=0.0
      TOTALB=0.0
      COUNT=0.0
      DO 490 M=1,NTSK
      MM=MTTD(M)
      KK=NPSINK(M)
      K=MZONE(KK)
      IF(TRAV(MM).GT.999990) GO TO 490
      TAV(K)=TAV(K)+TRAV(MM)
      ETAV(K)=ETAV(K)+ECES(MM)
      TOTALT=TOTALT+TRAV(MM)-ECES(MM)
      TOTALE=TOTALE+ECES(MM)
      COUNT=COUNT+1
      CNTT(K)=CNTT(K)+1
490   CONTINUE
      TOTALE=TOTALE/(COUNT*60)
      TOTALT=TOTALT/(COUNT*60)
      DO 370 J=1,NZONE
      IF(IGD.LT.1) ETAV(J)=0.0
      TOTALA=TOTALA+ATAV(J)
      TOTALB=TOTALB+BTAV(J)
      TAV(J)=TAV(J)/CNTT(J)
      ETAV(J)=ETAV(J)/CNTT(J)
370   CONTINUE
      TOTALA=TOTALA/(NZONE*60)
      TOTALB=TOTALB/(NZONE*60)
C
C           Write equilibrium data
C
      WRITE(6,21)
      WRITE(6,29)
      WRITE(6,22)
      WRITE(6,23)
      WRITE(6,20)  (NS(NHOME,M),M=1,3),(EW(NHOME,M),M=1,3)
     +,TOTALA,TOTALB,TOTALT,TOTALE
C
C           Call SPLIT compute mode split and new auto-transit
C           demands
C
      CALL SPLIT(I,NHOME,NGROUP,NZONE,IGI,IXT,DIFF,TMOD,TMAX)
400   CONTINUE
C
C           Write equilibrium statistics produced by SPLIT
```

```
C
      REWIND 19
      WRITE(6,24)
      WRITE(6,26)
      WRITE(6,27)
      DO 450 M=1,NGROUP
      DO 450 I=1,NORIGN
      TTOTAL=0.0
      ATOTAL=0.0
      DO 455 K=1,NZONE
      TTOTAL=TTOTAL+TOD(M,I,K)
      ATOTAL=ATOTAL+O(M,I,K)
455   CONTINUE
      SPLT=ATOTAL/(ATOTAL+TTOTAL)
      NHOME=MTTO(I)
      WRITE(6,12)  (NS(NHOME,L),I=1,3),(EW(NHOME,L),L=1,3)
     +,ATOTA;,TTOTAL,SPLT
      WRITE(19,7)  (O(M,I,K),K=1,NZONE)
450   CONTINUE
      DO 460 M=1,NGROUP
      DO 460 I=1,NORIGN
      WRITE(19,7)  (TOD(M,I,K),K=1,NZONE)
460   CONTINUE
C
C
C
      IF(IGD.GT.0)  GO TO 510
      GO TO 550
510   ERROR=DIFF/TMOD
      WRITE(6,11)  ERROR
C
C          Print option for statistics on bus lines
C
550   IF(NOPB.EQ.0)  GO TO 9998
      DO 600 JJ=1,NOPB
      LIN=NOPTB(JJ)
      NM=NBSTP(JJ)
C
C          Call BNET prepare bus line data for print out
C
      CALL BNET(NOB,NBSTP,LIN,NM,IBT,BTM,NTT,NTR,NU,SPED)
      WRITE(6,13)
      WRITE(6,14)
      WRITE(6,15)  HEAD(LIN),LIN,(NAME(LIN,K),K=1,18)
      WRITE(6,16)
      WRITE(6,17)
      DO 650 K=1,IBT
      NM=NOB(K)
      BTM(K)=BTM(K)/60
      IXT=NTT(NM)
      WRITE(6,18)  (NS(NM,M),M=1,3),(EW(NM,M),M=1,3),PERSON(NM),
     +PERSOF(NM),BTM(K),(NTR(NM,II),II=1,IXT)
650   CONTINUE
      WRITE(6,28)  SPED
600   CONTINUE
C
C
C
1     FORMAT(3F8.2,14I4)
2     FORMAT(I4)
```

```
3     FORMAT(I4,8X,I4)
4     FORMAT(F20.0)
5     FORMAT(20I4)
6     FORMAT(2I4)
7     FORMAT(8F10.0)
8     FORMAT(8F10.0)
11    FORMAT(/10X,'THE PERCENT CHANGE IN TRAVEL TIME FROM ONE '
     C'ITERATION TO THE NEXT IS',F10.5)
12    FORMAT(10X,2(3A4),5X,F6.0,5X,F6.0,10X,F4.3)
13    FORMAT('1',10X,'     BUSLINE  BUSLINE')
14    FORMAT(10X,'HEADWAY  NUMBER   NAME')
15    FORMAT(/10X,F3.0,' MIN',3X,I2,6X,20A4)
16    FORMAT(/18X,'BUS STOP',14X,'PEOPLE',11X,'PEOPLE',11X
     +,'LINK,TIME',11X,'BUS LINES')
17    FORMAT(16X,'INTERSECTION',10X,'ON THE BUS',7X,'AT THE STOP'
     +,7X,'& TOTAL TIME',8X,'AT THE STOP')
18    FORMAT(10X,2(3A4),8X,F3.0,14X,F3.0,12X,F5.1,10X,10I4/89X,10I4
     +/89X,10I4)
19    FORMAT(////50X,'EQUILIBRIUM STATISTICS')
20    FORMAT(10X,2(3A4),7X,F6.1,5X,F6.1,10X,F6.1,8X,F6.1)
21    FORMAT(///10X,'TRAVEL TIMES FROM THE GIVEN INTERSECTION',
     +' TO ALL DESTINATIONS')
22    FORMAT(/18X,'INTERSECTION',11X,'CURRENT',6X,'PREVIOUS'
     +,6X,'IN VEHICLE',7X,'EXCESS')
23    FORMAT(34X,2(4X,'TRAVEL TIME',4X,'TRAVEL TIME'))
24    FORMAT(////10X,'CAR AND BUS SPLITS FOR THE GIVEN '
     +,'INTERSECTION TO ALL DESTINATIONS')
25    FORMAT(/10X,'NUMBER OF BUS LINES=',I4,
     +/10X,'NUMBER OF BUS STOPS=',I4,
     +/10X,'BOARDING TIME FOR THE BUS (SEC PER PERSON)=',F4.1,
     +/10X,'BUS ACCELERATION (FT/SEC/SEC)=',F4.1,
     +/10X,'BUS DECELERATION (FT/SEC/SEC)=',F4.1,
     +/10X,'NUMBER OF TRANSIT ORIGINS=',I4,
     +/10X,'NUMBER OF TRANSIT DESTINATIONS=',I4,
     +/10X,'NUMBER OF VEHICLE ORIGINS=',I4,
     +/10X,'NUMBER OF VEHICLE DESTINATIONS=',I4,
     +/10X,'NUMBER OF LINKS=',I4,
     +/10X,'NUMBER OF EXTERNAL VEHICLE ORIGINS=',I4,
     +/10X,'NUMBER OF ZONES=',I4,
     +/10X,'NUMBER OF SOCIOECONOMIC GROUPS=',I4,
     +/10X,'MAXIMUM WALKING TIME=',F10.0,
     +/10X,'PERIOD OF ASSIGNMENT=',F5.0,
     +/10X,'ITERATION INDEX=',I4,
     +/10X,'ORIGIN NODE FOR MINIMUM PATH PRINT OUT IS=',I4,
     +/10X,'NUMBER OF PATHS PRINTED IS=',I4,
     +/10X,'NUMBER OF BUS LINES TO BE PRINTED OUT IS=',I4)
26    FORMAT(/16X,'INTERSECTION',11X,'PERSONS',5X,'PERSONS',5X,
     +'AUTO SPLIT')
27    FORMAT(40X,'BY CAR',6X,'BY BUS')
28    FORMAT(///10X,'THE AVERAGE SPEED OF THE BUS IS ',F4.1,' MPH.')
29    FORMAT(/47X,'AUTO',24X,'BUS')
30    FORMAT(//10X,'DATA FROM UNIT 5 READ IN')
31    FORMAT(//10X,'VEHICLE ORIGINS & DESTINATIONS FROM ',
     +'UNIT 15 READ IN')
32    FORMAT(//10X,'PEDESTRIAN WALK TIMES FOR TRANSIT READ ',
     +'IN FROM UNIT 11')
33    FORMAT(//10X,'BUS NETWORK DATA READ IN FROM UNITS 17&13')
34    FORMAT(//10X,'VEHICLE & BUS NETWORK READ IN FROM UNIT 12')
35    FORMAT(//10X,'AUTO TRIPS READ IN FROM UNIT 19')
36    FORMAT(//10X,'TRANSIT TRIPS READ IN FROM UNIT 19')
```

```
37    FORMAT(//10X,'PARKING DATA READ IN FROM UNIT 18')
38    FORMAT(//10X,'ZONE TO ZONE WALKING TIMES FOR AUTO DRIVERS '
     +,'READ IN FROM UNIT 18')
50    FORMAT(10X,'IMPROPER READ IN ON UNIT 11')
52    FORMAT('THE NO OF AUTO ORIGINS ',I4,'IS NOT EQUAL TRANSIT '
     +,'ORIGINS',I4)
      GO TO 9998
9999  WRITE(6,50)
9997  WRITE(6,52) NORIGN,NTSCE
9998  RETURN
      END
C
C
C
C
C
C
C
C
C
C
      SUBROUTINE MINPTH(NHOME,MTTD,NTSK,IOPT,NS,EW,NTHR,NTHRU,NOPTD
     +,NOPD)
      COMMON/MEIN/ TTO(1500,50),NBL(1500),NUMDEP(1500),
     +       LINKDP(1500,10),TLINK(2100),TRAV(1500),NT(1500,50)
     +       ,IKT(1500),NLINK,LAST,NNODE,ND(2100),NBT(2100),
     +       NBUS(2100,30),DIST(2100),NO(2100),ECES(1500)
      COMMON/TME/HEAD(1000),PERSON(1500),NNN(1500,5),DEC,ACC,LLINE
     +,ECARD
     +,PERSOF(1500),FREFLO
      DIMENSION NBU(1500),IPED(3500),NCUM(1500),TCUM(1500)
     +,MTTD(1500),KEEP(5),TCM(5),ESE(5),NS(2100,4),EW(2100,4)
     +,NTHRU(30),NOPTD(50),ECUM(1500)
      COMMON /ASS/ IPEDO(3500),NN(1500),ITAC(1500)
C
C            Initialize vectors
C
      DO 100 I=1,LAST
      TRAV(I)=999999.
      ITAC(I)=0
      NN(I)=0
100   ECES(I)=0
      DO 105 I=1,LAST
      DO 105 J=1,5
105   NNN(I,J)=0
      NTREE=1
      NN(NHOME)=0
      NCM=0
      KZZ=0
      NM=NHOME
      II=NLINK
C
C            Determine whether nhome is on a thru bus line or not
C
      DO 110 I=1,NTHR
      IF(NHOME.EQ.NTHRU(I)) GO TO 129
110   CONTINUE
C*****************************************************************
C
C       DETERMINE WALK TIMES TO BUS STOP & WAIT TIME FOR BUS
```

```
C       :SECTION #1
C
C*************************************************************
C
C            Find walk links & times to bus stops
C
      IK=IKT(NM)
      DO 120 J=1,IK
      K=NT(NM,J)
      IF(NBL(K).EQ.0) GO TO 120
      SUM=0
      N=0
      ECE=0.0
      IN=NUMDEP(K)
      IF(IN.EQ.0) GO TO 120
C
C            Find bus lines passing bus stop
C
      DO 125 L=1,IN
      I=LINKDP(K,L)
      IF(NBUS(I,1).EQ.0) GO TO 125
      IT=NBT(I)
C
C            Compute wait time for bus
C
      DO 126 IA=1,IT
      IS=NBUS(I,IA)
      N=N+1
      SUM=SUM+HEAD(IS)*60.0
126   CONTINUE
125   CONTINUE
      IF(N.EQ.0) GO TO 127
      ECE=SUM/(N*2)
      IF(ECE.GT.210) ECE=.13*SUM+2.8
      IF(PERSON(K).GT.60) ECE=ECE+SUM
C
C            Enter times & links into the list
C
127   NCM=NCM+1
      TCUM(NCM)=TTO(NM,J)+ECE
      ECUM(NCM)=ECES(NM)+TTO(NM,J)+ECE
      II=II+1
      NBU(NCM)=2
      NCUM(NCM)=II
      IPED(II)=K
      IPEDC(II)=NM
120   CONTINUE
      IFLAG=0
      GO TO 180
C*************************************************************
C
C       DETERMINE TRAVEL TIME FROM NODE TO NODE BY BUS
C       :SECTION #2
C
C*************************************************************
129   NTREE=2
      NM=NHOME
      TRAV(NM)=0.0
      II=II+1
      NN(NM)=II
```

```
C
C          Find vehicle links departing the bus stop
C
130   IN=NUMDEP(NM)
      NTB=0
      IF(IN.EQ.0) GO TO 180
      DO 150 L=1,IN
      I=LINKDP(NM,L)
      K=ND(I)
C
C          Determine if there are buses running on the link
C
      IF(NBUS(I,1).EQ.0) GO TO 150
      IF(TRAV(K)-999999.) 145,140,145
145   IF(NN(K).LE.NLINK) GO TO 150
140   NCM=NCM+1
      KZZ=KZZ+1
C
C          For links with bus lines call TIM find travel time
C          on link
C
      CALL TIM(NM,K,I,TIME,NTBEE,ECE,LINK)
C
C          Enter link & times into list
C
      TCUM(NCM)=TRAV(NM)+TIME
      ECUM(NCM)=ECES(NM)+ECE
      NCUM(NCM)=I
      NBU(NCM)=0
      ITAC(K)=1
      NZZ=K
      IF(NBL(K).EQ.1) GO TO 147
      GO TO 150
C
C          Determine if destination node is a bus stop
C
147   NTB=NTB+1
      KEEP(NTB)=K
      TCM(NTB)=TCUM(NCM)
      ESE(NTB)=ECUM(NCM)
150   CONTINUE
      IFLAG=1
      ICOUNT=0
      NM=NZZ
      IF(NTB.GT.0) GO TO 155
C
C          If destination node is a bus stop go to section 3
C
      GO TO 180
C*****************************************************************
C
C       DETERMINE TRAVEL TIME FROM LAST BUS STOP TO FINAL
C       DESTINATION :SECTION #3
C
C
C*****************************************************************
155   DO 167 JJJ=1,NTB
      NQ=KEEP(JJJ)
      IFLAG=1
      ICOUNT=ICOUNT+1
```

```
      IK=IKT(NQ)
C
C           Find walk links from bus stops
C
      DO 160 J=1,IK
      K=NT(NQ,J)
      IZ=1
      IF(TRAV(K)-999999.) 170,165,170
170   ABC=TRAV(K)
      AB=TRAV(NQ)+TTO(NQ,J)
      IF(AB.GT.ABC) GO TO 160
165   NCM=NCM+1
C
C           If total time to destination is less than minimum
C           already stored add to list.
C
      TCUM(NCM)=TCM(JJJ)+TTO(NQ,J)
      ECUM(NCM)=ESE(JJJ)+TTO(NQ,J)
      II=II+1
      NCUM(NCM)=II
      NBU(NCM)=1
      ITAC(K)=1
      IPED(II)=K
      IPEDO(II)=NQ
160   CONTINUE
167   CONTINUE
C*****************************************************************
C
C       DETERMINE MINIMUM TRAVEL TIME TO THE NODES WHICH HAVE
C       BEEN COMPUTED
C
C
C*****************************************************************
180   TMIN=999999.
      IF(NCM.EQ.0) GO TO 270
      DO 200 K=1,NCM
C
C           Consider invehicle bus links only until they have all
C           been removed from the list. Then consider walk links.
C
      IF(NBU(K).EQ.1.AND.KZZ.GT.0) GO TO 200
      IF(TMIN-TCUM(K))200,200,190
190   TMIN=TCUM(K)
      EX=ECUM(K)
      L=NCUM(K)
      M=K
      IF(NBU(K).EQ.0) LINK=L
      IFAG=NBU(NCM)
200   CONTINUE
C
C
      IF(L.GT.NLINK) GO TO 205
      K=ND(L)
      GO TO 206
205   K=IPED(L)
206   IF(NN(K).LE.NLINK.AND.NN(K).GT.0.AND.L.GT.NLINK) GO TO 210
      IF(TRAV(K)-TMIN) 210,210,220
C
C           If travel time found above is less than that already
C           stored then change stored value to new value.
```

```
C
210   I=1
C
C           If travel time is greater than that already stored
C           don't change stored value.
C
      GO TO 230
220   TRAV(K)=TMIN
      ECES(K)=EX
      NN(K)=L
      I=0
      NTREE=NTREE+1
      IF(NTREE-NNODE) 230,270,230
C
C           Remove link & times from list
C
230   IF(M.EQ.NCM) GO TO 250
      DO 240 MM=M,NCM
      TCUM(MM)=TCUM(MM+1)
      NCUM(MM)=NCUM(MM+1)
      ECUM(MM)=ECUM(MM+1)
      NBU(MM)=NBU(MM+1)
      IF(MM+1-NCM) 240,250,240
240   CONTINUE
C
250   NCM=NCM-1
      IF(L.LT.NLINK) KZZ=KZZ-1
C
C           If stored value was not changed go to 180
C
      IF(I) 180,260,180
260   IF(NN(K).GT.NLINK.AND.IFAG.NE.2) GO TO 130
C
C           If last link was a walk link go to 130 & use origin
C           node (bus stop) of link as the new origin node for
C           the next bus link.
C
      NM=K
      GO TO 130
C
C           Print option of minimum transit path.
C
270   IF(IOPT.NE.NHOME) GO TO 320
      WRITE(6,9) (NS(NHOME,M),M=1,3),(EW(NHOME,M),M=1,3)
      DO 310 J=1,NOPD
      KK=NOPTD(J)
      IF(KK.EQ.NHOME) GO TO 310
      IF(TRAV(KK).GT.999990.) GO TO 312
      WRITE(6,4) TRAV(KK),ECES(KK)
      WRITE(6,7)
      WRITE(6,8)
      LL=NN(KK)
      DO 305 JJ=1,NLINK
      IXT=NBT(LL)
      WRITE(6,6) (NS(KK,M),M=1,3),(EW(KK,M),M=1,3),NN(KK)
     +,PERSON(KK),(NBUS(LL,II),II=1,IXT)
      GO TO 290
290   IF(LL.GT.NLINK) KK=IPEDO(LL)
      IF(LL.LE.NLINK) KK=NO(LL)
      LM=LL
```

```
      LL=NN(KK)
      IF(LL.GT.NLINK) GO TO 311
      IF(KK.EQ.NHOME) GO TO 311
305   CONTINUE
311   WRITE(6,6)  (NS(KK,M),M=1,3),(EW(KK,M),M=1,3),NN(KK)
     +,PERSOF(KK),(NBUS(LM,II),II=1,IXT)
      GO TO 310
312   WRITE(6,5) KK
310   CONTINUE
320   RETURN
4     FORMAT(///10X,'TOTAL TRAVEL TIME (SECS)',F10.0,
     +/10X,'TRANSFER, WAIT AND WALK TIME (SECS)',F10.0)
5     FORMAT(///'THE MINIMUM PATH FOR DESTINATION NODE',I5,'
     +WAS NOT COMPUTED')
6     FORMAT(10X,2(3A4),I10,F10.0,5X,14I4/59X,14I4)
7     FORMAT(/13X,'INTERSECTION',15X,'LINK',3X,'PERSONS ON'
     +,3X,'BUS LINES')
8     FORMAT(48X,'THE BUS',5X,'AT THE NODE')
9     FORMAT(////10X,'MINIMUM PATH TREE FROM INTERSECTION',2(3A4))
      END
C
C
C
C
C
C
C
C
C
C
      SUBROUTINE TIM(NM,K,I,TIME,NTREE,ECE,LINK)
      COMMON/MEIN/ TTO(1500,50),NBL(1500),NUMDEP(1500),
     +       LINKDP(1500,10),TLINK(2100),TRAV(1500),NT(1500,50)
     +       ,IKT(1500),NLINK,LAST,NNODE,ND(2100),NBT(2100),
     +       NBUS(2100,30),DIST(2100),NO(2100),ECES(1500)
      COMMON/TME/HEAD(1000),PERSON(1500),NNN(1500,5),DEC,ACC,LLINE
     +,BOARD
     +,PERSOF(1500),FREFLO
      DIMENSION NN(1500)
C*************************************************************
C
C       TRAVEL TIME FOR PASSENGERS JUST BOARDING THE BUS
C
C*************************************************************
      ECE=0.0
      IF(NTREE.EQ.2) GO TO 100
      GO TO 120
100   IT=NBT(I)
      SUM=0
C
C           Store the bus lines which use link 'I'.
C
      DO 110 MT=1,IT
      II=NBUS(I,MT)
      NNN(I,MT)=NBUS(I,MT)
110   CONTINUE
C
C
      NN(I)=IT
      IF(TLINK(I).EQ.0) GO TO 115
```

```
      VEL=DIST(I)/TLINK(I)
      GO TO 117
C
C           Compute stopped time and link travel time.
C
115   VEL=FREFLO
117   STOP=BOARD*PERSOF(NM)
      AT=VEL/ACC
      DT=VEL/DEC
      S=.5*ACC*AT**2
      SS=DIST(I)-S
      TT=SS/VEL
      IF(SS.LT.0) TT=0
      TIME=STOP+AT+DT+TT
      GO TO 200
C*****************************************************************
C
C       TRAVEL TIME FOR PASSENGERS ON THE BUS WITH PROVISIONS
C       FOR STOPS TO PICK UP PASSENGERS
C
C*****************************************************************
120   N=0
      IFLAG=0
      IT=NN(LINK)
      ID=NBT(I)
C
C           Determine if passenger transfers.
C
      DO 130 J=1,IT
      DO 130 MT=1,ID
      IF(NNN(LINK,J).EQ.NBUS(I,MT)) GO TO 140
      GO TO 130
140   N=N+1
      NNN(I,N)=NBUS(I,MT)
C       WRITE(6,1) NNN(I,MT),NM,K,NTREE,I,TRAV(NM),ECES(NM),LINK
      IFLAG=1
130   CONTINUE
      NN(I)=N
      SUM=0
C
C           Compute stopped time to pick up passengers & link time
C
      IF(TLINK(I).EQ.0) GO TO 155
      VEL=DIST(I)/TLINK(I)
      GO TO 157
155   VEL=FREFLO
157   STOP=BOARD*PERSOF(NM)
      IF(PERSON(NM)-PERSON(K).GT.2*PERSOF(NM)) STOP=(PERSON(NM)
     +-PERSON(K))*BOARD/2
      IF(STOP.LT.0.1) GO TO 158
      AT=VEL/ACC
      DT=VEL/DEC
      S=.5*ACC*AT**2
      SS=DIST(I)-S
      TT=SS/VEL
      IF(SS.LT.0) TT=0
      TIME=STOP+AT+DT+TT
C       WRITE(6,2) TIME,STOP,AT,TT,SS,S,VEL,DIST(I),TLINK(I)
      IF(IFLAG.EQ.0) GO TO 160
      GO TO 200
```

```
158   TIME=TLINK(I)
      IF(IFLAG.EQ.0) GO TO 160
      GO TO 200
C*************************************************************
C
C       TRAVEL TIME FOR PASSENGERS MAKING TRANSFERS
C
C*************************************************************
160   DO 150 MT=1,ID
      II=NBUS(I,MT)
      SUM=SUM+HEAD(II)*60.0
      NNN(I,MT)=NBUS(I,MT)
C       WRITE(6,1) NNN(I,MT),NM,K,NTREE,I,TRAV(NM),ECES(NM),LINK
150   CONTINUE
      NN(I)=ID
      ECE=SUM/(ID*2)
      IF(ECE.GT.300) ECE=300
C
C           Compute transfer time
C
      TIME=TIME+ECE
200   RETURN
      END
C
C
C
C
C
C
C
C
C
C
      SUBROUTINE ASSN(MTTD,NHOME,NTSK,NZONE,NGROUP,I,TOD,NC
     +,NPSINK,MZONE,PERIOD)
      COMMON/MEIN/ TTO(1500,50),NBL(1500),NUMDEP(1500),
     +       LINKDP(1500,10),TLINK(2100),TRAV(1500),NT(1500,50)
     +       ,IKT(1500),NLINK,LAST,NNODE,ND(2100),NBT(2100),
     +       NBUS(2100,30),DIST(2100),NO(2100),ECES(1500)
      COMMON/TME/HEAD(1000),PERSON(1500),NNN(1500,5),DEC,ACC,LLINE
     +,BOARD
     +,PERSOF(1500),FREFLO
      COMMON /ASS/ IPEDO(3500),NN(1500),ITAC(1500)
      DIMENSION MTTD(250),NQQ(10),TOD(3,100,100),TTT(100),NC(15)
     +,NPSINK(400),MZONE(30)
C
C
C
      DO 90 K=1,NZONE
      TTT(K)=0.0
      DO 90 M=1,NGROUP
      TTT(K)=TTT(K)+TOD(M,I,K)
90    CONTINUE
C
C           Compute number of persons travelling between
C           origin - destination pairs
C
      DO 100 J=1,NTSK
      NSTART=MTTD(J)
      KK=NPSINK(J)
```

```
      K=MZCNE(KK)
      TOTAL=TIT(K)/NC(K)
      IF(ITAC(NSTART).EQ.0) GO TO 100
      L=NN(NSTART)
      IF(L.GT.NLINK) GO TO 120
C
C
      IT=NBT(L)
      DO 110 MT=1,IT
110   NQQ(MT)=NBUS(L,MT)
      NX=IT
      NM=NC(L)
      GO TO 140
C
C
120   NM=IPEDC(L)
      L=NN(NM)
      IT=NBT(L)
      IF(IT.EQ.0) GO TO 100
      DO 130 MT=1,IT
130   NQQ(MT)=NBUS(L,MT)
      NM=NC(L)
      NX=IT
C
C
140   DO 150 IIII=1,NLINK
      L=NN(NM)
      IF(L.GT.NLINK) GO TO 185
      IT=NBT(L)
      IF(IT.EQ.0) GO TO 100
      N=0
      SUM=0.0
C
C
      DO 160 MT=1,IT
      DO 160 MO=1,NX
C
C           Compute number of people boarding bus.
C
      IF(NQQ(MO).NE.NBUS(L,MT)) GO TO 160
      II=NBUS(L,MT)
      SUM=SUM+HEAD(II)
      N=N+1
      NQQ(N)=NBUS(L,MT)
160   CONTINUE
      NX=N
      IF(N.EQ.0) GO TO 180
      SUM=SUM/NX
C
C           Assign people to buses.
C
      PERSON(NM)=PERSON(NM)+TOTAL*SUM/(PERIOD*NX)
      GO TO 150
180   DO 190 MT=1,IT
      NQQ(MT)=NBUS(L,MT)
      II=NBUS(L,MT)
190   SUM=SUM+HEAD(II)
      NX=IT
      SUM=SUM/NX
C
```

```
C          Assign people to bus stops
C
185   PERSOF(NM)=PERSOF(NM)+TOTAL*SUM/(PERIOD*NX)
      PERSON(NM)=PERSON(NM)+TOTAL*SUM/(PERIOD*NX)
      IF(L.GT.NLINK) GO TO 100
      IF(NO(L).EQ.NHOME) GO TO 100
150   NM=NC(L)
100   CONTINUE
      RETURN
      END
C
C
C
C
C
C
C
C
C
C
      SUBROUTINE SPLIT(I,NHOME,NGROUP,NZONE,IGD,IXT,DIFF,TMOD,TMAX)
      COMMON/PARK/ OIN(100,100),O(3,100,100),JS(15),MR(15),NC(15)
     +,LZONE(30),ETAV(250),TAV(250),ADIS(250),NVSINK(250),NPSINK(400)
     +,ATAV(250),W(150,150),MZONE(30),C(150),TOD(3,100,100),P(100)
     +,WP(150,150)
C*************************************************************
C
C          1ST ITERATION COMPUTATIONS
C
C*************************************************************
      IF(IGD.GT.0) GO TO 200
      DO 100 M=1,NGROUP
      IXT=IXT+1
C       WRITE(6,121) IXT
C
C          Initialize vectors and scalars
C
      DO 110 K=1,NZONE
      TTTT=TAV(K)+ETAV(K)+1560
      WK=0.0
      CNT=0.0
      ATTT=0.0
      DIS=0.0
      CT=0.0
C
C          Prepare data for mode split computations
C
      DO 120 L=1,NZONE
      IF(WP(K,L).LT..05) GO TO 120
      WT=W(L,K)
      IF(WT.GT.TMAX)WT=TMAX
      WK=WK+WT*WP(K,L)
      ATTT=ATTT+ATAV(L)*WP(K,L)
      DIS=DIS+ADIS(L)*WP(K,L)
      CT=CT+C(L)*WP(K,L)
      CNT=CNT+WP(K,L)
120   CONTINUE
      WK=WK/CNT
      ATTT=ATTT/CNT+1200
      DIS=(DIS/CNT+30000)/5280
```

```
      CT=CT/CNT
C
C           Compute mode split
C
      GX=-.83+1.27*(TTTT/ATTT)+.095*(.35/(DIS
     L*.08))-.615*CT
      IF(GX.GT.170) GO TO 150
      PA=EXP(GX)/(1+EXP(GX))
      GO TO 160
150   PA=1.0
160   TOTAL=TOD(M,I,K)+O(M,I,K)
C
C           Compute auto - transit demands
C
      O(M,I,K)=TOTAL*PA
      TOD(M,I,K)=TOTAL-O(M,I,K)
      P(K)=PA
110   CONTINUE
      IST=IXT
C
C           Write mode split to sequential file
C
      WRITE(4'IST)  (P(K),K=1,NZONE)
100   CONTINUE
      GO TO 1000
C*************************************************************
C
C           MODE SPLIT COMPUTATIONS FOR SUBSEQUENT ITERATIONS
C
C*************************************************************
200   DO 300 M=1,NGROUP
      IXT=IXT+1
      IST=IXT
C
C           Read from sequential file the previous iteration
C            mode split
C
      READ(4'IST) (P(K),K=1,NZONE)
      DO 310 K=1,NZONE
C
C           Initialize vectors and scalars
C
      TTTT=TAV(K)+ETAV(K)+1560
      WK=0.0
      CNT=0.0
      ATTT=0.0
      DIS=0.0
      CT=0.0
C
C           Prepare data for mode split
C
      DO 315 L=1,NZONE
      IF(WP(K,L).LT..05) GO TO 315
      WT=W(L,K)
      IF(WT.GT.TMAX) WT=TMAX
      WK=WK+WT*WP(K,L)
      ATTT=ATTT+ATAV(L)*WP(K,L)
      DIS=DIS+ADIS(L)*WP(K,L)
      CT=CT+C(L)*WP(K,L)
      CNT=CNT+WP(K,L)
```

```
315   CONTINUE
      WK=WK/CNT
      ATTT=ATTT/CNT+1200
      DIS=(DIS/CNT+30000)/5280
      CT=CT/CNT
C
C           Compute mode split
C
      GX=-.83+1.27*(TTTT/ATTT)+.095*(.35/(DIS
     L*.08))-.615*CT
      IF(GX.GT.170) GO TO 320
      PA=EXP(GX)/(1+EXP(GX))
      GO TO 330
320   PA=1.0
C
C           Modify mode split based on previous mode split
C
330   DDD=P(K)-PA
      PP=P(K)
      IF(PP.LT.0.5) PP=1-PP
      PA=P(K)-PP*DDD
      TMOD=TMOD+P(K)
      DIFF=ABS(P(K)-PA)
      P(K)=PA
C
C           Compute auto - transit demands
C
      TOTAL=TOD(M,I,K)+O(M,I,K)
      O(M,I,K)=TOTAL*PA
      TOD(M,I,K)=TOTAL-O(M,I,K)
310   CONTINUE
      IST=IXT
C
C           Write new mode split to sequential file
C
      WRITE(4'IST) (P(K),K=1,NZONE)
300   CONTINUE
1000  RETURN
      END
C
C
C
C
C
C
C
C
C
C
      SUBROUTINE BNET (NOB,NBSTP,LIN,NM,IBT,BTM,NTT,NTR,NU,SPED)
      COMMON/MEIN/ TTO(1500,50),NBL(1500),NUMDEP(1500),
     +      LINKDP(1500,10),TLINK(2100),TRAV(1500),NT(1500,50)
     +      ,IKT(1500),NLINK,LAST,NNODE,ND(2100),NBT(2100),
     +      NEUS(2100,30),DIST(2100),NO(2100),ECES(1500)
      DIMENSION NBSTP(100),NOB(100),BTM(100)
     +,NTT(1500),NTR(1500,28),NU(400)
C
C           Initialize vectors
C
      BTT=0.0
```

```
      SPED=0.0
      DST=0.0
      IBT=1
      IT=0
      NOB(IBT)=NM
      DO 120 I=1,100
120   BTM(I)=0.0
C
C           Find auto links with bus line on it
C
400   IN=NUMDEP(NM)
      IF(IN.EQ.0) GO TO 100
      IAT=0
      DO 200 L=1,IN
      I=LINKDP(NM,L)
      K=ND(I)
      IH=0
      IXT=NBT(I)
C
C           Aggregate auto links between bus stops into bus links
C
      DO 300 KK=1,IXT
      N=NBUS(I,KK)
      KS=NTT(K)
      IF(KS.EQ.0) GO TO 340
      DO 320 JJ=1,KS
      IF(N.EQ.NTR(K,JJ)) GO TO 350
320   CONTINUE
340   NTT(K)=NTT(K)+1
      KS=NTT(K)
      NTR(K,KS)=N
      IF(IBT.GT.1) GO TO 350
      NTT(NM)=NTT(NM)+1
      KS=NTT(NM)
      NTR(NM,KS)=N
350   IF(LIN.NE.N) GO TO 300
      IH=1
300   CONTINUE
      IF(IH.EQ.0) GO TO 200
      IF(IBT.EQ.1) NTREE=2
      IF(IBT.GT.1) NTREE=100
C
C           Determine travel times on links by bus
C
      CALL TIM(NM,K,I,TIME,NTREE,ECE,LINK)
      LINK=I
      NM=K
      IT=IT+1
C
C           Compute aggregate bus link travel time
C
      BTM(IBT)=BTM(IBT)+TIME
C
C           Compute total bus travel time & trip length
C
      BTT=BTT+TIME
      DST=DST+DIST(I)
      IF(NBL(K).NE.1) GO TO 400
      IBT=IBT+1
      NOB(IBT)=K
```

```
      GC TC 400
200   CONTINUE
100   IF(IBT.EQ.O) GO TO 450
      BTM(IET)=ETT
C
C           Compute average speed of bus
C
      SPED=(DST/BTT)*.6818181818
      GC TO 470
450   WRITE(6,1) NM


       FCRMAT(10X,'THE INPUT SPECIFIED A START NODE FOR A BUS LINE'
     +,' WHICH HAS NO EXIT',I4)
 470   RETURN
       END
```