MODE CHOICE DETERMINANTS OF SELECTED SOCIOECONOMIC GROUPS: AN INVESTIGATION OF A PLANNING AND CONTROL MECHANISM TO DIVERT AUTOMOBILE DRIVERS TO PUBLIC TRANSPORTATION

by

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ABSTRACT

This study examines the determinants of individual commuter mode choice, and the feasibility of adjusting the mode split by public policy; with special reference to changes in parking arrangements and the price of parking. Hypotheses about the dimensions of travel time, cost, comfort, and convenience in the mode choice decision for various socioeconomic strata are formulated from an examination of a single travel corridor in Vancouver, Canada. A disaggregate stochastic behavioral model of the discrimination-classification type is developed and used to test the hypotheses within the context of a planning and control mechanism based on policy changes. The results indicate that adjustments in residential travel time, parking charges, and bus frequency would be most effective in changing mode split.

A second series of tests measured the propensity of different socioeconomic groups to shift from automobile travel to a multimode "park and ride" system. A so-called "propensity" model was formulated from individual preferences for the service characteristics required to encourage a shift to the multimodal system; or a change in downtown parking cost to effect a shift to transit. The propensity model indicates that substantial shifts could be expected with large percentage increases in parking charges in conjunction with improvements

in transit service. To be effective in promoting mode shift the park and ride service would require very efficient transfer arrangements at the fringe terminal, and frequent transit service. The statistical tests demonstrate that propensity to shift is related to the socioeconomic characteristics of the tripmaker. Those under 40, from single car families, with middle to lower incomes, and those in the non-professional occupations have higher propensity to shift than the population as a whole.

The study is conducted within the context of a philosophy of transportation planning which seeks to channel demand for transportation services toward community objectives. The results are antecedents of a planning and control mechanism which is both goal-oriented and incremental; incorporating both system planning and decision making in the long term context, and flexible operational control of the system to meet short term objectives. The mechanism suggested, using parking policy as the control factor, is aimed at incremental investment decisions which are more or less reversible. It is concluded that parking policy changes, if the institutional setting allows, can be an effective goal oriented instrument for mode split planning.

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CHAPTER I

INTRODUCTION

The Problem

The growth of automobile traffic after the Second World War resulted in an increased demand for better roads in urban regions. This trend has been accompanied by a steadily declining demand for public transportation. Consequently, the process known as urban transportation planning evolved primarily as a means to analyze and extrapolate the demand for roads and automobile oriented support facilities. Meeting the demand for roads has however produced some severe negative social consequences and has resulted in a recent concern with the need to revitalize transit services. This necessitates new approaches to transportation planning and decision making which go beyond the simple extrapolation of existing demand patterns and which incorporate societal objectives into the analysis of demand for transportation services. One such approach is the study of control mechanisms which can be used for public intervention and adjustment of the balance between the various transportation modes. This research is an investigation of the determinants of mode choice and preferences of selected socioeconomic groups, and an examination of the role of parking policy as a control mechanism to adjust the modal split.

There have been many suggestions for technological changes in transportation modes, along with a re-evaluation of more traditional forms of public transportation to change the modal split. But experience has shown that traditional forms of public mass transit modes have not been widely accepted by the public as an alternative to automobile travel. This has resulted in declining revenues and subsequent decreases in service. Yet, a rationalization of urban transportation services is explicitly bound up in the notion of a transportation system in which that mix of different types of service is found which maximizes community welfare.

A planning and decision framework to rationalize the system has two major requirements: a complete understanding of the dimensions of demand for transportation services, and a control mechanism to adjust the mode split in accordance with public objectives. If rationalizing the mode split means relatively more use of transit, adjusting the mode split is in practice creating a shift from car use to transit use. Forecasts are invariably pessimistic regarding any large shift of commuters from automobiles. However, several aspects of these forecasts are important to consider. First, even if only a very few car drivers shift to transit there will be a multiplier effect on relieving congestion since one car off the street is more than equivalent to the addition of one or two transit passengers to the system. Secondly, there is little

doubt that certain socioeconomic groups would have a high propensity to shift mode if their conditions were met by new policies. These groups would consist of those people who have little cultural or emotional attachment to the automobile as such, but who would select the mode providing the best service. Finally, we have very little knowledge of the limits of changes needed in a transit system to encourage a shift since behavior on the system is restricted by existing service. Only recently have some efforts been directed toward an approach for assessing transit patronage with radical changes in transit service.

A central concept in such an approach is to relate demand for the various means of transportation to satisfaction gained from the attributes of the system rather than to the mode actually used. The premise is that a traveller uses a particular mode because it provides him with the most desirable, or least undesirable, combination of travel time, travel cost, comfort and convenience. If the demand for each combination of attributes can be measured the effect of new combinations of attributes can be tested. If the new combination defines a practical means of transportation the change in demand, in terms of a shift from the car to the new mode, can be predicted. This depends upon a shift in demand patterns when a combination of attributes defining new parking and line haul arrangements is conceived.

These demand patterns can be assessed by means of mathematical models of individual decision processes. Models can be a useful means of predicting probable effects of various policy options on users of the transportation system. A few recently formulated travel demand models appear to have good promise in simulating individual decision making. Recent demand models are disaggregated to consider the travel decisions of an individual. They are also stochastic in that they predict the probability of an individual making a specific choice. Probability is assigned by the model on the basis of the characteristics of the choice of environment, or in this case, on the attributes of the transportation system. Transportation models have been relatively successful in exploring mode choice behavoir. However, given the severe restrictions on transit behavioral experience by poor or non-existent service a logical next step is toward preference models, or those which model traveller preferences as opposed to extant behavior. With such a model it would be possible to predict the probability of an individual shifting to a new mode if his preferences for system performance were incorporated in the new mode.

A shift from automobile commuting to commuting on some new system depends upon the perception of the system by the user, and specifically the relative attractiveness of the combinations of attributes available. Obviously some users will always favour those attributes which are only available with

automobile commuting, such as privacy and prestige. On the other hand individuals who have a choice may opt for transit because of its low fare or non-existent parking cost. Previous research indicates that groups of individuals react differently to various combinations of modes and their characteristics according to socioeconomic status.

Consequently, unlike previous demand models which treat the travel market as homogeneous, new models must account for the variance in socioeconomic status of the trip maker. The need to stratify users of the system into client groups with different sensitiveness to system attributes and changes in the system is now evident. Sommers in expressing the need for an expanded mode choice theory writes:

> market disaggregation is--considered endemic to a valid mode split model.[1]

While some econometric models have been designed to model the effect of system changes on mode split, only fragmentary attempts exist to show differential effects on the various sectors of the urban travel market. For example, question such as whether given price changes would have more impact on low income groups than on high income groups have not been systematically explored.

Clearly the effect of system changes on the mode choice of different groups is dependent upon the <u>perceived</u>

relative disutility of the attributes of the modes available. This implies that subjective preferences, if they can be reliably measured, can be used to understand dimensions of transportation demand. Attitudes, as manifested by stated preferences ; behavior; and group characteristics all interact in mode choice decisions. As Sommer states:

> Mode choice behavior,--is determined by traveller attitudes toward mode characteristics and by personal--or environmental factors.[2]

The strategy of measuring subjective preferences is particularly useful where poor transit service exists. A need is seen for this strategy in transit marketing. Since it is the expressed aim of marketing transit to make transit more desirable to certain groups than the automobile, an understanding of what it is that people value in making their choice of mode is critical to marketing strategies. As early as 1962 the Bureau of Public Roads recognized the need to study

> Why groups of people choose different means of urban travel under various conditions and how their choices would be affected by the quality and cost of different kinds of private and public transportation.[3]

Consequently, it appears necessary to study preference patterns for any full understanding of mode choice and policies which would be successful in changing mode split.

The second requirement of a planning and decision framework for system rationalizing is a planning control mechanism to implement mode shifts. This requires in turn a change in the concept of transportation planning as practiced in the past. Basically this implies a change from the traditional concept of planning to meet demand for automobile travel to one of planning to channel demand in accordance with community objectives.

Steger and Lakshmanan[4] have outlined the traditional process. They isolate four sub-processes: goal identification, policy and plan design, plan testing, and plan evaluation. This schema is a formalization of the practical process which has evolved since about 1950 in which an "end state" development plan or plans were formulated and various alternative transportation plans were devised, tested, evaluated and ultimately resulted in a "best" plan to achieve transportation goals.

This practical process, evolving as it did in response to the growth of automobile traffic, has recognizable shortcomings for planning mode split adjustment. Mode split in this schema is a simple division of gross travel demand into those who use cars and those who use transit. As such the process contained no mechanism to plan mode split but is based on the extrapolation of existing mode split conditions and thereby tended to perpetuate existing auto dominance. By simply

projecting demand the transportation planner is nothing more than a passive observer and forecaster of trends. The Steger and Lakshmanan schema goes further however and recognizes the active role of the planner in changing trends. They write:

> An increasing emphasis on processes by which changes are introduced that will affect future (sic) character of the city and the effectiveness with which persons and activities will be able to interact in the future has become evident.[5]

They seek to do this either by a pricing system or some other such relatively automatic and impersonal rationing mechanism. Such a device requires the identification of each control variable that can respond to public policy. Thompson[6] suggests this is the mature stage of urban transportation planning, where the "tactics of price making" would largely replace the currently used cost accounting approach.

This implies a planning and control mechanism to adjust mode split. Thomas and Schofer[7] define the process of control as involving

> Those activities or decisions intended to result in short-term changes.[8]

Thomas and Schofer's definition of planning in this context is

> The set of activities associated with long-term system decisions.[9]

A planning and control mechanism thereby incorporates both system planning and decision making in a long term context and flexible operational control of the system to meet short term objectives. A very high degree of interaction between these processes is necessary to rational transportation planning and decision making.

A decision process which has the above characteristics is necessarily dominated by a central philosophy of problem solving by incremental steps. One such public decision making philosophy is "disjointed incrementalism"; a strategy directed to the identification and solution of problems by incremental changes from the "status quo." Braybrooke and Lindblom describe it as a "margin-dependent" mechanism for solving problems.[10] There is no goal achievement orientation in the philosophy as documented, but Steger and Lakshman have combined "disjointed incrementalism" with a "forward-seeking" goal oriented process for the development of transportation plans. Their process (1) models the system (2) identifies problems (3) establishes problem solving short-term objectives and (4) generates alternative strategies or policy controls to guide the modelled environment toward a stated set of goals. The combination of incremental problem solving within a long range planning context appears to have merit as a philosophical basis for mode split planning.

Two methods have been suggested as means to regulating the flow of traffic in the short run; congestion pricing policies and parking policies (including pricing controls). Pricing to restrict automobiles from congested areas has been most forcefully advocated by Beesley[11] and Roth.[12] The concept is based on marginal cost pricing which means, as Beesley states:

> charging vehicles' users according to their liability to cause congestion to themselves and to other vehicles at specific road locations, and thus deny access to users who value their own costs plus those imposed on others.[13]

This involves imposing a charge directly related to the length of time and section of road used, and to the level of congestion at the time the charge is levied. Although the economic arguments for restrictive road pricing are impressive very little specific attention has been given to congestion pricing and mode split. Roth suggests that road pricing alone would not encourage people to use buses, but the bus system also must be made attractive in conjunction with restrictive measures. The major problem with congestion pricing is a lack of any effective technique to meter and administer the charge for congestion. This would also apply to mode split adjustment. A more practical and easily administered system may be to control parking policies. Parking charges have been criticized as a mechanism for congestion pricing because it neglects through traffic. This criticism does not, however, apply to mode split adjustment since each trip has a common terminating

point and adjustment is effected to the mode used, not to whether or not the trip is made.

Available evidence of sensitivity to parking charges or taxes suggests that a mechanism based on parking controls would be successful in adjusting mode split; on both conceptual and practical grounds. However, such a mechanism should include non-price factors because of the overall sensitivity to time and comfort aspects of system users. These include walking time at the destination and parking time as well as parking fees or a parking tax. If the parking scheme is extended beyond the CBD to include a park and ride system, residential times, overall travel times, frequency of buses leaving the park and ride terminal, bus fares, and transfer and waiting characteristics of the system are all critical to planning a rationalized system.

A main advantage of such an approach is in its incremental strategy for public decision-making. Investment decisions are usually derived either through an analysis of resource flows; or an appraisal by cost-benefit analysis in which costs and benefits are in equivalent social units (i.e., units which include non-economic as well as economic considerations). In view of the low level understanding of the effects of policy changes on demand, as well as the indirect effects which accrue to spatial reorganization; and the largely unsuccessful attempts to include intangibles and social costs into the cost-benefit

formula, a procedure based on resource flows appears to be needed. By this is meant the incremental adjustments to the system by operational improvements or small capital projects and simultaneous observation of the effects on the system. If results are not in the direction desired to reach societal goals, the next increment of resource input is designed to correct the previous misallocation. This is not unlike a public pricing mechanism in which revenues from pricing policy are returned to the system to maintain a balance in the resource flows in accordance with social goals.

This research examines some of the possibilities and the ramifications of parking policy as a planning and control mechanism to adjust mode split.

OUTLINE OF RESEARCH

The study examines mode choice decisions and preferences of several socioeconomic groups for the purpose of understanding what type of system changes are needed for a modal shift, and to what degree automobile commuters may be encouraged to shift mode. The question that is being investigated is whether or not municipal parking policies can be effectively used to change mode split. The method of investigation is to construct a statistical model consisting of instrumental variables which are manifest public parking policies. In this way shifts in flows between car and transit modes can be

investigated through simulating changes in policies by changing the instrumental variables of the model.

The central working hypothesis of the study is that individual choice of the means of transportation to work is a function of the performance attributes of the transportation system and of socioeconomic characteristics of the user. Each trip taker will choose that mode for which the combination of service characteristics minimizes his travel disutilities. Furthermore, the combinations of service attributes chosen, or preferred, will group themselves according to the socioeconomic groups to which the individual trip maker belongs. The system attributes examined are those which are conceptually included in potential municipal parking policies.

Research procedure is largely an empirical analysis of a case study corridor. Data for the investigation consist of a type of origin destination study of traffic and bus passengers traversing a major travel corridor in Vancouver, Canada. The methods selected for analysis were done so with a view to investigating four specific questions:

(1) What are the major influences of mode choice in the case study corridor, and how do these compare with findings elsewhere?

(2) What is the interdependence of the socioeconomic structure of users and the service attributes of the mode used?

(3) Can users of the corridor be classified into two distinct client groups based on the mode used, and what are the instrumental, or policy, variables which have the largest influence in separating these client groups? And are those influences pertaining to a parking policy significant in mode choice behavior?

(4) Can statistically aggregated utility functions of stated preferences for system changes be used to predict the propensity of car drivers to shift to a park and ride system, and what is the influence of socioeconomic structure on a car driver's propensity to shift mode?

Conceptually, the study is taxonomic. That is, individuals are classified according to their perception of transportation service and the value they place on different service attributes of the system. Sufficient research has now been done to be able to identify the major quantifiable variables associated with mode choice. From this past research an *a priori* classification of mode choice influences is possible. In this study the *a priori* classes are tested according to the importance each class attaches to the variables defining system performance. In this way two aspects of travel demand can be investigated: system performance influences which tend to differentiate those who commute by car from those by transit,

and those influences which tend to differentiate car drivers into socioeconomic groups according to their propensity to shift to a park and ride system.

The data are analysed by means of multivariate statistical procedures. Multivariate analysis is concerned with analyzing multiple measurements that have been made on a number of individuals in which the multiple variates are considered in combinations, ie. as a system of variates. Two specific techniques are used in the study: canonical correlation analysis to describe the fundamental interdependence of a set of selected socioeconomic variables with the system performance variables; and multiple discriminant analysis to test the classification systems.

CHAPTER II

CONCEPTUAL BACKGROUND

Analysis of mode split is a part of the urban transportation planning process to measure and predict travel demand. The process is subdivided into studies of travel generation, trip distribution, mode split, and trip assignment. Mode split studies have evolved through three distinct stages. The first studies related travel demand to the structural characteristics of geographical zones delineated by the aggregation of socio-economic and land use phenomena. Mode split consisted of a diversion of the total trips generated for each zone to the road system or to the transit system. In these early studies no account was taken of the effects of the system on mode split. Second stage studies were those which emphasized the system effects, and treated the alternative modes as if they were competing for a share of the total travel market. Competition was on the basis of the relative advantage of the modes with regard to travel time, travel cost, comfort and convenience attributes. The variables describing the system attributes were zonal averages and therefore were not analogous to the decision framework of an individual in selecting a mode of travel. Third stage studies disaggregate travel phenomena to individual measurements and mathematical models are constructed

to replicate the behavior processes of the individual. However, two extensions of the third stage are needed to begin to fully appreciate the ramifications of transportation policy. These are analyses of the interdependence of the socioeconomic structure and system attributes, and the extensions of behavioral observations to include subjective preferences.

Research on the mode split has emphasized the influences on mode choice through the use of some type of mathematical model. The first stage studies concentrated almost entirely on models of urban structural influences at the global level of analysis. The second stage studies emphasized models of transportation system influences. These two stages, mostly carried out in conjunction with the major urban-region transportation studies, form the conceptual bases of determinants of mode choice. A brief review of the socioeconomic structural characteristics and those of the transportation system which have been found to influence mode choice is given below as a prelude to an analysis of the interdependence of these influences.

INFLUENCE OF URBAN SOCIOECONOMIC STRUCTURE ON MODE SPLIT

Early attempts to estimate mode split relied largely on the variation in urban structural characteristics as they related to percentage of transit use. Mitchell and Rapkin[1] in the early 1950's formulated the concept that land use activity

was the causal factor in urban travel. Further work in the early region-wide transportation studies,[2,3,4] established firmly the link between urban structure and interaction by observing empirical regularities between urban activity and traffic flows. Since mode split was a simple division of total person trips the basis for structural association with those who used transit and those who used private modes seemed obvious. Curran and Stegmaier[5] found the proportion of work trips by transit increased with city size. Adams,[6] in 1959, disaggregated global factors to relate population, labour force characteristics and automobile ownership rates to transit use.

The Chicago Area Transportation Study,[7] the first of the major urban-region studies to include a specific stratification of trips by mode, concluded that mode split was related to the unique activity of the Central Business District. The relationship between mode split and the structure of the CBD is supported elsewhere. A study by Taaffe et al[8] showed that socioeconomic and modal differences existed between those who commuted to the Central Business District and those who commuted to peripheral job locations. Recent studies have tended to show that the mode split of trips to the CBD is changing in favour of automobile commuting in association with structural changes in the CBD daytime population. Evidence indicates that while total CBD activity remains constant in large cities there has been an increase in automobile commuting and a decrease in transit commuting.[9,10,11]

Several socioeconomic factors are associated with mode choice. Clear associations have been found between the number of transit riders generated by a traffic zone and factors such as car ownership, income, family composition and social status.

Car Ownership

Some investigators believe that car ownership and mode choice are synonomous. Lansing and Hendricks[12] document that 92 percent of commuters in the United States use an automobile if there are as many automobiles as adults in the family. However, as car ownership per family increases the reductive effect on transit ridership decreases. It appears that there is a minimum level of transit usage which is therefore to a degree independent of car ownership. This minimum is referred to as "captive" transit riders, or those who have no other means of travel.

Car ownership is in fact a proxy measurement of car availability for a specific trip. Clearly if a one car household has more than one employed member the competition for the car enters into the mode choice decision. Some investigators have used an index of household trip generation (related to income) divided by the number of automobiles as an indepedent influence on mode choice rather than car ownership.[13,14]

The use of car ownership (or availability) as an independent variable for mode choice is fraught with conceptual difficulties. There is the problem of causality (i.e. does owning an automobile "cause" its use for the work trip, or does lack of alternative service "cause" one to purchase a car). There is also the problem of the interaction of auto ownership with income and travel cost variables. Lave[15] points out the two extremes; if a family owns a car for only one reason, transportation to work, and if total cost (time and dollar) is less by auto than by transit, auto ownership would predict mode choice, but would not explain it because causality is still confused. If, on the other hand, cars were treated as purely social goods which are purchased for activities other than commuting to work, car ownership would be a function of family income. If the former situation prevailed auto ownership as an environmental constraint should not be included in a mode split analysis since the cost and time factors consider its effect; if the latter case prevails it is a function of income. For these reasons, car ownership, although used extensively, is not a good explanatory factor in mode choice.

An associated question is whether or not a car is necessary at work. Recent studies have tried to assess this factor and the concensus is that if a car is a necessary part of the work situation no mode choice exists. However, the importance of this factor in potential transit use depends

upon the frequency of car use, and whether or not actual use is made of the car when it is reported as necessary for work. It is possible that many respondents report a need for the car at work to justify taking it to work, whereas its use may be very infrequent or even non-existent. These people may be potential transit patrons under different conditions, specifically if transit service improves dramatically.

Income

Income as an influence on the mode split may act as an environmental constraint, through car ownership for example, or it may act through time and cost on the system by influencing the relative weight given to these in the mode choice decision. Transportation study findings, which typically consider both "captive" and "choice" riders have shown income to be an important constraint on mode choice.[16,17,18,19] If a car is available for a specific trip, however, the effect of income is doubtful. Recent studies controlling the income constraint by considering only those respondents with a car available have shown that family income levels do not act directly in mode split models but only through system variables. Warner[20] considered the income effect (holding car ownership constant) to have two components. The first when automobile travel is more expensive than transit (thereby postulating that higher incomes lessen the effect of cost as a deterrent to automobile choice); and second when transit is more expensive (where lower incomes

would favour car use). He found that the income effect treated in this manner had little effect on mode choice. Quarmby[21] found the income effect insignificant even though he found the mode cost difference significant, inferring that income had no effect beyond its effect as measured by cost of travel. Both Warner and Quarmby conclude that once car ownership and location of residence is decided upon, income has little effect on mode choice.

In summary the evidence shows that if both captive and choice trips are included in the analysis, income is an important environmental factor in the choice of mode: with those of low income being captives and therefore locational factors of home and work carrying more weight in the mode choice decision than service attributes. On the other hand, where only choice trips are considered, income as an environmental factor may be unimportant.

Family Composition

Sex, age, family size have been shown to be associated with modal split in varying degrees. Women in all age groups are more likely to take transit than men. Hoel et al,[22] Warner,[23] Taaffe,[24] Bock,[25] Leathers,[26] and Wilson[27] have all found transit use increases with the number of females in the work force. Age structure may be a factor also. Increased transit use is associated with age groups on both ends of the

population age distribution. Bock found that significantly fewer persons in the 25-44 age group used public transit to work. Hoel et al found the highest proportion of transit users in the 35-65 age group. On the other hand, Warner found no influence due to age.

Family size is a direct determinant of mode choice through its effect on auto ownership and competition for auto use in the family. Wilson[28] found family size to be a determining influence. Family size effects in Kain's model operated through residential space preference.[29] Warner and Bock's household restriction factors of the competitive effects of family size and number of autos available has been mentioned. Oi and Shuldiner[30] concluded that larger families utilize each auto more intensively, but that the increased utilization of transit according to family size increases at a faster rate than intensity of auto use.

Social Status

Although bus transit is commonly associated with low prestige, factors measuring social rank have not been considered major contributing ones mainly because they act through measurable variables (such as income). Some work has related occupation to mode choice. Reeder[31] was specifically concerned with the variation of certain socioeconomic groups with transportation time-cost expenditures. Although Reeder found

statistically significant difference in occupational groups on the overall time of travel (higher status occupations spend less time travelling), he found no relationship between occupation and cost, nor between occupation and mode of travel to work. Bock, on the other hand, found occupation to have an influence on mode that "is to some extent independent of car ownership." Oi and Shuldiner's study made an extensive analysis of occupation and trip generation with the concomitant variables of car ownership and household size controlled, and demonstrated that occupation of household head affects trip generation. No analysis of mode split variation however was done in this study.

Kain[32] has examined race and transportation and records that negro commuters are more likely to use transit than whites. No studies have concentrated on educational determinants, except to the extent education acts through other variables.

INFLUENCE OF TRANSPORTATION SERVICE ON MODE SPLIT

The consideration of transportation service as an influence on mode split began with the Erie and Puget Sound Transportation studies.[33,34] In these studies it was recognized that transportation service quality in relation to opportunities would affect the mode split. Each zone was assigned an "accessibility index," which was a function of all job opportunities available and the total travel time for each mode. The ratio of accessibility indices became known as the

accessibility ratio and was a measure of relative service quality applied to each zone. Curves, stratified by zonal household characteristics and relating accessibility ratios to percent transit from each zone, became the basis of mode split estimation.

Although service quality in the form of an accessibility index for each zone was used in these studies, system performance was abstracted to the zonal level and therefore did not truly represent the choice of service factors facing a traveller. The next stage in the evolution of mode split techniques was to include actual service characteristics as a determinant in the choice decision.

Hill and von Cube[35,36,37] working with 1956 origin destination data of the Metropolitan Toronto Planning Board were instrumental in developing the idea that system attributes were central to the mode choice decision. The concept was that the volume of people moving between origin and destination form a travel market, and the various modes are competing for a share of this market. Each will be successful in achieving a portion of the market depending upon its competitive position vis-a-vis the advantages and disadvantages it offers as measured by the attributes of relative travel time, travel cost, and convenience. External factors such as economic status (income) and trip purpose are market characteristics which determine reaction to the performance attributes. In applying these

ideas Hill and von Cube calculated ratios of relative times, costs, and convenience for each zonal interchange. All trip interchanges were stratified according to several income categories and again stratified by the ratio of transit fares to vehicle operating and parking costs. A third stratification was made of service ratios as measured by walking and waiting times by transit divided by parking delay and walking time for auto drivers. A family of curves derived by regression analysis for each group of travellers showed percentage transit interchange against the travel time ratio between zones. This meant that a traveller in facing a decision about his choice of mode considers the relative merits of the modes available to him in making his journey, and chooses that mode he perceives to provide the best service within his environmental constraints (in this case his income). The behavioral basis of this concept was recognized but no attempt was made by the developers to relate this to consumer choice theory.

The basic concepts and technique initiated by Hill and von Cube, were applied to several urban areas.[38,39] Their work was also closely paralleled by others who used some extensions of modifications of this approach.[40,41] The importance of these studies were that they documented the transportation system variables which influenced mode split.

Overall Travel Time

All transportation planning studies are based on the central importance of travel time as a factor in both spatial distribution of travel and the mode split. In a simple mode split model such as those used before the mid fifties, a minimum time path algorithm assigns trips to the alternate modes by means of an empirically derived diversion curve which determined what percentage of trips would be "diverted" to transit on the basis of the relative travel times by transit and automobile. The importance of travel time is firmly rooted in transportation study procedures for two reasons. First, it represents a valid single parameter of travel. Cost and distance parameters have been considered in various studies but travel time is invariably used as a singular influence. Secondly, it has been found in virtually all subsequent studies to be an important influence, particularly at the micro-level. Overall travel time is made up of walk times at both ends of the trip, wait times, time spent in the vehicle, transfer times if by public transit, and time to park.

Both absolute and relative travel times have been used in mode split research, although the relative times via the mode used to the best alternative is favoured. This arises from the concept that once the decision is made to travel to a particular destination, the mode choice decision is based on the competitive advantage of the attributes of the modes

available. A controversy exists about the proper measurement to replicate the calculus of the decision maker: the ratio of travel times or absolute differences in travel time. Neither seems completely adequate. Ratios are considered not sufficiently intuitive, in that one does not think in terms of ratios but in terms of minutes saved (or lost) and large differences in overall travel time could exist for trips with the same ratio. The reverse problem exists with the use of travel time differences; that is, a time difference of (say) 5 minutes in a 40 minute trip would have a different perceived value than in a 10 minute trip.

Overall Travel Cost

Overall travel cost include fares for transit and vehicle operating costs, parking costs and/or tolls for automobiles. The same difficulties in replicating traveller decision calculus in cost ratios of differences applies to relative cost as to relative time. If all other factors are equal the cheaper mode should be the preferred one, and given that the user has a propensity to economize, the relevant question is whether the cost stimulus is proportional to the ratio of difference in costs. Most investigators opt for the use of cost differences.

Excess Travel Time

Excess travel time is that which occurs outside the transit vehicle, walk, wait, transfer and parking time and

walking time for automobile drivers. Excess times are usually aggregated and treated as a separate factor in the mode split equation because these times appear more onerous to travellers than the in-vehicle times. Where they have been treated specifically they are usually found to weigh 2-3 times the value of overall travel time. Quarmby found excess times to be 2.5 to 3 times overall travel times.[42] Pratt uses a factor of 2.5.[43] No studies have disaggregated excess time into policy components, say the effect of CBD fringe parking, or a park and ride system which incorporates transfer times for auto drivers at the fringe terminal.

Comfort and Convenience

There is intuitive appeal to the idea that comfort factors are major determinants of the choice of mode. Air conditioned buses, non-crowded vehicles, transit shelters are all factors which the literature suggests may attract more people to transit. Unfortunately very little research has explicitly concentrated on these factors in mode choice. Nash and Hill[44] have used factor analysis to assess the importance of attributes of an ideal transportation system. They report that destination reliability, convenience and comfort factors rank first and second as desirable attributes. The comfort and convenience factor included such items as avoiding changing vehicle, weather while travelling, weather while waiting, shortest time, and avoid waiting more than 5 minutes. Bock[45]

found comfort ranked second of all factors determining mode choice.

Ackoff[46] attempted to assess comfort factors by means of a 7 point Likert scale. He found that his subjects could not discriminate between changes in the sub-components of comfort but could scale the relative level of overall comfort. For work purpose trips his subject's sensitivity to comfort was only exceeded by their sensitivity to travel time. For "other" purpose trips comfort ranked the highest in sensitivity.

Parking Factors

High parking costs are among the most important reasons some people use transit. Sensitivity tests have shown that changing parking costs, parking delay, and walking times in the CBD have a greater effect on the modal split than changing line haul service levels.[47] Quarmby[48] simulated parking cost changes in his model and found a 43 percent diversion to public transport with a 1s surcharge per day, and a 59 percent diversion with a surcharge of 3s per day. If walking times from parking lot to workplace were increased by 5 minutes a 39 percent diversion would occur. The Metropolitan Toronto Planning Board tested the effects of doubling the cost of parking in downtown Toronto and estimated that 33,730 persons might be diverted from autos to transit during the 7-9 am peak. The subway

ridership alone would increase by 26.5 percent on the Yonge-University line and 28.4 percent on the Bloor-Danforth line. Where parking has been supplied at transfer points on rail commuter and subway lines the number of commuters, as measured by the number of parkers who previously drove all the way downtown, also shows some dramatic increases.[49,50]

All indications point to parking policy as an excellent instrument to adjust mode split. Parking restrictions could be used to influence demand providing a municipal parking authority is established to retain control of the supply of parking spaces, their location, and charges.

The urban transportation studies and the ancillary research carried out in conjunction with these studies were extremely valuable in delineating those influences which could be useful to predict mode split. However , the process has one very serious conceptual problem; that of data aggregation.

The Problem of Aggregation

Comprehensive urban transportation planning studies use macro-analysis. There was originally a good reason for this; decisions were needed about total transportation systems to meet immediate post-war backlogs in freeway construction. Empirical generalizations of human behavior were observed and aggregated to geographical zones which were designed to be homogeneous in terms of demographic characteristics. In many

cases "traffic zones" were coincident with census tracts. The presumption was that within zone characteristics had less variation than between zone characteristics. This has the implied assumptions that the zone sample mean is representative of the households in a zone, that the zone sample mean is a reliable estimate of the population mean, and that zonal sample data are homogeneous with respect to the characteristics being studied. These assumptions are now highly suspect. Consequently, as Stopher[51] points out, the process of transportation planning is really defined in terms of socioeconomic characteristics of the population rather than in terms of transportation services. Forecasting mode choice is based on the assumption that people will change their socioeconomic class, and that their travel habits will change to conform with the class they have moved into. This assumes value structures are constant within a social class, a highly debatable assumption.

The first studies on analyzing mode split at the zonal level showed little effect from system attributes. This may have been the result of large variation on measures of transportation system characteristics within the zones relative to those between zones.[52*] Hutchinson[53] has found, for example, that in a test of one area of 247 zones the variance of trip making within zones was almost 80 percent while the between zone

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*McCarthy has found that zone sampling distributions are skewed, and that the mean is therefore not representative of the central tendency of the zonal data (see Ref. 52).

variance in trip making was only 20 percent of the total. If individuals within a zone, while having similar socioeconomic characteristics, have large variation in travel habits, or propensities for travel, it is unlikely that projects based on the relationships between these characteristics and mode split will reflect the values of individual travellers. This may account in part for the difficulty in replicating actual trips to the CBD where systems characteristics have a recognized influence. It may also account for the lack of universality of formulations based on geographic aggregation. It appears logically reasonable that variations in the form and structure of different urban regions relative to the transportation services would mean that relationships between structure and transportation service in one area would not be the same as in another area. This seems to be reflected in the many different determinants used in the models.

Lowry[54] has a general criticism of the aggregated approach to urban analysis; the universal substitution of empirically derived generalizations for theory. This criticism applies equally to transportation planning. Variables are included by introspection and by a knowledge of what other studies have found significant. The purpose of the process is to make the model work. This has meant that mode split models have virtually no generality. A second general criticism of aggregation is that the analysis may not lend itself to rational resource allocation. The impact of transportation plans falls

on individuals and social and institutional units and must be evaluated in terms of their welfare.[55] Evaluating transportation plans which have geographical aggregation as the basic analysis unit may create a misallocation of resources to the degree that values of system attributes vary within the zone.

The implicit assumption in aggregation is that zonal averages are representative of the travel behavior of individuals. That this is believed so has been termed the ecological fallacy and has resulted in aggregate variables being so strong as to cloud the real behavioral associations.[56] The recognition of this basic fallacy has led to behavior analysis based on statistically disaggregated data. This allows both a more reliable behavior model as well as the association of mode choice with the theoretical concept of individual consumer choice theory.

BEHAVIOR MODELS

Warner's study, published in 1962, is important for the development of mode choice theory for two reasons: he observed individual behavior; and he introduced probability theory into mode split analysis. Working with data collected by the Cook County Highway Department, Warner was concerned with the influence on an individual consumer's probability choice exerted by three economic variables; trip time and trip costs by the different modes, and the income of the trip taker.

His research space included 6 sets of binary choice; (1) that between automobile and city mass transit, (2) automobile and train, and (3) city mass transit and train for each of work and non-work purpose. Warner addresses his study to the question: given that choice of mode is a binary choice (i.e. between only two alternatives) what are the odds of an individual choosing mode (say automobile) given that his choice is dependent upon his perceived relative combination of time and cost attributes of the modes available, and upon his household income. His analysis relates the probability density of sample responses to the economic demand function.

The income variable in the demand equation is that which affects mode choice separately from the car ownership factor, and enters the function as a relative travel cost/income index. A car availability variable was also included which was a proxy made up of household income, number of adults in the household and number of cars. That is,the level of income creates the level of demand for travel, while an adult/car ratio defines the supply of auto resources for travel.

Theory of Abstract Modes

Lancaster,[57] Quandt and Baumol[58] were instrumental in changing the course of mode choice research in 1966. Lancaster's paper in that year argued that it was the intrinsic properties of goods which were the object of utility, not the goods themselves. This was a break with traditional utility theory which

treated the goods in combination as the object of utility. Lancaster argued that a good, per se, does not give utility but it possesses characteristics and it is these characteristics which give consumer satisfaction. Further, he added, "a good will possesses more than one characteristic, and many characteristics will be shared by more than one good." Moreover, "goods in combination may possess characteristics different from those pertaining to the goods separately." Lancaster's thesis was based partly on Quandt's previous work and the latter with Baumol, applied these ideas to the mode split problem. In the above quotes if we read "mode" for "good" the theory of abstract modes becomes clear.

Quandt and Baumol outline several aspects of their theory of abstract modes. Defining a mode as a bundle of attributes rather than the traditional institutionalized definition allows the planner to assess the results of a radically different mode by simulating the new mode's characteristics in the model. Any number of abstract mode types may be studied by simulation while having no real world counterpart. The theory presupposes that individuals are characterized by modal neutrality, or in other words choose a mode purely on the basis of its intrinsic attributes and not on the basis of what it is called. The authors recognized the tenuousness of strict modal neutrality (their example is an aversion to flying by some people), but aside from those intrinsic qualities which may be identified with an institutionalized mode and may not be

objectively measured, (such as prestige of driving your own car) the theory has great relevance to the study of new, technologically radical modes. Their model in a loglinear form was tested by regression analysis on inter-city trips using variables relating to the populations of the modal pairs, median incomes, least travel time and cost, relative travel time and cost, and absolute and relative departure frequencies.

Quandt[59] in a later paper defines an abstract mode model as that which uses a generalized cost or disutility function. Young[60] demonstrates that not only is the concept of generalized price in the demand function intuitively sound, but also theoretically rigorous. Young shows that an individual in maximizing utility can be made subject to modal constraints similar to the traditional income constraint and by this means demonstrates that the demand functions for individuals can be expressed in terms of generalized prices which include both non-monetary as well as monetary characteristics of the modes in question. Young's argument appears simply to consider institutionalized modes as an environmental constraint, as is income, and develops demand functions on mode characteristics.

Utility Theory and Mode Choice

The application of the utilitarian concept, that an individual traveller will seek to maximize satisfactions (or minimize dissatisfactions), pre-dates the development of the

concept of abstract modes and generalized prices, although these latter developments were to give utility analysis greater theoretical weight in subsequent work. Warner, for example, makes implicit reference to the utility hypothesis. He says, "the theoretical objects of choice constitute different collections of transportation services."[61] However, the parameters of his choice functions (probability functions) are described in elasticity terms where the resultant parameter estimates of "elasticity of choice" are identical with demand elasticities.

Ackoff[62] appears to have been the first to formulate an explicit utility model for mode choice. The model was based on the hypothesis that an individual would change from his usual mode to the best alternative when the perceived differences between the characteristics of the modes became great enough. Using the characteristics of travel time, travel cost, comfort and convenience he reasoned that when perceived differences in any one mode characteristic reached a certain level it would cause certain individuals to make a decision to change mode. The model was intended to aggregate individuals on the basis of their sensitivity to changes in mode characteristics. The study was not published however and the data destroyed.

Quarmby[63] was instrumental in relating utility theory to a successful mode split model. Quarmby conceived of travel "dimensions" (travel time, walking time, cost etc.) each of

which gives rise to some disutility. The traveller will choose that mode which gives him minimum disutility. If some change occurs in one or more "dimension" causing an alternative mode to assume a lower value for disutility, it was postulated that an individual would change to the alternative mode. The relative contribution to the disutility of each dimension are the estimating parameters in the equation. Assumptions of the model were that the disutility function is linear and additive. Reducing mode choice to a binary choice and expressing disutility as a relative measure (i.e. disutility mode 1 relative to that for mode 2) Quarmby develops a general relative disutility function where the variables are measured in terms of differences. The model is a discrimination-classification type where the discrimination function is the statistical aggregation of individual utility functions.

Several approaches to this basic formulation have followed. Quandt's[64] utility model of inter-city travel is probabilistic with a non-linear utility function. Pratt's[65] theoretical approach is based on the fact that the probability of using the best mode, for those with a free choice, follows the normal probability density function. McGillivray[66] uses a discrimination-classification model similar to Quarmby but including budget constraint, residential space and leisure time, and with service levels described by ratios.

Attitudes in the Mode Choice Decision

Some work has been carried out to attempt to assess the extent of the influence of attitudes in the mode choice decision and the relevance of attitude studies for planning of mode balance. These have not as yet formed any consistent pattern.

Ackoff[67] used a type of attitude survey to assess scaled responses to the difference needed in modal characteristic to cause the respondent to change from his usual mode to the best alternative. Sensitiveness of each respondent to changes in characteristics were compared to the mean of the distribution of all respondents for that characteristic allowing individuals to be aggregated by their sensitiveness to changes in modal characteristics relative to the sensitiveness of the typical (mean) individual. Nash and Hill[68] used factor analysis to determine the components on which respondents reduced an original list of several variables to an ideal transportation system. The authors found many non-quantifiable and psychological attributes desired in an ideal system. Recent unpublished studies are now underway using attitude surveys to validate hypotheses relating to the subjective assessment of modal attributes.[69,70]

Perceived vs Actual Values of Time and Cost in Mode Choice Models

Measures of system attributes used have been engineering measures. Time values are estimated by schedules, speed limits, trial runs or sometimes by a distance proxy. Vehicle operating costs are invariably based on an average per mile value and parking costs are imputed costs. However, recent studies are based on reported times, and if possible reported costs on the assumption that it is the subjective values of these attributes upon which the mode choice decision is based. Warner for example uses subjective responses. This in turn creates a further planning problem; the evaluation of projects based on engineering costs against a demand measured by subjective responses. Several of the studies have attempted to overcome this by relating subjective values to objectively measured values. Quarmby reasoned that people's perception of time might be related to such factors as trip length and relative comfort.

He therefore analysed by linear regression actual terminal walking times against reported times and found "extremely" good correlations. He also found "remarkable" agreement between perception of overall speed and time of car travel by car and bus users, but that car users' perception of bus travel times is about 20 percent slower than that of bus users. Car users do not perceive walking and waiting times as accurately as bus users. There is also a significant difference in

perceived in-bus travel times between car users and bus users. Bock also found high correlation between reported and computed times in Chicago.

While there appears some correspondence between "objective" measures of time and perceived time, a different conclusion on cost perception is reached. Based on two national surveys (1963 and 1965) Lansing[71] concluded that "people are well aware of costs which must be paid in cash" such as parking fees and fares, but most people have not made an estimate of vehicle costs and those who made estimates of fuel costs were "unreasonably high" related to actual "engineering" costs.

NEEDS OF A NEW APPROACH

Mode split research has shown an evolution from simplified global models to highly refined theoretical models based on individual behavioral associations. These new models are potentially successful in predicting mode choice behavior if sufficient data is collected. However new models must be incorporated into a policy and decision framework for planning, and this involves some possible restructuring of the models. The models must be formulated so they respond to public policy and they must be stratified by the groups affected by policy. Some problems with regard to this are outlined below.

The Problem of Policy Content

Mode mode choice research has little policy content. The transportation studies viewed mode split as a mechanical algorithm, which had relevance for policy only to the extent that the final product was an estimation of the volumes on the system. The behavior models are defined by variables which can theoretically be influenced by policy decisions on travel time and cost. Two models (Quarmby's and McGillivray's) have been used to estimate the change in mode split with changes in time and cost values. McGillvray compares the two studies and finds that effects from the two models are of the same order of magnitude. He concludes that the effect of cost changes is never greater than the effect of changing travel time. These results are hypothetical, based on simulated changes and ignore system effects due to decreases in congestion with increased transit ridership.

Assuming the approach used in these models is a valid one it is necessary to identify the functional system and to determine the relationships between the system and the socio-economic environment, and in the final stage, between the system and urban spatial form. Wingo describes the "new policy framework" in terms of new decision criteria which incorporate the "interrelatedness of public and private decisions and...the critical linkages of the urban community."[72]

Furthermore, client group value systems must be incorporated into new decision criteria. Behavioral related models, particularly the abstract mode concept, allow the estimation of behavioral effects on the system. However, these models are constrained in two ways; the lack of behavioral studies for all segments of the urban population as well as for a wide ranging set of land use-transportation system conditions; and the changes in the value systems of client groups. While the transportation studies assume constant behavior on the system for a given socioeconomic group, the behavioral studies assume constant value systems. That is, the value of a given time-cost-comfort relationship will remain constant through time. This assumption may not apply in the context of our rapidly changing social environment. For example cost factors do not appear to weigh heavily in the mode choice decision in relation to time in this period of affluence. However, it seems reasonable to expect changes in relative values given to mode attributes under new social conditions. Therefore mode choice research needs to examine the subjective aspect of decisions through the preference structures of different socioeconomic groups.

The Problem of Stratification

There is a well known conceptual link between transportation systems and urban structure. The transportation study has as its basis a specific urban form and structure for which

transportation needs are derived. The transportation system may under some circumstances influence land use.* The mode split model has been treated mostly as a sub-model in the transportation planning process in which the land use linkages are handled in some sequentially previous analysis: for example in the trip generation stage.

But any control mechanism which adjusts mode split, and therefore the relative performance of the system, will surely have an eventual impact on land use and socioeconomic patterns. Because of this impact it is imperative to stratify the control mechanism by its influence categories. The most direct of these is socioeconomic groupings which are related to further structural changes.

A systematic attempt to show how the mode choice varies with socioeconomic groups has not been attempted. The mode choice is simply a manifestation of a bundle of transportation related decisions which includes home and job location. Thus, the service performance of a travel corridor will influence spatial relationships and the influence area of any corridor transportation system over the long term will reflect how the different groups value the system choices available to them. If the transit service, for example, is good those who value highly the combination of attributes manifested by the transit

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*This is not self evident. The understanding of this influence at best is only tenuous.

system will be attracted to the corridor. This illustrates the close relationship between the structure of transportation service area and the service provided. Therefore any analysis of transportation policy effects on changing the mode split must ultimately be reflected in the socioeconomic groupings of the service area. Furthermore, predictions of mode split must be related to a stratification of the population since different combinations of service levels are viewed differently by each socioeconomic grouping. It would appear from the literature, for example, that policies affecting cost would have more impact on low income groups than high income groups, whereas policies affecting travel time may have more effect on high income groups.

This need has been recognized in some mode split studies.[73,74] The emphasis of these has been on stratification by income groups. Notable is the Traffic Prediction Model which is a family of curves stratified by income classes.* Zupan[75] also concluded that sensitivities to selected mode split determinants changed with income stratification and only when income level distribution was not changing radically would an unstratified equation be adequate for mode split forecasts. These models are linear regression tests to predict the proportion taking transit in any given income group based on the explanatory variables found to be significant for each group. However, as

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*Developed by Traffic Research Corporation for the Metropolitan Toronto Planning Board (see Ref. 37).

pointed out by Rulon,[76] linear regression is not the proper model structure to predict individual membership in a group based on behavior characteristics of the individual because stratification is performed before the test.

The problem of mode choice is that of group membership given a behavior pattern on the system of all individuals measured by time, cost, and convenience variables. The relevant question is to what group is an individual likely to belong; that group which uses car to commute or that group using the bus? Similarly, if a shift preference pattern of automobile drivers for system changes is known to what socioeconomic group does this individual belong? This concept can be used to test the significance of the separation of groups on the basis of how they behave on the system or their preference profile. The testing of *a priori* groups, and the posterior assignment of individuals to a group has been called the discrimination-classification approach.[77]

RESEARCH ASSUMPTIONS

The research is an empirical investigation of a case study which consists of a transportation corridor terminating in the Central Business District of Vancouver, Canada. The influence area of this corridor is the research space for the study. The structural elements which form the basis of the research space are selected socioeconomic characteristics of

those who live in the corridor influence area and use the corridor for the journey to work. These characteristics can be divided into two client groups; that group which use a car for the journey to work and that group which makes the journey by bus. Each client group is further viewed in terms of its subdivision into several groups defined by their socioeconomic characteristics; those selected for this investigation being sex, age, occupation, car ownership and income.

The functional elements of the research space is the transportation system consisting of the facilities for auto travel and those for bus travel. These are further viewed as abstract modes defined by the relative performance provided to the CBD for each group of corridor commuters. Performance factors studied analytically are overall travel times, excess travel times, and out-of-pocket expenses. Relative comfort of the modes is also investigated. System performance is examined in regard to both the behavioral and preference profiles of individuals using the corridor for commuting to the CBD; in which an individual's profile constitutes that combination of system attributes which are selected, or which would be preferred, by a car user to have him change mode.

It is necessary to separate the variables into structural and functional elements as above to be able to analyse the incidence of the effects of transportation policy. Public decisons on transportation projects have, among others, direct

effects on users. User direct effects refer to the use or non-use, or the change in mode of the system; that is, it is related to the decisions of the user based on his perception of the system. But the consequences of any public decision is valued differently and therefore it is necessary to identify those sections of the public who are affected by each policy change. Therefore each socioeconomic group is examined as to possible relationships with the performance of the system.

The study is related to demand for travel between modes. Demand for travel appears to satisfy the conditions postulated by the economic theory of derived demand.* Marshall states the theory very succinctly.

> the demand for each of several complementary things is derived from the services they jointly render in the production of some ultimate product.[78]

In the context of this definition transportation is an intermediate and complementary service in the production or consumption of some good which has direct value. The derived nature of demand is accounted for in transportation planning by doing

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*Travel is only more or less a derived demand to the degree that trips and travel expenditures (e.g. car purchase) are not undertaken for their own sake. Thus, the journey to work may be almost entirely a derived demand for the economic necessity of earning a wage; whereas an annual motor vacation may be demanded almost entirely by itself. Also, for example, Troxel conceives demand for movements of people to be related to "net products" of travel in which just "getting out of the house" is a positive net product of travel. (See Ref. 83).

separate analyses for each trip purpose. In this study concern is with a single trip purpose: the journey to work.

To study intermodal demand for the journey to work in isolation from the jointly demanded complementary good two assumptions are necessary; (1) that the demand for jobs remain unchanged both in terms of incidence and location, and (2) that there are no changes in the supply of other complementary factors. We assume a given set of travel habits, tastes and incomes; and a fixed land use pattern. That is, residence and work place are in equilibrium with travel patterns established at the time of the travel decision, where no individual is planning to change either job or residence location. The demand function then incorporates two decisions--whether or not to make the trip at all, and what mode to use. The first decision depends upon the anticipated rewards of travel to a specific location for a specific purpose. The value placed on the perceived rewards of the trip will determine the generalized price an individual is willing to exchange in a trade-off with all other expenditures, within the constraints of a fixed budget and socioeconomic and cultural makeup. This component of travel demand is analogous to the trip generation and distribution aspects of the transportation planning process. For the present study the generation/distribution component is controlled by considering only the work trip, and by assuming that work place is in spatial equilibrium with residence. That is, the number

of work trips to any geographic area is equal to the number of jobs in that area and a decrease in transportation costs or travel time will not increase the number of trips but change only the modal split.

The remaining component of the demand analysis (the mode choice) will depend upon the socioeconomic characteristics of the behavioral unit,* and the attributes of the modes available. These act interdependently to produce the choice of mode. The attributes of the mode can enter into the analysis as absolute values of the best combination of attributes for the set of socioeconomic characteristics in question; or as relative values of the mode used to its alternative(s). (See for example Quandt and Baumol whose model incorporates both these measures simultaneously).[79] The interaction of the individual socioeconomic characteristics with the attributes of the mode which shows the best perceived characteristics within a given set of characteristics for those with a choice of mode defines the demand function for mode split.

The concept of isolating a study of intermodal demand to the CBD from total demand for travel appears reasonable, at least for larger cities. It has been observed that employment

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*It would appear that demand also stems in part from direct cultural pre-conditioning which, it can be argued, could have substantial causal relationship to mode choice. This factor has not been taken into account in this study, but considered as homogeneous across the population.

in the central city areas stabilizes when the population of the region approaches 1 million.[80] Fluctuations in CBD activities are such that in many cases cordon counts of people entering (or leaving) the CBD each day is virtually constant.[81] These trends have been accompanied with a mode shift away from public transit to automobile. Studies the author has conducted in Toronto show that between 1950 and 1965 entrances were constant and the increase in person trips entering by car was exactly equivalent to the decrease by transit.[82] While not conclusive for any particular urban region, there is therefore some evidence to support the study of mode split to the CBD more or less separately from the spatial and land use implication.

CHAPTER III

DESCRIPTIVE ANALYSIS OF CASE STUDY

DATA PREPARATION

Data for the investigation consist of a modified origin destination survey of commuters from the "North Shore" communities who cross the First Narrows Bridge to the CBD of Vancouver.* The "North Shore" of the Vancouver metropolitan region consists of a number of communities organized into three municipalities: the Municipality of West Vancouver, the City of North Vancouver, and the District of North Vancouver. The most recent Census (1966) gives a combined population of 106,962 (31,987; 26,851; 48,124 respectively). In most aspects important to this study the municipalities are typical suburban communities, with the exception of parts of West Vancouver which have developed into high density bedroom residential areas for high status CBD employees. Thus, incomes in West Vancouver are substantially high than the average for the metropolitan region, and this municipality is characterized by a higher proportion of managers and professional employees than the region as a whole.

The communities are separated from the CBD of Vancouver by Burrard Inlet which is crossed by two bridges: the Lion's

*See Appendix A.

Gate suspension bridge at the First Narrows; and the Second Narrows Bridge. The former bridge connects West Vancouver with the CBD, while the latter crossing is some 5 1/2 miles to the east. The focus of this investigation is on the commuters who crossed the First Narrows Bridge between 7am and 9am on a weekday in March 1967. While there is some diversion of automobile traffic from the western part of the study area to the Second Narrows Bridge because of saturation volumes on the First Narrows Bridge, these bridges essentially define two separate travel corridors; the First Narrows Bridge serving commuters to the CBD, as well as a substantial number of those going past the CBD; and the Second Narrows Bridge serving areas to the east of the CBD.

Traffic volumes on the First Narrows Bridge during the morning peak period of 7-9am vary between about 6,200 vehicles per hour in mid week to about 6,500 on Mondays and Fridays. Peak hour volumes are about 50 percent of these. The hourly rate of flow based on 15 minute counts peaks at 3,400, this rate remaining more or less constant between about 7:15 and 8:45 and represents saturated flow and the limiting capacity of the Bridge.* Flow speeds are about 20mph under these traffic conditions.

The North Shore is served by two different bus services; the British Columbia Hydro Authority buses, and those of

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*These statistics are based on counts taken Feb. 4, 1967 - Feb. 10, 1967 by N.D. Lea and Associates (see Ref. 1).

the West Vancouver Municipal Transportation System. During the two hour morning peak in 1967 (at the time of the survey) 30 Hydro and 22 West Vancouver buses carried 2,490 persons, most of whom were destined to the CBD; 1,633 via BC Hydro Service and 857 via West Vancouver service. At the time of the survey buses carried 21.8 percent of the total of 11,140 persons across the Bridge in the peak period from 6:45-9:15am. Since the fall of 1967 buses have been given priority at the Bridge-head, and allowed to use a separate collector lane to facilitate entry to the Bridge. This has improved bus travel times and patronage.*

Data Reduction

The study data consist of the results of a separate bus and automobile survey of commuters on the Bridge during the morning peak period in March, 1967; conducted by N.D. Lea and Associates for the B.C. Highways Department. Questionnaires** were distributed to all bus riders, and 80 percent of car drivers and passengers between 6:45 and 9:15am.[2] Bus questionnaires were distributed by the drivers to all passengers, while auto questionnaires were handed to the driver at the Bridge-head. The questionnaires were to be returned by mail within a week, with overall response rate 58 percent of the bus and 49 percent of the car questionnaires returned.*** The

*Mr. D.W. Mills of B.C. Hydro estimates that transit ridership increased 15-20 percent because of the improved service.

**See Appendix B

***Actually 65 percent of car passengers destined to the CBD who received a questionnaire returned a useful response, thereby bringing the relative response rates close to the proportion of users of each mode even though a smaller proportion of car drivers were originally sampled.

survey responses were coded and put on punched cards by the survey agency and duplicates of these cards were made available to the author. After editing and eliminating non-work purpose trips, 3,776 useful interviews constituted the sample for this investigation. These trips were subdivided into the two modes, and further subdivided into those trips to the CBD and those destined to non-CBD locations. A summary of the response is given below.

Mode	Destination	No. of Responses in Sample	Percentage of Transit Mode in Sample
CAR	CBD	1,607	42.5
BUS	CBD	1,185	
CAR	NON-CBD	875	11.1
BUS	NON-CBD	109	

The 42.5 percent sample proportion of transit response to total sample response is reasonably close to the proportion of transit riders to total commuters to the CBD. Reported average proportion of transit trips to all person trips to the CBD in peak periods are about 35 percent (N.D. Lea reports 33 percent of all person trips across the bridge in the peak period are transit passengers).[3] The decision was made to accept without further adjustment the sampled proportion found in the total commuter population.

The overall sample response rate of 34 percent of person trips in the corridor is high for a mailed questionnaire, and therefore was considered a satisfactory data base for the present investigation. The car and bus modes to the CBD were combined and the resultant sample of 2,792 subjects became the primary data for investigation.

This data base differs from a typical origin destination survey and requires some explanation. Measurements are taken on the modal characteristics, rather than on household characteristics as is the usual practice in O-D surveys. That is, the clients of each mode were asked their travel habits and household characteristics while engaged in a single trip, their journey to work; whereas in the home interview origin destination study the complete trip making pattern is surveyed, usually for the day before the survey. The present survey may therefore produce more accurate results in determining the characteristics of the modes, their differences, and in particular the structure of their client groups and the relationships between modal client group structure and modal client group structure and modal attributes. This type of survey, however, will allow only limited generalizations to be made about the mode split of different structural combinations. That is, the survey is more useful to explore the characteristics of a particular mode than to predict mode split from urban structural conditions, a general practice used in analyzing home interview studies.

Furthermore, measurements of travel dimensions are entirely in terms of subjective responses. This allows an examination of the direct relationships between user calculus and the mode choice.

The mailed questionnaire is sometimes subject to response bias. The survey agency anticipated this and an independent consultant performed a follow-up home interview telephone check survey to estimate for bias. A random sample of 313 households were asked whether or not a car questionnaire was received and returned, and whether or not the Bridge was normally used during the morning peak period of 7am-9am. The punched cards with the survey response were made available to the author, and a Chi-square contingency test performed to test the validity of the sample in representing the total population of automobile commuters shows that the sample responses and the total number of commuters who normally use the bridge in the peak period are not significantly different (Table I). The largest contribution to the Chi-square statistic are zones E, F,G which are high socioeconomic status areas which have a higher than average response rate; a typical situation in most sample surveys of traffic.*

The data were reduced for further analysis in two ways. A multivariate tabulation procedure, using the MVTAB, U.B.C.

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*See Appendix A.

Table I

CHI-SQUARE CONTINGENCY TEST OF CAR SAMPLE VALIDITY,

NUMBER OF RESPONSES IN EACH CATEGORY SHOWN

ZONE	USE BRIDGE, RECEIVED AND RETURNED QUESTIONNAIRE	USE BRIDGE, BUT DIDN'T RECEIVE QUESTIONNAIRE	DO NOT USE BRIDGE	CONTRIBUTION TO CHI-SQUARE
A,B,C,D	5	6	21	.01
E	4	0	5	1.20
F,G	9	3	20	2.37
H	5	8	7	.06
I	6	7	12	.12
J,K,L	4	6	9	.03
M,N,O	4	13	22	.55
P,Q,R,S	5	10	39	.15
T,U,V,W,X	5	15	37	.36
TOTAL	47	68	172	

$\chi^2 = 4.85$

d.f. 8

$p^* > .70$

*p, in this and other tables is the probability of making an error in rejecting the null hypothesis of no difference.

library program for the IBM 360/67 computer, was used to analyze the questionnaire responses and form the basis of the analysis in this chapter. The data were also reformatted for further multivariate statistical analysis. This procedure is discussed in the next chapter.

MODE SPLIT AND THE SOCIOECONOMIC STRUCTURE OF COMMUTERS

This investigation is directed toward the analysis of the socioeconomic space of commuters to the CBD, but a brief analysis of the relationships between CBD commuters and non-CBD commuters is given below as a contextual framework for the further analysis of CBD commutation and mode choice.

It is clear that both socioeconomic characteristics and the relative accessibility of the CBD by various modes available are factors differentiating the CBD commuter from the non-CBD commuter. The implication is that any geographical area of travel generation may be hypothetically dimensioned into two socioeconomic spaces; that space which differentiates those commuting to the CBD from those which do not; and that space which differentiates those who use transit from those who use automobiles.

A comparison of the socioeconomic characteristics of those who commute to the CBD with those who pass through or around the CBD shows some differences (Table II). Proportionately fewer males commute to the CBD than to other destinations.

Table II

PERCENT OF EACH SOCIOECONOMIC GROUP COMMUTING TO CENTRAL BUSINESS DISTRICT LOCATIONS COMPARED TO OTHER DESTINATIONS, BY CAR AND BY BUS

	SOCIOECONOMIC GROUP	PERCENT					
		CENTRAL BUSINESS DIST.			OTHER DESTINATIONS		
		BY CAR[a]	BY BUS[b]	ALL	BY CAR[c]	BY BUS[d]	ALL
SEX:	MALE	88.1	58.3	73.2	83.9	39.8	79.3
	FEMALE	11.9	41.7	26.8	16.1	60.2	20.7
AGE:	0 - 20	2.2	9.3	5.2	1.5	12.8	2.7
	21 - 40	42.2	45.9	43.9	43.4	36.8	42.7
	41 - 60	52.2	40.6	47.2	51.6	47.7	51.5
OCCUPATION:	MANAGERIAL	37.0	16.8	28.5	34.0	10.1	31.4
	PROFESSIONAL	30.0	27.7	29.2	31.0	15.6	29.2
	SECRETARIAL	5.2	30.8	16.0	4.6	37.6	8.3
	CLERICAL	9.5	5.5	7.8	5.6	5.5	5.6
	SALES	12.8	18.8	15.2	13.5	20.2	19.2
	OTHER	5.5	0.4	3.3	11.3	11.0	11.3
CAR OWNERSHIP	NONE	0.7	9.2	4.4	0.4	17.8	2.4
	ONE	42.0	67.3	52.9	37.0	63.5	40.0
	TWO	50.5	21.2	38.0	55.3	14.0	50.6
	THREE OR MORE	7.0	2.3	4.2	7.3	4.7	7.0
INCOME	4,000	6.4	30.0	15.6	7.3	43.6	11.4
	4,000-8,000	25.9	41.7	32.7	34.4	48.1	36.0
	8,000-12,000	34.8	22.9	29.6	35.2	6.5	32.0
	12,000	33.0	7.4	22.1	23.1	1.8	20.6

a. 1,607 responses
b. 1,185 responses
c. 875 responses
d. 109 responses

More secretaries, clerks and sales people commute to the CBD, while low status trades and service workers predominate for non-CBD destinations. Managerial and professional workers are about evenly split, with managers showing a slightly greater propensity to travel beyond the CBD. The CBD commuter is slightly younger than the non-CBD one.

In comparing car ownership and incomes of CBD commuters with non-CBD ones it is apparent that those commuters to the CBD have fewer cars and slightly lower incomes. The median number of cars per household for commuters to the CBD is 0.86 whereas it is 1.15 for non-CBD commuters. Median income is 10,350 for CBD commuters and 10,750 for non-CBD commuters. The Chi-square statistic shows that the differences found are significant* except for sex differentiation (Table III).

Table III

SIGNIFICANCE TEST OF SOCIOECONOMIC CHARACTERISTICS OF CBD COMMUTERS VERSUS NON-CBD COMMUTERS

CHARACTERISTIC	D.F.	X^2	P
SEX	1	2.87	.10
AGE	3	16.03	.01
OCCUPATION	5	125.01	.001
CAR OWNERSHIP	3	80.08	.001
INCOME	3	12.95	.01

*Statistical significance is defined in this study as $p \leq .05$.

A substantial portion of the variation in socio-economic characteristics between CBD and non-CBD commuters is explained by the relationship between these characteristics and mode used. Generally while there are small differences in commuters for a given mode, large variations occur in the characteristics of those using different modes. For example male commuters dominate the car mode regardless of whether the destination is in the CBD or not, while only slightly outnumbering females who go to the CBD by bus. Females actually dominate the bus mode to non-CBD locations. Caution however, is needed in interpreting these statistics since non-CBD bus travel represents a very small proportion of total non-CBD travel (109 trips or 11.1 percent of all non-CBD trips). The disproportionate number of females to non-CBD locations may be due to picking up low status, part-time employees, and those providing domestic services in the sample, while missing manufacturing workers who travel to the suburban locations but did not use the Bridge.

Younger age groups use the bus and the variation between CBD and non-CBD groups within each mode is small. Substantially more "other" employees (presumably craftsman, labourers and service workers) take the bus to non-CBD locations, while fewer managers do so. Non-CBD bus commuters have fewer cars and lower incomes than their counterpart who commutes to the CBD. This is in direct contrast to the somewhat higher

incomes and car ownership of all non-CBD commuters, and indicates the importance of the car mode for commuting outside the CBD.

The findings indicate that the CBD commuter has a unique socioeconomic space which is differentiated from those in the travel corridor who do not commute to the CBD. Furthermore, inferences can be made regarding the variation in the socioeconomic space of the CBD commuter due to the mode used. The following sections enlarge upon these inferences.

Socioeconomic Characteristics

Substantial differences exist between those who use a car and those who use the bus. One way of considering these differences is to visualize the clients of the same mode as consisting of a number of individuals with relatively homogeneous characteristics, while the client group characteristics of different modes are relatively heterogeneous. The degree of hetergeneity (variation between users of different modes) to homogeneity (variation of individual socioeconomic characteristics for the same mode) can be used as a means of defining the differences of the modes.

Chi-square statistical tests indicate that all characteristics considered are significant in explaining the differences between those who use cars and those who take transit. The result of this test is shown below (Table IV).

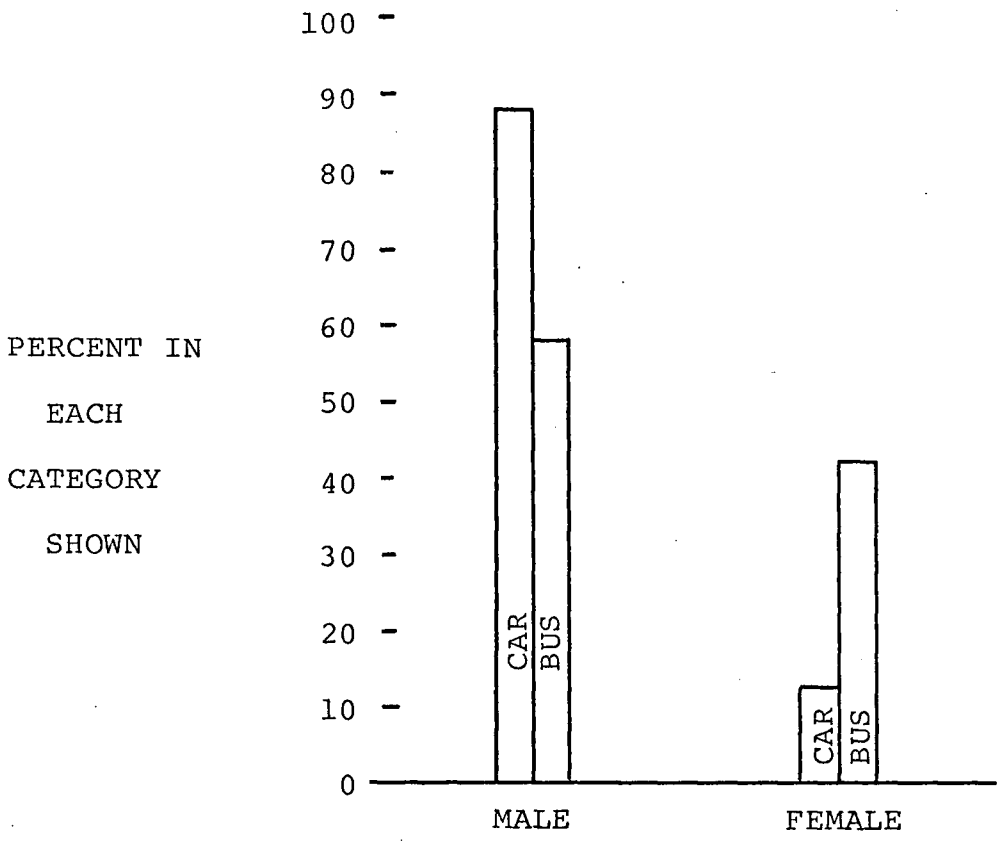
Table IV

SIGNIFICANCE TEST OF SOCIOECONOMIC CHARACTERISTICS OF CAR USERS VERSUS TRANSIT RIDERS

CHARACTERISTIC	D.F.	χ^2	p
SEX	1	438.5	$p < .001$
AGE	3	87.5	$p < .001$
OCCUPATION	5	407.4	$p < .001$
CAR OWNERSHIP	3	385.4	$p < .001$
INCOME	3	482.1	$p < .001$

Figure 1 indicates that males greatly outnumber females in using the car for the journey to work, but females constitute close to half of all those who travel by bus. The conclusion that the female labour force is transit oriented is supported by virtually all studies which have investigated sex and mode split.

Figure 2 shows that the greater proportion of clients of the car mode are between 41 and 60; whereas bus passengers are more likely to be under 41, or over 60. Those who have recently entered the labour market (probably without a car, and perhaps without a drivers license), and those too old to drive, or find it tiresome or who may never have had a drivers license or automobile, are transit patrons. The figure also indicates

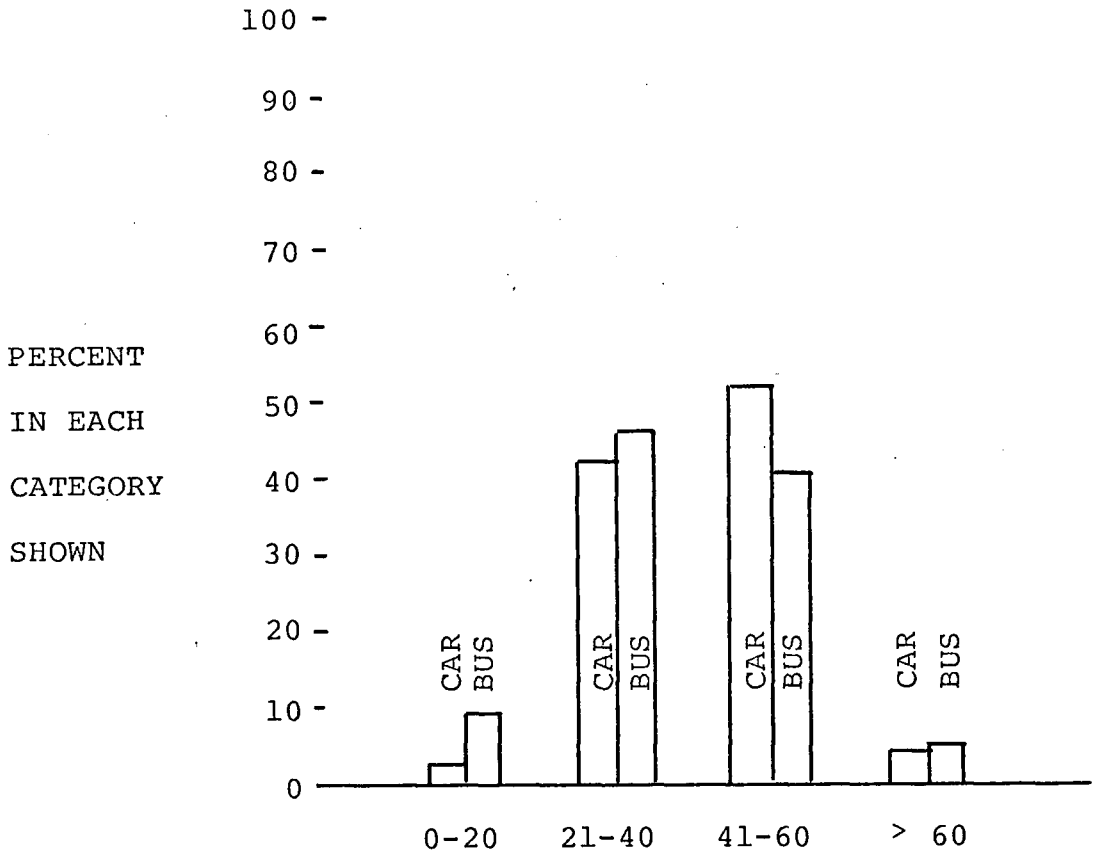


	COMMUTERS	
	CAR	BUS
MALES	1,388	686
FEMALES	189	488

FIGURE 1

SEX CHARACTERISTICS OF COMMUTERS TO CBD,

BY MODE USED



AGE CATEGORY

	COMMUTERS	
	CAR	BUS
0 - 20	34	110
21 - 40	666	543
41 - 60	822	481
> 60	54	47

FIGURE 2

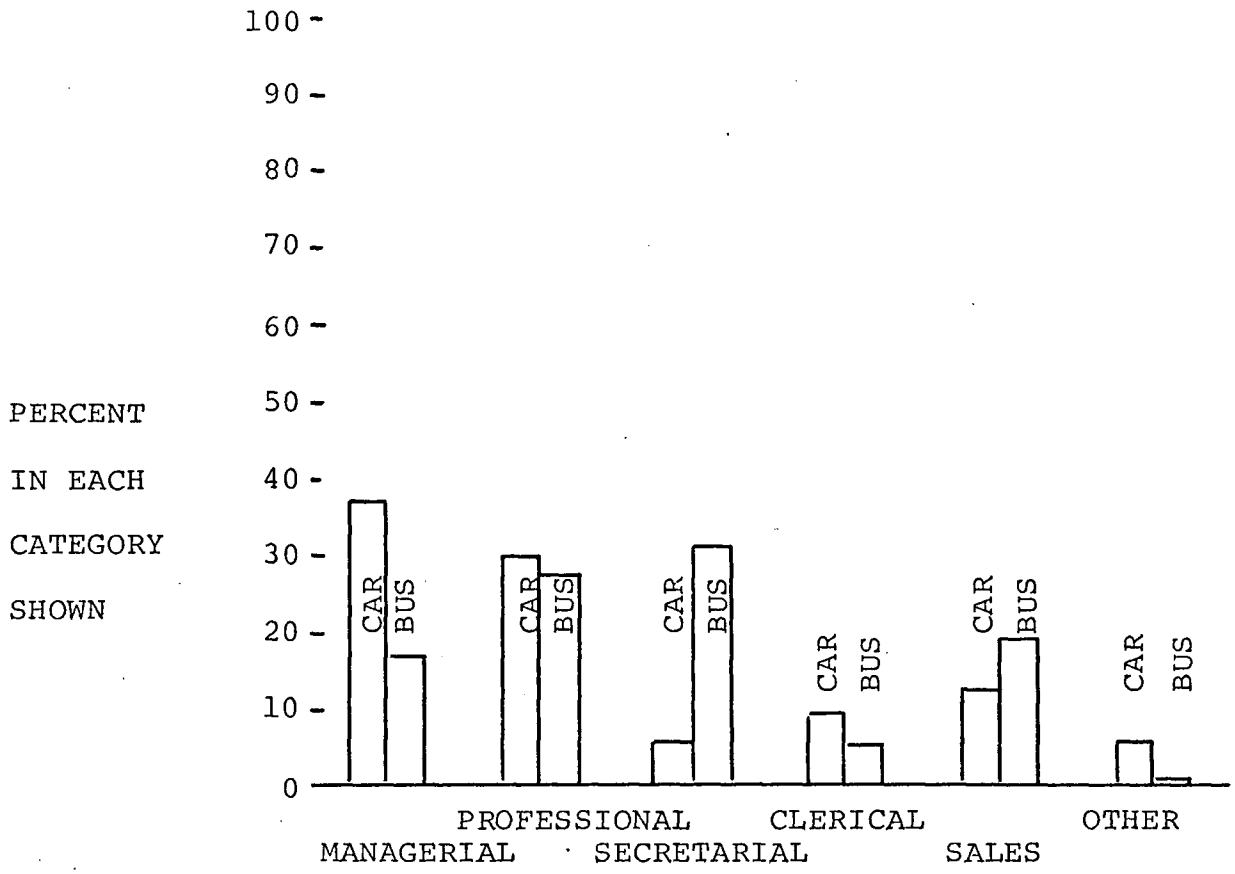
AGE CHARACTERISTICS OF COMMUTERS TO CBD,

BY MODE USED

that a large proportion of bus riders are in the 21-40 age group, an age group which would be expected not to have the barriers of choice imposed upon the younger and older employee. It is apparent that a great number of these constitute those who prefer the bus.

In comparing the occupations of the two client groups, some seemingly contradictory tendencies emerge (Figure 3). First, almost 45 percent of bus patrons are in the high status professional and managerial occupational categories. No systematic studies are available of the relationship between mode choice and occupation, but fragmentary evidence suggests that high status occupations (including concomitant high incomes, educational levels and car ownership rates) are associated with the use of the car for the journey to work.[4] Although the automobile is the principal mode for managerial and professional employees (as can be seen by comparing columns for each of these categories), a significant number of those who ride the bus are in the professional category.

Secondly, a high proportion of car passengers are in the "other" category which includes unskilled craftsmen, labourers etc. As expected there are relatively few of this class destined to the CBD but virtually all of those which are, go by car (94.5 percent). Car ownership amongst unionized unskilled workers, may account for the larger proportion of labourers using the car mode than that using the transit mode.



	COMMUTERS	
	BY CAR	BY BUS
MANAGERIAL	582	192
PROFESSIONAL	476	315
SECRETARIAL	82	351
CLERICAL	149	62
SALES	201	213
OTHER	85	5

FIGURE 3

OCCUPATIONAL CHARACTERISTICS OF COMMUTERS TO CBD, BY MODE USED

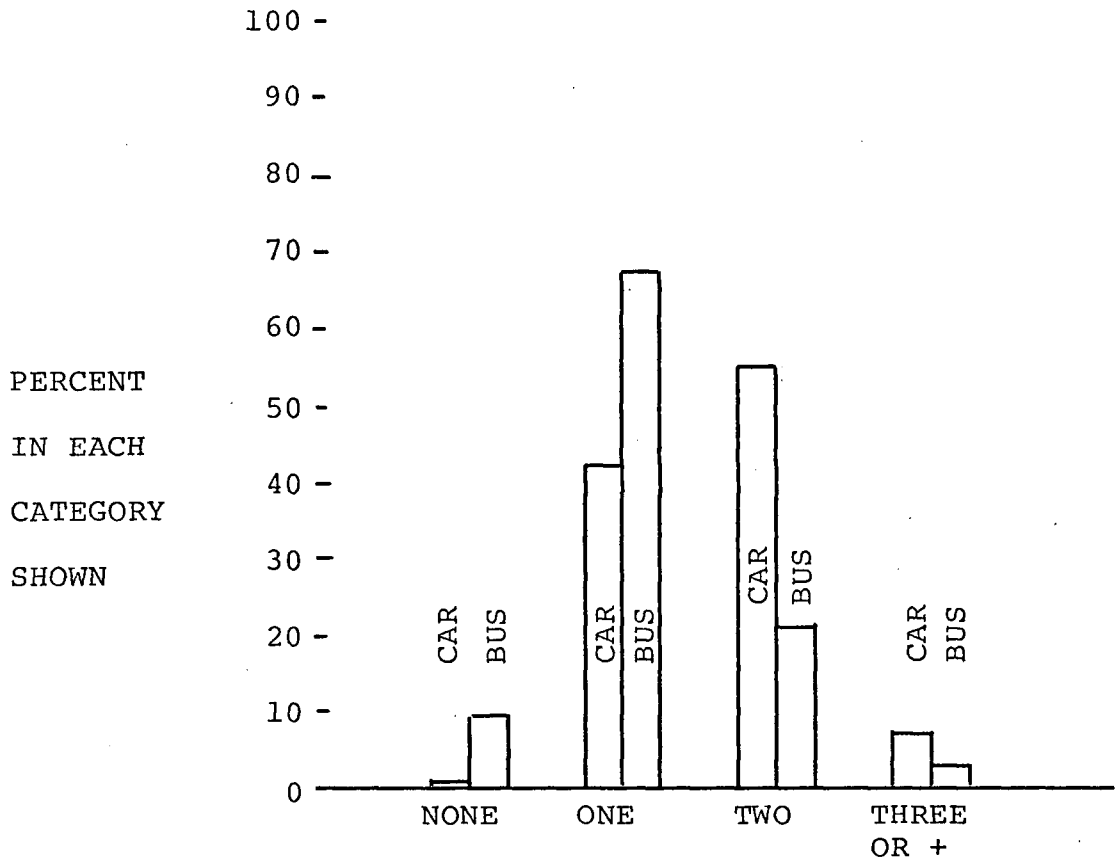
Clerical staff, also normally a heavy user of transit shows a substantial percentage using cars to work. This may be due to the same factors as that suggested for unskilled labourers. Secretarial workers show the usual heavy use of transit and is probably due more to the fact that secretaries are mostly women, which have a high proportion of non-drivers, than to any inherent occupational characteristic of secretaries which differ from like-salaried employees (say clerical).

Sales workers appear to be slightly more oriented to transit than to car. There may be some reporting inaccuracies introduced in the sales/clerical categories, which may account for the relative low use of the bus by clerks and the relatively high use by sales people. Since the responses were self-administered, people in these two categories would tend to answer this question by indicating the category they felt to be the more prestigous. If sales was more prestigous to them than clerk they would probably report sales as their occupation. In most socioeconomic index scales clerical employment ranks ahead of sales workers in social prestige.[5] This is particularly the case if stenographers and secretaries are included in the clerical classification, as they are in the U.S. Census. Only tentative conclusions may be drawn here since these classifications are not well defined. It appears on the evidence that those who consider themselves secretaries (probably a minimum amount of confusion exists in this category), and those

who consider themselves sales people are bus oriented; whereas those who consider themselves clerical workers are car oriented. Again it may be that more sales people are women than is the case for clerks, resulting in the bus orientation found in their class.

A surprising factor (Figure 4) is the high rate of car ownership amongst those using the bus. This could be due to two factors: there are more adult workers than cars in a substantial number of families, or some commuters find the bus a desirable alternative to the car for the work journey, thus allowing them to leave the car at home for shopping and school trips. The fact that a large proportion (21.2 percent) of bus riders come from 2 car families would indicate that competition amongst family members for cars may not be a major factor; although undoubtable in some of the high density apartment areas in West Vancouver with childless families and both husband and wife working, the competition for a single car is great. The conclusions reached here is that a significant number of commuters take the bus, even if a car is theoretically available.

Another significant factor is the high overall rate of car ownership, with 95.7 percent of those families interviewed owning at least one car, and 43.5 percent owning two or more. These rates are very high. For example, Lansing's study of automobile ownership based on a sample of the population



AUTOS OWNED PER HOUSEHOLD	COMMUTERS BY CAR	COMMUTERS BY BUS
NONE	11	109
ONE	662	795
TWO	795	249
THREE OR MORE	110	27

FIGURE 4

CAR OWNERSHIP CHARACTERISTICS OF COMMUTERS TO CBD, BY MODE USED

of continental United States shows rates as high as these in only the highest income brackets, and even at that for only certain years.[6] Also the area of investigation with a car ownership rate of 1.39[7] is higher than the overall rate for metropolitan Vancouver region, which is 1.12.* This average for the "North Shore" communities is exceeded in only 7 zones of the remaining 59 traffic zones of Metropolitan Vancouver.

The proportions of those of different incomes attracted to the car mode and bus mode are as expected with income groups towards the high end of the scale favouring car mode, and those near the low end of the income scale favouring the bus (Figure 5).

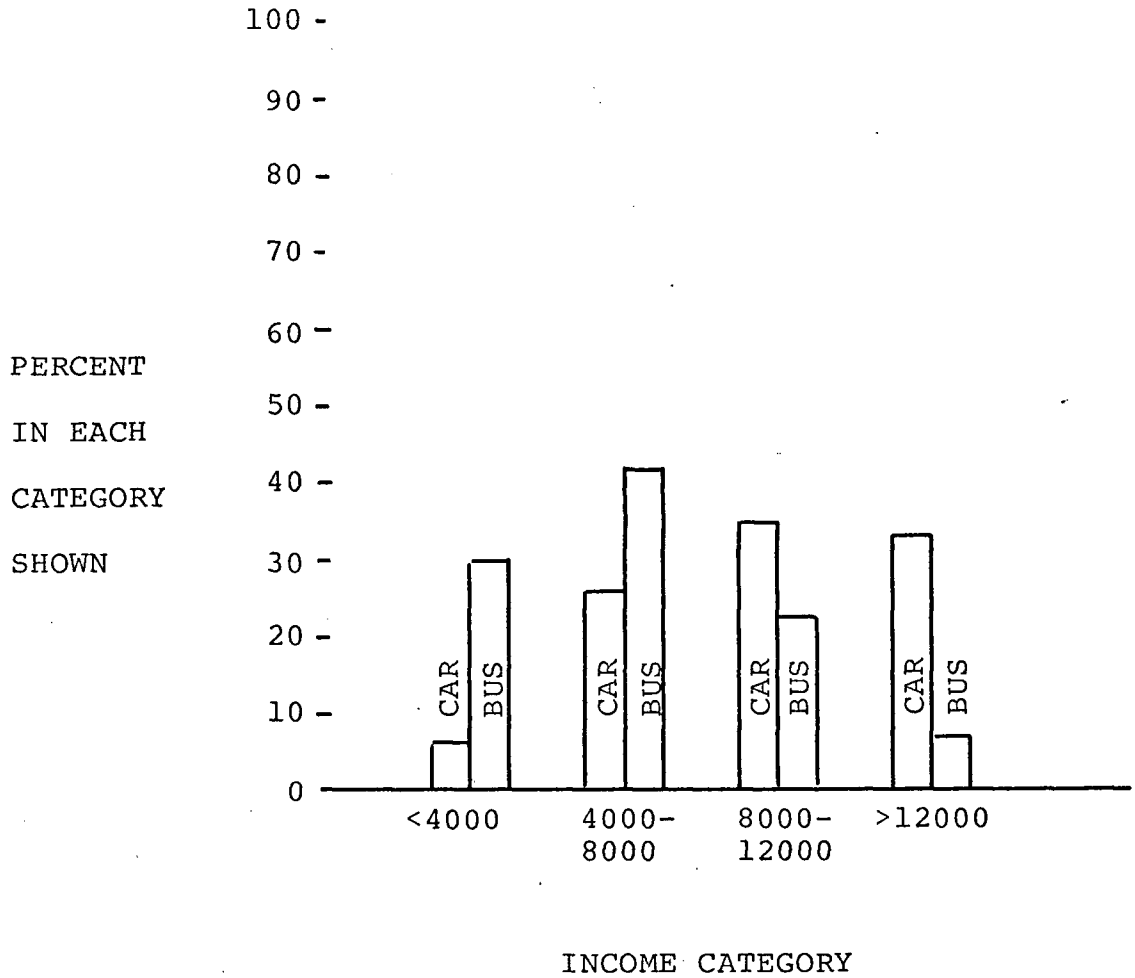
BEHAVIOR PROFILES OF MODAL GROUPS

Travel Time

Diversion curves of the ratio of travel time by transit divided by travel time by automobile have been documented for a number of cities, and the curves indicate a stable relationship between the travel time ratio and the percent trips diverted to transit for a substantial number of cities. However, mode used and available alternatives modifies the influence of time as a factor.**

*This rate is based on estimates of the Vancouver Planning Board on the basis of selected zones. The study area rate is for 1967 while that for the metropolitan region is for 1965. It is assumed that these years are roughly equivalent.

**Bock's study shows 41 percent of car users with railway alternative to consider time most important, while 6.9 percent public transit passengers with a car available found time most important (see Ref. 9).



INCOME CATEGORY	COMMUTERS BY CAR	BY BUS
< 4000	99	325
4000-8000	402	487
8000-12000	540	265
> 12000	511	86

FIGURE 5

INCOME CHARACTERISTICS OF COMMUTERS TO CBD,

BY MODE USED

Absolute travel time is not valued the same, relative to other factors, by all groups. For example Voorhees found that workers of high income groups had an average trip duration greater than low income groups.[8] This could mean either that high income groups have a higher propensity to travel (cultural conditioning to auto use) or that residential-workplace relationships are different from low income groups, or both. Spatial separation of residence from workplace for reasons other than travel is probably the reason for longer trip duration since, logically, if the value of time is related to the wage rate we would expect high incomes to be associated with less time spent on the journey to work if no other factors are effective.

Mean reported overall travel time for all case study corridor commuters to the CBD is 33.2 minutes. The mean for automobile users is 30.9 minutes from their residence location to their destination in the CBD, and 36.8 minutes for bus passengers (Table V). The average travel time for all auto trips in Vancouver is not available, but the corridor mean of 30.9 minutes by car is much greater than the average for cities the size of Vancouver. For instance Voorhees[10] found that the average work trip duration by car for a city of about 1 million (Vancouver size), based on an analysis of 34 cities, is about one-half of the mean found in this case. The highest average for all cities studies was Philadelphia at 20.1 minutes, indicating that corridor mean travel time by car in Vancouver is

Table V

TOTAL TRAVEL TIME, BY MODE*

TRAVEL TIME** (MIN)	MODE			
	CAR		BUS	
	No.	%	No.	%
10	29	(1.80)	63	(4.47)
15	56	(3.48	3	(0.25)
20	203	(12.63)	31	(2.62)
25	260	(16.18)	75	(6.33)
30	440	(27.38)	218	(18.40)
35	227	(14.13)	249	(21.01)
40	214	(13.32	243	(20.51)
45	134	(8.34)	170	(14.35)
50	34	(2.12)	102	(8.61)
55	10	(0.62)	41	(3.46)
	1,607	(100.00)	1,185	(100.00)

SIGNIFICANCE TEST: difference of means

$\bar{X}_C$	=	30.9	$\bar{X}_B$	=	36.8
S_C	=	8.97	S_B	=	12.33
z	=	-13.00			
p	<	.001			

*"How long is your door-to-door journey in minutes?"
**Central value of 5 minutes intervals.

unusually high and probably represents the longest average trip length of any major travel corridor with both origin and destination in the metropolitan urban region. This phenomenon is largely because of congestion on the Bridge during peak periods.

Significance tests of the difference of means shows that the overall travel time for auto drivers is statistically different than that for bus passengers (Table V). The corridor, with reasonable similar overall mean travel times is a unique characteristic of this study area, and inferences about travel times must be made on the basis that while auto driving times are high, bus times are reasonable when compared with other cities, and may be a factor in the high proportion of professional occupational status who ride the bus and who are time sensitive. On the other hand, the proportion of bus passengers to auto drivers in the commuter stream is not unusually high, indicating that time savings by bus may not be valued particularly important by all commuters.

When overall travel time is related to socioeconomic group as well as to mode used, a different and significant, pattern emerges.

The variation by income class in the travel time to work is substantial (Table VI). In all income classes the bus is slower. Car travel time increased with increasing income as expected, but by bus, the travel time decreases with income

Table VI

MEAN TOTAL TRAVEL TIME, BY INCOME CATEGORY AND MODE

INCOME CATEGORY	MEAN TRAVEL TIME BY CAR	BY BUS	OVERALL
< 4000	25.4	41.0	37.3
4000-8000	30.8	37.5	34.6
8000-12000	30.8	36.4	32.5
> 12000	32.3	38.0	33.2

$\bar{X}_C$ = 31.0* $\bar{X}_B$ = 38.3* $\bar{X}_0$ = 34.1*

SIGNIFICANCE TEST: Variance Ratio**

SOURCE OF VARIATION	D.F.	SUM OF SQUARES	MEAN SQUARE	F	p
MODE	1	54.50	54.50	2.32	n.s
INCOME	3	55.44	18.50	0.79	n.s
ERROR	3	70.44	23.50		
TOTAL	7	180.38			

*Overall means of each category differ from total sample as reported on Table V because of the different response frequencies by each socio-economic group.

**Variance Ratio F, is the estimate of S^2 based on the variation in travel time by mode ÷ the estimate of S^2 based on the variation in income.

up to the $12,000 income class. The percentage points separating the mean travel times of car users and bus passengers decrease with increasing incomes, although $12,000 income class again deviates from this trend. It appears that those of low income

who have a car available for the work journey have the least travel time to work. This may be a result of several factors: (1) these are industrial workers and start work at early morning hours, thereby avoiding the main traffic peak, (2) they may be young, unmarried persons who have just entered the labour force and living communally in the high rises of West Vancouver close to their work. It is in the low income category where the striking difference is seen between those who are captive to buses and have a very long journey time, and those who have a choice. This represents the major difference in service levels between bus and car modes.

Absolute travel times by all modes decrease with income up to the $12,000 group. The variation within income groups in their overall travel time is great enough to largely eliminate travel time as a factor in mode choice (Table VI). Variance ratios, or F values, are small both for the difference between modal travel times and for the differences in travel times within the income groups. This indicates that when the variation between income groups is considered, travel time is not a significant factor in the differences between modes. Although the variation between modal travel times is great, that between income groups is also large enough to reduce the effect of mode time. It also means that mode choice, as it is dependent upon travel time, does not vary significantly between different income groups, a conclusion which is supported as well by Zupan who found that income stratification would only improve mode

split prediction if incomes changed very radically.[11] Our inference is that while real differences appear to exist in the travel times of the two modes, when incomes are considered what appears to be substantial differences in modal times are in fact due mainly to differences in the travel times of different income groups.

A different conclusion comes from an analysis of occupation groups and mode split (Table VII). Like income, all travel times by bus are greater, but high status occupations are not associated with the longest trip lengths. By car, secretaries have the greatest trip length, followed by sales persons and managers. By bus, clerical workers followed by "other" (craftsmen, labourers), are longest. Secretaries and managers have the next longest trip lengths. Professional employees have the shortest travel duration in their respective modes, and the lowest of all groups regardless of mode; although trip lengths for professionals travelling by bus is substantially greater than those by car. These results indicate that, although occupation and incomes may be correlated, there is an independent dimension of occupational category which is important for mode choice. It appears to suggest that although professional employees may be in higher income categories they are more time sensitive than the higher income group as a whole, and therefore may also have different mode choice habits and residence-workplace relationships.

Table VII

MEAN TOTAL TRAVEL TIME, BY OCCUPATIONAL CATEGORY AND MODE

OCCUPATIONAL CATEGORY	MEAN TRAVEL TIME		
	BY CAR	BY BUS	OVERALL
MANAGERIAL	31.5	37.5	33.0
PROFESSIONAL	27.8	36.7	31.3
SECRETARIAL	34.0	37.5	36.8
CLERICAL	29.7	28.3	32.0
SALES	31.5	36.9	34.0
OTHER	28.6	37.8	31.7

$\bar{X}_c = 31.5$ $\bar{X}_B = 36.8$ $\bar{X}_0 = 33.8$

SIGNIFICANCE TEST: Variance Ratio

SOURCE OF VARIATION	D.F.	SUM OF SQUARES	MEAN SQUARE	F	p
MODE	1	28.58	28.58	15.00	< .05
OCCUPATION	5	141.50	28.25	14.90	< .05
ERROR	5	9.53	1.90		
TOTAL	11	179.61			

Variance ratios as shown on Table VII for mode use and occupational class on travel time indicate that there is a significant difference in the travel times within each occupational group between those of that class who use car and those who use bus. There is also a significant difference in each occupational group's travel time to work, regardless of mode used. This would indicate that travel time attributes for a

transportation system are valued differently by different occupation groups.

Perceived Travel Time

Travel time is usually that which is the difference between the average zone to zone travel time by each mode as measured by an over the road distance proxy, or actual travel time as measured in the field. Some recent surveys have measured perceived travel time, and a modification of this, the time of departure and arrival, but only one or two surveys have been made of the perceived relative travel times; (i.e. the perceived travel time of the mode used as well as that of its alternative). Measures of the perceived travel time by the alternative mode for North Shore commuters are shown in Table VIII. Two facts emerge from this table; (1) relatively few auto drivers report that the bus is faster while still taking the car (10.26 percent) contrasted with close to 30 percent (29.13) of bus riders who report the car is faster, and (2) the great number of auto drivers reporting that they do not know the travel time of the bus. These findings are consistent with what is known about mode choice. The greater numbers of bus riders who report the car faster includes captives. It is probable that bus riders know reasonably well the travel time by auto. However, it is obvious that many car drivers do not know the travel time by bus. In fact 57.2 percent of all car drivers reported that they never travel by bus and another 36.8 percent

Table VIII

RELATIVE TRAVEL TIME BY BUS COMPARED TO THAT BY CAR FOR CAR AND BUS ALTERNATIVE*

TRAVEL TIMES BY		PERCEIVED TRAVEL TIME OF ALTERNATE			
BUS COMPARED TO THAT BY CAR		FOR CAR USERS		FOR BUS USERS	
		NUMBER	%	NUMBER	%
	> 15 Min	23	(1.43)	55	(4.64)
BUS	11-15	29	(1.80)	109	(9.20)
FASTER	6-10	65	(4.05)	118	(9.96)
BY	1-5	48	(2.98)	63	(5.32)
	0	149	(9.27)	92	(7.76)
BUS	1-5 Min	57	(3.56)	47	(3.97)
SLOWER	6-10	172	(10.70)	121	(10.21)
BY	11-15	427	(26.60)	147	(12.41)
	> 15	na**		156	(13.16)
	D.K	513	(31.90)	277	(23.38)
	N.R	124	(7.71)		
	TOTAL	1,607	(100.00)	1,185	(100.00)

*"How does the door-to-door journey by bus compare to that by car?"
**Not included in the survey.

said they did only occasionally. Therefore, it is reasonable to conclude that a large proportion of car drivers are not aware of the bus times, and would have a low propensity to use transit, even if travel time was decreased substantially.

As one would expect, the proportion of those commuting by car who said they did not know the time by bus went up with increasing income levels. For the under $4,000 group only 7.5 percent said they did not know bus travel time, whereas of those over $12,000 46.4 percent said they did not know. Likewise,

occupational status determined perception of the bus alternative with 38.0 percent of professionals and 39.8 percent of the managers in the "don't know" category, whereas only 13.3 percent secretaries and 19.2 percent clerks were in this category. Salesmen who drove reported 56.2 percent "don't know."

Relative Overall Travel Cost

A substantial concern has been given to cost as a factor in mode choice because of the consuming interest in cost and price functions for transportation project evaluation and economic investment in the commodity sector. The same emphasis has permeated the passenger transportation aspect of transportation planning and therefore much effort has been extended on relations between mode choice and the price (cost) of travel. It is clear that cost is a factor where the total market (captive and choice) is considered. It is not clear what effect cost has on only choice riders.

The level of transit fares may have some effect on ridership, although the effects of fares are not conclusive from the literature. The consultants for the Seattle Public Transportation Plan state: "fare level, unless it was substantially different from the present, would not have significant effect."[12] The Metropolitan Toronto Transportation Plan using the model cited above, included a series of tests of various service level changes on vehicle and transit usage. Doubling transit fares increased auto trips by about only 3 percent

and decreased transit use by about 4 percent.[13] If transit fares were reduced by 50 percent vehicle trips would decrease 5 percent and transit trips increase about 7 percent. With no transit fare (i.e. free transit), vehicle use would drop about 8 percent with an 11 percent increase in transit ridership. These appear to be modest changes in mode split in considering some of the more drastic changes in fare structure. A search of the experimental studies carried out in conjunction with the Demonstration Grants Program in the U.S. revealed only fragmentary results. The success of the Minibus experiment in Washington D.C. is at least partly attributed to its 5¢ fare,[14] but patrons are shoppers and similar results may not be achieved for commuters. It thus appears that fare changes either upward or downward are expected to have only modest effects on mode split planning.

The consideration of vehicle operation costs (oil, gas, depreciation etc.) is a difficult problem in mode choice research. Those that have used this variable have invariably imputed costs from some average cost per mile multiplied by the trip distance in miles. This is used as an "objective" measure of vehicle operating cost and has very little relevance for mode choice because of two major difficulties; (1) over the road distances used may have very little relationship to actual over the road costs since running speed is seldom measured over this distance (because cost varies with running speed, grades etc., straight distance measures using assumed or average

running speeds, and the use of average costs per mile may be subject to large errors), (2) the engineering measures of vehicle costs. There is some evidence to support the conclusion that a great proportion of travellers do not perceive what it costs to use their car for a given trip to work. This has lead Quarmby to the conclusion that it may well be "hazardous" to use "engineering" costs to try to explain behavior.[15] If people do not perceive the amount of the cost of operating their vehicle the question is do they perceive that there is some cost. This is tied in with auto ownership. If a car is perceived to be primarily a social good and, once purchased, used for work purposes it is conceivable that the cost of the journey to work is not considered at all in the mode choice decision. If the car is purchased solely for commuting the cost of operating it on the commuting trip is probably part of the mode choice decision, although if it is a second car comfort and convenience factors may play a greater role than cost. That is, the car is purchased for commuting because transit service is not acceptable. Presumably car purchase and use is a complex decision with both motives being present, but the author believes that most auto purchase decisions tend toward that for a social good and all round use, with little thought given to the cost of a single journey to work.

For these reasons, and because of data limitations on individual distance measures and on average per mile vehicle

costs this investigation uses out-of-pocket expenses as the sole measure of cost factors. These are the costs incurred at the time of use; transit fares and parking costs, and therefore serve to preserve the logical nature of the mode choice decision coincident with the perceived measures of modal attributes used throughout this investigation.

Vehicle costs, parking costs, tolls, and transit fares are only meaningful in the mode choice decision if related to the ability to pay (i.e. to income levels). Quarmby summarizes this relationship:

> From the axiom that higher income travellers are better able to afford to pay a premium to satisfy their preferences than are low income travellers, it follows that if the cost of travelling by car is greater than by public transport the effect of higher income is to lessen the effect of cost as a deterrent to using car.[16]

If relative costs of the modes is very different the effect of cost will depend upon income; if costs are nearly equal the effect of cost will probably become insignificant. Quarmby argues therefore that costs should always be expressed as a function of income.

The out of pocket expenses used in this study include transit fares and parking costs. The commuted transit fare for B.C. Hydro Bus service serving virtually all the area east of the Bridge is 35 cents per trip to the CBD. West Vancouver buses had variable distance fares in 1967 with the highest

commuted fare from the most distant point at 54 cents and the lowest at the Bridge-head of 20 cents.

Table IX

PARKING CHARGE AT CBD DESTINATION*

MONTHLY CHARGE	No.	%	DAILY CHARGE	No.	%
FREE	368	(30.34)	FREE	44	(24.31)
0-10.00	250	(20.61)	0- .50	15	(8.29)
10.01-20.00	472	(39.91)	.51-1.00	74	(40.88)
20.01-30.00	119	(9.81)	1.01-1.50	37	(20.44)
30.01-40.00	3	(0.25)	1.51-2.00	6	(3.31)
>40.00	1	(0.08)	>2.00	1	(0.55)
N.R				4	(2.21)
TOTAL	1213	(100.00)		181	(100.00)

*"What do you now pay for parking?"

Parking charges are shown in Table IX. A striking fact is that over 30 percent of monthly parkers have no parking charge, and a high percentage of daily parkers as well. Presumably these people have parking space provided by their employers. If we assume that vehicle operating cost is not a perceived cost of the work trip and with free parking (again perceived free since it may be paid for as part of the wage structure of the firm) fully 30 percent of the auto driving workers to the CBD have no perceived costs. Another 20.6 percent pay less than $10 while close to 90 percent of all parkers pay less than $20 per month. Somewhat less people, who pay daily rates are in the same cost equivalent situation with

73.5 percent paying less than $1.00 per day.* This generally low parking charge has great implications for mode choice.

It was expected that parking rates may be related to income category with those of higher incomes paying greater parking fees (Table X). No pattern is conclusive however with parking charges by income much the same as the total sample. There is some tendency for very low income workers to pay very high parking rates. This may be due to the inability of this group to bargain for parking as part of the fringe benefits of their job.

Table X

PARKING CHARGE BY INCOME CATEGORY**

INCOME CATEGORY	FREE		<10		10-20		>20		
	No.	%	No.	%	No.	%	No.	%	
<4000	13	(28.9)	8	(17.8)	21	(46.6)	3	(6.7)	(100.0)
4000-8000	107	(33.0)	84	(25.8)	116	(35.6)	18	(5.6)	(100.0)
8000-12000	151	(31.4)	96	(20.0)	175	(36.4)	59	(12.2)	(100.0)
>12000	123	(31.5)	70	(14.6)	219	(45.6)	78	(16.2)	(100.0)

**"What do you now pay for parking?"

Parking charge by occupation is shown in Table XI. Again in most cases, the parking charge for each group is close to the average, with the exception of industrial workers who appear to have a high proportion of free parking. This probably

*Assuming 20.8 working days per month less 10 statutory holidays the monthly and daily rates become equivalent.

Table IX

PARKING CHARGE BY OCCUPATION CATEGORY*

OCCUPATION CATEGORY	FREE No.	FREE %	10 No.	10 %	10-20 No.	10-20 %	20 No.	20 %	
MANAGERIAL	122	(29.3)	81	(20.2)	150	(36.0)	61	(14.6)	(100.0)
PROFESSIONAL	164	(30.2)	91	(16.8)	225	(41.4)	64	(11.8)	(100.0)
SECRETARIAL	9	(21.4)	13	(31.0)	20	(47.6)	0	(0.0)	(100.0)
CLERICAL	26	(29.6)	26	(29.6)	33	(37.5)	3	(3.3)	(100.0)
SALES	46	(24.2)	31	(16.3)	85	(44.7)	28	(14.8)	(100.0)
OTHER	34	(45.5)	15	(20.0)	22	(29.3)	4	(5.3)	(100.0)

*"What do you now pay for parking?"

reflects the peripheral location of the work places of these employees with free or inexpensive parking available at their industrial plants.

Convenience

Convenience constitutes time-distance factors which are incurred outside the vehicle and include excess travel times or terminal times. Excess travel time is defined as that portion of travel time which is non-vehicular; walking and waiting times. It is generally felt that savings in these times are more important to the user than in-vehicle times. It is recognized that non-running times have more influence on travel behavior than running time, because of the psychological effect of waiting, transferring, and the discomforts of walking. The weight given is usually taken to be about 2.5 of running time.[17]

Table XII

TERMINAL TIME AT ORIGIN BY MODE

MINUTES	CAR MODE* No.	CAR MODE* %	BUS MODE* No.	BUS MODE* %
0	1107	(68.89)	36	(3.04)
1-3	385	(23.96)	504	(42.53)
3-5	18	(1.12)	377	(31.81)
5-10	11	(0.68)	186	(15.70)
10 or +	39	(2.43)	79	(6.67)
N.R	47	(2.42)	3	(0.25)
TOTAL	1607	(100.00)	1185	(100.00)

*"How long does it take you to travel: from the start of your journey to your car (to the bus stop)?"

Table XII shows that fully 92.9 percent of auto users are within 3 minutes of the vehicle at the residential end of the trip, while only 45.6 percent of bus passengers are within this limit. Although no definitive standards exist the 54.4 percent of bus passengers who walk more than 3 minutes probably feel constrained to use transit if a car is available. There are no accepted tolerances on how far people will walk to use transit if a car is theoretically available. Lansing and Hendricks found for example that auto users did not consider that they had a choice of mode unless they were closer to transit service than the average distance actually walked by transit riders.[18] By arbitrarily using a 10 minute distance as the definition of transit availability they were able to increase those who said they had a choice from 26 percent under the

perceived availability (less than transit walkers) to 44 percent at the 10 minute service area. If the perception of whether or not transit is available is taken as the cut-off for the tolerable distance to transit, it is clear from Lansing and Hendrick's work that a great number of respondents would consider that a choice is available only if this distance is somewhat less than 10 minutes.

Relatively few respondents reported a transfer (22 percent) and less than 12 percent reported an actual time involved in making the transfer (Table XIII). Of those who experienced transfer time only a very small proportion said it was more than 5 minutes. It is conceivable that transfer time is not important to the mode choice decision, but that the mere interruption of the journey is the operative factor i.e. comfort. No study is available on this, but it has been found that an analogous situation, vehicles interruption by traffic signals has some effects on route choice.[19]

For those who used bus, 83.0 percent waited less than 5 minutes at the bus stop. Since the bus frequency is relatively low for most parts of the North Shore, these relatively small waiting periods infer that most riders have streamlined their journey by knowing schedules and local bus conditions.

The distribution time at the CBD destination may be particularly critical to mode split. Parking time, unparking

Table XIII

OUT-OF-VEHICLE TIMES FOR BUS PASSENGERS

MINUTES	TRANSFER TIME*		WAITING TIME*	
	No.	%	No.	%
0	123	(10.38)	35	(2.95)
1-3	59	(4.98)	383	(32.32)
3-5	49	(4.14)	566	(47.76)
5-10	22	(1.86)	168	(14.18)
10 or +	8	(0.68)	19	(1.60)
N.R	924	(77.97)	14	(1.18)
TOTAL	1185	(100.00)	1185)	(100.00

*"How long does it take you to wait at transfer point (wait for bus)?"

time, the walk from transit vehicle or parking lot to final destination are factors considered important for mode choice.

Table XIV shows the distribution of walk times for those who arrive at their destination by automobile and for those who arrive by bus. The auto walk trip length distribution is bimodal indicating that a dichotomous situation prevails. It is hypothesized that those who park close to their work location either have free parking or pay high rates, and that another group exists which cannot afford the high rates associated with close-in parking and therefore must find a suitable trade-off between parking cost, and walking distance. These park at greater distances, and form a definite secondary group. About 58 percent of all workers park within 5 minutes of their

Table XIV

TERMINAL TIME AT DESTINATION BY MODE*

MINUTES	BY CAR		BY BUS	
	No.	%	No.	%
0	272	(16.93)	12	(1.01)
1-3	431	(26.82)	302	(25.49)
3-5	228	(14.19)	436	(36.79)
5-10	125	(7.78)	253	(21.35)
10 or +	512	(31.86)	21	(1.77)
TOTAL	1607	(100.00)	1185	(100.00)

*"How long does it take you to travel: from your car (the bus) to end of journey?"

final destination whereas about 40 percent park more than 5 minutes away and 32 percent are 10 minutes or more away. Useful criteria for subway station service areas are a 5 minute walk at 300 ft. per min. or straight line distance of 1500 feet. Using this standard for automobile users indicates that a large proportion are inconvenienced, but obviously not enough to switch to the bus. Indeed bus service is such that almost 35 percent of bus users walk more than 5 minutes to their destination. This means that certain groups will tolerate substantial walking distances at the destination before switching mode.

Table XV shows the percentage of each income group walking less than 5 minutes and those more than 5 minutes. There is a definite tendency to park closer to final destination as income increases. The significance test using the

Table XV

PERCENTAGE OF THOSE GOING BY CAR IN EACH WALKING DISTANCE CATEGORY FROM PARKING LOT TO FINAL DESTINATION, BY INCOME AND OCCUPATION

	WALKING DISTANCE		
	LESS THAN 5 MINUTES	MORE THAN 5 MINUTES	
INCOME CATEGORY:			
<4000	54.3	45.7	(100.0)
4000-8000	55.0	45.0	(100.0)
8000-12000	60.0	40.0	(100.0)
>12000	62.5	37.5	(100.0)

SIGNIFICANCE TEST: Chi-square

$\chi^2 = 8.12$
D.F. = 3
$p < .05$

OCCUPATION CATEGORY:			
MANAGERIAL	59.0	41.0	(100.0)
PROFESSIONAL	62.6	37.5	(100.0)
SECRETARIAL	44.3	55.7	(100.0)
CLERICAL	55.6	44.7	(100.0)
SALES	53.7	46.3	(100.0)
OTHER	71.6	28.4	(100.0)

SIGNIFICANCE TEST: Chi-square

$\chi^2 = 21.22$
d.f. = 5
$p < .001$

chi-square statistic shows that the differences in walking distances with income levels is significant at the .05 level. This supports the conclusion that lower income groups are walking substantial distances to attempt to trade off parking charges with the inconvenience of walking.

Since walking distances in the CBD varies with income it might be expected also to vary with occupational groups, with those of the high status occupations walking shorter distances. Table XV shows this to be generally the case with professional and managerial employees favouring less than 5 minute walking times with higher percentages in the lower status occupations walking more than 5 minutes. An exception is those who report "other" occupation, which includes craftsmen and labourers, and who show a tendency to walk less than 5 minutes from their parking location to their work. This is to be expected since most of these employees work in industry on the fringe of the CBD where parking is available either free from their employer or at lower rates than that towards the core. Significance tests show these differences to be significant at the .001 level.

Comfort

Comfort is undoubtedly a factor in mode choice, but meaningful quantification nor precise definitions have as yet evolved. Therefore, it is difficult to assess relative comfort

in comparison with those factors discussed here. The literature has included such items as air conditioned buses, freedom from crowding, amenities of the ride and vehicle, security, destination reliability, and stop shelters. Factors which are usually included in convenience, or time units, may also be more properly considered as comfort factors. For example, it may be that walking times, waiting times, transfers and extra vehicular activities are related to mode choice with regard to the relative discomfort involved rather than the time disutility of these activities. This could be the case in Vancouver where the precipitation is high, with inclement weather for a substantial number of days of the year.

Regardless of the level of quantification there is a conviction by many planners and policy makers that comfort weighs heavily in the mode choice calculus. There is little doubt that the relative comfort of the automobile, whatever components are included in the concept, has been a significant factor in its growth and use since World War II. The role of comfort in mode choice is evident from attempts to include a high level of comfort and amenity factors in recent rapid transit projects. Montreal's rubber tired transit vehicles, individually designed stations, and wide escalators are examples. San Francisco, in BARTD, has provided for an unprecedented concession to comfort and aesthetics in design and operational characteristics. According to promotional literature BARTD's success depends almost entirely on creature comforts. The

object as stated is to make the trains above all, more comfortable and attractive than private cars.

The relative value of comfort for bus commuters in the corridor can be inferred from the survey questionnaire. Bus riders were asked to rank those attributes of the system which were felt to need improvement in order of preference. Of the comfort factors, to have a seat proved to be the most important preference for improvement with 8.9 percent rating this as first priority for improvement, and 15.5 percent rating it second. If is fourth in order of preferred improvement. Over 38 percent ranked the ability to get a seat as either first, second, or third. Shelter at bus stops had a higher rating than better lighting and airconditioning, although both these preferences came after improvement in time and cost factors. A great number of respondents did not indicate a rank ordered preference, either by not answering any part of the question or by only ranking certain items. If we assume a non-response as indifference to the item, with fewer non-responses indicating an interest in improvement; to be seated rates second in importance of all items tested. Slightly more than 37 percent were non-respondents, whereas the most important item, express service, had only 19.4 percent non-responses.

A comparison of all items was carried out by N.D. Lea and Associates in which all ranks were weighted by the number of responses, and each item then taken as a percentage

of the total weighted responses.[20] Ranked in order of importance the results were:

1st	Express routes and service
2nd	Lower fares
3rd	All passengers seated
4th	Frequency of service
5th	Shelters at bus stops
6th	Bus route closer to home or work
7th	Better lighting and air conditioning

Based on these results for bus passengers, comfort and convenience factors appear to be less important than travel time and cost factors. It is well to note however that these are rankings of preferences for improvement and do not indicate any propensity for changing behavior.

Since automobile drivers are not faced with these discomforts, there is no way to compare levels of improvements which would affect the mode split. However, there is one aspect which is an important comfort factor to motorists; and that is the ability to park easily. In the study corridor a large percentage of bus passengers indicated they had switched from car to bus, and of those who switched 21.8 percent said the did so because parking was too "difficult." Parking difficulty in this context may mean delay, or possibly too high a price, but it also undoubtably has some comfort component as well. The frustrations of parking, and the insecurity of being faced

with a difficult parking situation each day may well be a factor in switching to transit.

PRINCIPAL FINDINGS

The foregoing description of the socioeconomic and behavior profiles of each of the client groups has related the case study corridor to the body of literature and has pointed out new hypotheses.

It has been shown that most socioeconomic characteristics of commuters to the CBD are significantly different from those of non-CBD commuters. For CBD commuters, client groups are different for each mode and the socioeconomic characteristics of each mode's client group are a factor in how the attributes of the system are valued. Consequently, the effects of policy options act at three levels of socioeconomic space defined by the study corridor: that space which defines the CBD commuter, that space which defines the client group for each mode, and that space which defines the behavior pattern of each client group. The former is of interst only because sets of policy options concerned with changes in the corridor system will have indirect effects of those corridor client groups which are not directly affected by system changes. For example, if a parking and/or pricing policy in the CBD is successful in shifting the mode split in favour of transit, thus relieving automobile congestion in the corridor, commuters travelling through the

corridor to points outside the CBD which are thereby not subject to the policy changes may switch to automobiles, or more automobile trips may be generated, because of the increased service.

There appears to be a relationship between the socioeconomic space of client groups and the mode used for the journey to work. For each mode, group socioeconomic characteristics are relatively homogeneous compared to the difference in characteristics between modes. Male commuters are car oriented, female ones bus oriented. Commuters in the prime working age groups of 40-60 are car oriented, while younger and older age groups are bus oriented. Indications are that substantial commuters in the 20-40 age group prefer the bus. Occupational structure is related to mode choice somewhat differently than expected. A high proportion of managers, and professional employees use the bus, an unexpected finding. Also a substantial proportion of unskilled workmen and clerical employees are car oriented, groups which are often though to be transit "captives." Secretaries and sales workers are transit oriented as expected. Car ownership is high in this case and may be expected to moderate the usually high correlation between car ownership and mode split. Income shows the expected trend with high income households associated with car mode and low income with bus use.

The analysis shows tendencies toward differentiated socioeconomic characteristics of client groups for each mode. The behavior profiles of each mode group describe what modal attributes are important to the various socioeconomic groups in evaluating the relative merits of each component of the system. One apparent contradiction emerges. While the higher income groups travel further to workplace than low income groups, these groups seem to be more sensitive to the relative travel time between modes. The explanation for this phenomenon is that what appears to be an effect of relative travel time is due to an intervening variable such as residential amenity or a high level of comfort and amenity on the transit system. An analysis of variance of travel time by each of the modes against income substantiates this conclusion, and the variation in the travel times for different income groups wipes out the effect of travel time differences of the modes. It may be that relative travel times may not be an important factor in mode choice as it relates to income, except to the extent it is a proxy for other variables. However, this conclusion needs to be supported by a greater range of travel times and travel time differences than is available for this single corridor.

Clearly, occupation shows a different pattern of time effects than income. Different occupational groups value travel time attributes differently, with some non-expected tendencies. For example, the professional group which would be associated

with higher incomes, have shortest travel times in their respective modes. It appears that professional employees are more time sensitive than the higher income group they belong to, and therefore have different mode choice habits and residence-workplace relationships. The relationship of occupation, separate from income, with travel times substantiates the hypothesis that the CBD occupational structure and the relative modal characteristics serving the CBD are related.

The choice of mode is dependent at least in part upon the perceived differences between the modes. Only however to the degree individuals perceive one mode to be advantageous and actually use that mode. However, it appears that most individuals in this case act rationally according to perceived attributes. Auto drivers fall into two categories: those who perceive car faster and use that mode, and those who report they do not know bus travel times. Relatively few car users, who perceived the bus to be faster, used their cars for the journey to work. Those who were ignorant of bus travel times increased with income level and occupational status. A great number of these commuters are able to negotiate a high level of comfort and convenience in designated and free parking, and therefore are never faced with the bus alternative. Over 57 percent of car users said they never use the bus.

On the other hand a substantial proportion of bus riders report the car to be faster, but use the bus. These include captives.

Policy options which include pricing as a control mechanism for congestion or the manipulation of mode split must contend with existing pricing practices and the insensitivity of client groups to price changes. Effects of changing the price of parking is not as straight forward as generally presumed. First, it is obvious that a great number of car drivers face no charge for parking. Since parking stalls for executives is becoming a condition of tenancy in newer office buildings, supplied free to the user by the tenant, and since the CBD is becoming more and more a managerial and financial center it is probable that the proportion of CBD employees who have "free" parking will increase. Pricing policies will have virtually no effect on this group. It is also difficult to see how any municipal rate structure or taxing scheme would effect this situation directly. (It might, by making the opportunity cost of potential parking stalls in a development greater, eliminate some spaces for a higher and better use if executive parking is otherwise provided at no cost to him). Secondly, it appears that parking cost and parking convenience is complementary, with the mixture dependent upon the socioeconomic structure of the client. While this relationship is confused by the fact that relatively large numbers of higher income commuters have free parking thereby wiping out the positive relationship expected between income and parking charge, it is apparent that low income commuters walk further to avoid high parking rates. Low status income and occupational groups

generally will tolerate substantial walking distances to be able to use their cars for the work journey.

Comfort, with the exception of being able to obtain a seat, does not weigh heavily as factors which bus passengers desire as improvements. After express services and lower fares bus riders would like to be seated for the trip. However, shelters at bus stops and better lighting and air conditioned buses are not as important as travel time, cost, and convenience factors. Part of the results of this test is related to the existing level of service, and is not indicative of an objective hierarchy of importance. Frustrations of parking may be a discomfort for auto drivers. These results however, do not allow any inference with regard to the effect improving comfort would have on attracting motorists to the bus system.

CHAPTER IV

MULTIVARIATE ANALYSIS OF INTERMODAL DEMAND

This chapter is an analysis, using multivariate statistical procedures, of behavior on the system; and how it is related to mode choice and the socioeconomic structure of those using the two modes to get to work.

PREPARATION OF DATA MATRIX

Substantial preparation was necessary to reduce the questionnaire responses to allow processing by high speed computer, and to prepare the matrices necessary for the multivariate statistical analysis. Each item of the survey questionnaire was examined and reformatted. Since many answers were alphabetically coded on the original cards a conversion program was written to format a data matrix which was machine compatible. The conversion program is shown in Appendix C. Since the auto questionnaires and bus questionnaires were of different design the program also converted both to a common format. Alphabetical codes for zone designations were changed to numerical codes, and those for door-to-door travel times were given their original travel time designations in interval scale. The conversion program was designed also to reorganize the relative travel time questions so that differences and ratios could be calculated.

Questionnaire responses were in the form of categorical data. This was handled in several ways. Where the categories were scaled in equal intervals the mid-point of the category was taken to be the value for all responses in the category. Where the scale was open, or if intervals were not equal, the response was reduced to ordinal scaled values and a code assigned to each category. An example where this was done is question 13 and 14 of the auto questionnaire concerning travel times to and from the vehicle. The resulting scale was a high order ordinal scale. Most of the ordinal codes are better than a simple rank order since across most of the scale (the end categories excluded) the ranks were based on equal distance between categories. Occupation, for the first series of tests, was ordinalized in accordance with Blishen's Socio-economic Index of Occupations in Canada.[1] With the exception of door-to-door travel time, the interval scaled responses were grouped and category mid-points used as the measure of the variable under consideration.

Because the number of categories in some cases were less than 10, the minimal number recommended for statistical accuracy by McNemar,[2] Sheppard's correction factor for grouping was applied. The theory behind this correction is as follows. When data are grouped and all observations assumed at the mid-point, it hides the fact that individual observations within a category interval cluster toward the direction of the mean, rather than at the mid-point as assumed. That is, for categories

to the left of the mean observations would tend to cluster at the right hand side of the interval, while for categories to the right of the mean the observations would cluster toward the left of the interval. Thus the standard deviation of the grouped data would appear larger than that based on individual observations. Sheppard's correction factor is applied to the standard deviation by reducing the observed standard deviation by a factor which relates the actual interval size to one in which no difference exists between the standard deviation for grouped and ungrouped data.*

The data conversion program translated both auto and bus questionnaire data from the two card decks into a single data format, and transcribed the data matrix to magnetic tape. The data tape matrix arrays all travel and socioeconomic information for each individual who has a choice of mode, where choice is defined by having at least one car in the household.

Preparation of Score Matrices

Score matrices were developed from the data matrix as needed for each test. For the first series of tests, the score matrix consists of an array of original data and transformations selected from the data matrix, as well as new data input. Blank entries, incorrect coding of the original cards, resulting in impossible values of the variables, and other

*$S_{Corrected} = \sqrt{S^2 - (i^2/12)}$, where i = number of intervals.

anomolies in the data matrix were also screened out at this stage. This process resulted in a matrix of 14 variables and 2211 individual entries, with 1244 auto and 967 bus users. Appendix D shows the computer program to develop this matrix (Score Matrix #1), and to transcribe it to magnetic tape.

The variables selected for the tests were the socio-economic characteristics which were available in the survey and those variables which measured the actual travel behavior of the individual.

The behavioral variables are those which reflect performance attributes of the system and which can be manipulated in a generalized parking policy. Those used denote the broadest concept of parking policy which incorporates park and ride potential, as well as the CBD parking system. Inherent to the idea of abstract mode as measured by the attributes of the system is the concept of a multimodal system in which transfers from one mode to another is possible. The facilities for such a concept may be viewed within a park and ride system and therefore virtually all performance factors could be adjusted by such a system. Residential travel time overall travel time, CBD travel times, frequency at the interface and the overall cost could be as important as parking charges. Since any multimodal system, such as park and ride, incorporates to some degree all of these elements it is necessary that the influence of each be known as inputs to any realistic parking policy.

Age. The age category of each respondent was coded between 1 and 4.

Occupation. The occupational categories in the survey were reorganized in a new hierarchy in accordance with Blishen's socioeconomic index for occupations. Blishen devises an interval scaled index of occupations in Canada. The occupation variables in the multivariate analysis were rank ordered according to Blishen's hierarchy. A code number between 1 and 6 was assigned to the six categories of the work purpose trip in accordance with the rank of that occupation.

Car Necessary for Work. The question "how often is it absolutely necessary to use your car during the day" was coded from 1 to 4 to designate "never," "very seldom," "once a week" or "frequently." All bus passengers were coded "1" (i.e. as never having to use the car for work). It is possible that those bus passengers responding on the day of the survey would sometimes use their cars during the day. However, symmetry is ordinarily assumed in origin destination cross sectional behavior in which errors are presumed to be compensating. The typical example is that traffic measured in one direction during a 24 hour period will be reflected in the opposite direction, even if the survey shows unequal directional flows, and the flows are thus arbitrarily balanced. For this reason if a commuter used the bus to work it is obvious he would not use his car during the day of the survey and therefore, for that

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trip on that day, it is equivalent to never using the car. Presumably some car user who took his car only that day and on no other would balance out the bus passenger.

Car Ownership. This variable was coded 1 to 4 designating none, one, two, three or more cars in the household. Since the mode choice analysis to follow is for "choice" trips, only those households which reported owning one or more cars were included in the score matrix.

Income. Income was coded 1 to 4 designating $4000, $4-8000, $8-12000, and $12,000 categories.

Car Availability. Since household ownership of an automobile may not reflect the actual availability of a car for a given trip, a proxy based on the estimated availability of a car, and the competition amongst members of the household for car use was included. This variable accounts for different levels of car ownership, persons per household (zonal average), and income:

$$\text{Car Availability} = \frac{\text{PERSONS PER HOUSEHOLD X LOG INCOME}}{\text{CARS PER HOUSEHOLD}}$$

This proxy variable defines the competition between members of the household in terms of the number of persons in the household and the number of cars owned, modified by the demand for travel. If the car was purchased for commuting only, the availability of a car for commuting is a simple relationship between the number of commuters and the number of cars owned.

If there is one car per commuter there would be no competition for the use of the car and the mode choice would be related to factors other than car ownership. Intuitively, the use of transit would increase as this simple ratio decreased from the value of one. However, the number of persons and cars owned per household for commuting must be related to competition from other purpose trips as well, such as shopping and social-recreation trips carried out by non-commuting members of the family. The income factor takes this into account. As income per person increases the number of trips demanded increases. That is, as Warner states: "the more each individual has to spend, the more often he can travel for the purpose of spending."[3] But there is a limit to the number of trips, and also possible economies of scale. Therefore it is postulated that the desire for individual travel is related to income, but at a decreasing rate, and the log of income becomes the proper modifier for car availability. Income is the reported individual income, and persons per household is the average number of persons per household in each zone. Persons per household is taken from the 1966 Population Census tracts and converted to the survey zones. Cars per household is that reported by survey respondents.

Hour End. This variable is the reported time of arrival at work. It was reasoned that mode choice is related to work hours for two reasons. First if a commuter was to leave home and arrive at work at a time when bus frequency was high he would be more likely to take the bus, and vice versa. Secondly, the "lag" time for bus travel is related to required time of

arrival at work. For example, a bus commuter may be required to arrive at his work place some substantial time before he needs to report for work because of the bus frequency at his residence location. For example, the first bus available may put him at his work place 15 minutes before the starting hour, whereas the next bus may make him late. The work place time lag between his "forced" arrival time and required starting time could be a powerful incentive to use a car, if one is available.

Residential Travel Time. This variable measures the length of time to travel from the start of the work journey to the bus stop or to a car. Although the original survey times were categorized (0 minutes, 1-3 minutes, 3-5 minutes, 5-10 minutes and 10 or more minutes) the intervals were unequal and a significant number of responses were in the open ended category (10 or more minutes), it was decided to treat this variable as an ordinal scaled response. Therefore the categories were coded from 1 to 5 inclusive.

CBD Travel Time. This variable is the walking time from the parking location or bus stop to final destination. It was also ordinalized in the same way as residential travel time, since all conditions were parallel.

Overall Travel Time. This measures door-to-door travel time for both auto and bus passengers in 5 minute increments. These increments are probably the minimum which can be perceived

by users. That is, perceived and reported times are given to the nearest 5 minutes, and any finer breakdown probably meaningless in terms of subjective responses.

Parking Charge. Parking charges levied are the manifestation of out-of-pocket expenses for automobile drivers, as are fares for transit riders. Most commuters pay parking fees by the month. Reported monthly fees were converted to daily rates to be compatible with the other components of daily travel. On the assumption there are 20.8 working days per month, less 10 statutory holidays per year (or .8 per month) the reported monthly rate is equivalent to the reported daily rate if divided by 20 (20.8 - 0.8). Occasionally researchers split parking fees, with one half of the fee assigned to the journey to work, and one half to the journey from work. It was however reasoned that the perceived parking charge would be the total charge per day, since this would be the manner in which the transfer of money would take place. This is particularly true of subscribers, who it is postulated, would not attempt to cost a single trip.

Fare. Both transit agencies reported that most fares are in fact commuted fares, but no precise breakdown is available. Therefore it was assumed that all commuters would take advantage of commuted fares where available. The one-way fares were then doubled to conform with the nature of the perception of parking charges.

Parking Charge/Income. This variable is a proxy incorporating parking charge divided by income, on the premise that the parking rate as an influence in mode choice would be more meaningful if related to income.

Frequency. This was taken as the average frequency over the period between 7am-9am. Since the minimum difference in average frequency for commuters is 5 minutes, and since the original survey did not report exact frequencies facing individual travellers, it was decided that average frequency for each zone would adequately describe the perceived dimension of transit frequency.

Standardization of Scores

The variables are measured in different scales of time, space and dollar units. For those tests which included socioeconomic variables with performance variables the score matrices were standardized and adjusted by Sheppard's correction factor by dividing each row score by the corrected standard deviation of the variate. Standardization, in which the mean of the variate over the population is zero and the standard deviation equal to unity was necessary in some tests to reduce both sets of variates (the socioeconomic ones and the behavior ones) to the same metric. Standardization of the variates has no effect on the results of the analysis.[4] Comparative tests

on the second series of discriminant tests showed negligible differences in results between raw scores and standardized scores adjusted by Sheppard's correction and therefore raw scores were used for some tests. The computer program for standardized scores is shown in Appendix E. The data matrix was edited to remove car cassengers, zero entries, and those bus passengers who had no car available for the work trip, where car availability was defined by owning at least one car. The resulting score matrix was transferred to magnetic tape, and consisted of 1244 car drivers and 967 bus passengers.

Several hypotheses about the dimensions of intermodal demand suggested in the previous chapter require testing. These are: (1) that behavior on the system is related to the socio-economic characteristics of each mode's client group, (2) that the mode choice is a function of both socioeconomic structure of the user and system performance, and (3) that individual behavior profiles can be used to define each mode's client group. In addition, one other point needs to be investigated: the relative influence of those performance factors which could conceivably be a part of an intermodal, park and ride system.

INTERDEPENDENCE OF SOCIOECONOMIC STRUCTURE AND SYSTEM PERFORMANCE

What are the interdependencies between the socio-economic structural characteristics of the corridor and behavior towards modal attributes? The relevant structural dimensions

and their interdependencies with behavior dimensions gives a clue to the underlying pattern of the mode choice decision. The primary research questions are (a) is socioeconomic structure of each modal client group significantly related to the performance of the system of the CBD and (b) how are the two sets of variables which describe these concepts combined in maximizing the interaction between the sets. This question recognizes the reciprocal effect of socioeconomic structure and system performance in the decision process of the individual and infers that these relationships may be different for each client group. That is; first, that mode choice is not only dependent on socioeconomic structure and system performance but that the choice decision also causes changes in these concepts. For example, the decision to purchase a car, or change household location could be the result of making a prior decision on modal choice. Secondly, it recognizes that each modal client group puts a value orientation on the attributes of the system in accordance with his structural characteristics. That is, for example, we might expect that car drivers may show an interdependence between income and time factors, whereas bus riders may show significant interdependency between income and cost factors. We assume moreover that each individual's decision calculus is such that equilibrium occurs when the interdependence between his socioeconomic and behavioral characteristics is maximized. This assumption, based on extensive empirical findings that spatial structure and transportation

is interrelated, adds conceptual reality to the idea of maximizing two sets of variables where otherwise there may be only "artificial" relationships brought out by the nature of the statistics.

Canonical correlation analysis as outlined by Anderson,[5] and Cooley and Lohnes[6] is a statistical technique to bring out the relationships between variates when correlations between two sets of variates are in some sense maximized. Canonical correlation analysis is a generalized extension of multiple linear regression analysis with both multiple dependent as well as multiple independent variables. By multiple linear regression it is possible to stratify the socioeconomic variables into separate tests and in turn determine the weighting on the behavioral variables which would give the maximum correlation. But multiple regression does not consider the relationships among the socioeconomic variables. The previous chapter showed multiple interrelationships among the sets of socioeconomic and behavior variables. For example, the relationship between income and the manner in which different attributes were valued was in turn dependent upon occupation. Canonical correlation analysis allows some explanation of these multiple relationships in that it tells us how the two sets of variables are related to each other and how the variables within each set influence the relationship. Canonical correlation is the maximum correlation between the linear functions of the two sets of variables.

However, several linear combinations of the two sets are possible and each pair extracted is maximally correlated but orthogonal (independent) of the previous derived combinations.

Assume there are p socioeconomic variables, $X_1, X_2, X_3, \ldots, X_p$; and q behavior variables $X_{p+1}, X_{p+2}, X_{p+3}, \ldots, X_q$; and N observations for each variable. The two sets of variables form a random vector of observations, X. We choose a reference system which makes $\Sigma X = 0$, with unit variance. If the two sets are designated by $X^{(1)}$ and $X^{(2)}$ then

$$X = \begin{bmatrix} X^{(1)} \\ X^{(2)} \end{bmatrix} .$$

As X is partitioned into vectors of p and q components the variance-covariance matrix is also partitioned into p and q rows and columns;

$$X'X = \begin{bmatrix} X^{(1)}X^{(1)} & X^{(1)}X^{(2)} \\ X^{(2)}X^{(1)} & X^{(2)}X^{(2)} \end{bmatrix} ,$$

with $$D = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix}$$; and the correlation matrix is

$$R = \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix}^{*} ,$$ in which

*D = R when mean = 0 and variance = 1.

R = matrix of intercorrelations of p+q variables,

R_{11} = intercorrelations among the p socioeconomic variates,

R_{22} = intercorrelations among the q behavior variates,

R_{12} = intercorrelations of socioeconomic with behavior variates; and

R_{21} = transpose of R_{12}.

The canonical correlation problem is to bring out the nature of the interdependence of the two sets of variates when the linear combination of the two sets are maximally correlated. Consider an arbitrary linear combination $U = \alpha' X^{(1)}$ of the p socioeconomic variates and an arbitrary linear combination $V = \gamma' X^{(2)}$ of the q behavior variates. The maximum correlation is found by rotating the reference axes for each set of variates in the test space so that the axes of the p variate set and that of the q variate set form a new axes system. If the parameters α and γ are normalized such that U and V have unit variance then;

$$\Sigma U^2 = 1 = \Sigma \alpha' X^{(1)} X^{(1)'} \alpha \quad , \text{ and}$$

$$\Sigma V^2 = 1 = \Sigma \gamma' X^{(2)} X^{(2)'} \gamma \quad .$$

The correlation between U and V is, therefore,

$$\Sigma UV = \Sigma \alpha' X^{(1)} X^{(2)'} \gamma \tag{1}$$

because $\Sigma X^{(1)'} \alpha = 0$ and $\Sigma \gamma' X^{(2)} = 0$.

Thereby, substituting in (1), the correlation between the two sets is

$$\Sigma UV = \alpha' R_{12} \gamma \ . \tag{2}$$

The canonical correlation problem is to find the values of α and γ when ΣUV is maximized, i.e. when the derivative of ΣUV with respect to α and γ is zero. Anderson[7] has shown that ΣUV is maximized when*

$$\begin{bmatrix} -\lambda R_{11} & R_{12} \\ R_{21} & -\lambda R_{22} \end{bmatrix} \begin{bmatrix} \alpha \\ \gamma \end{bmatrix} = 0 \ . \tag{3}$$

The determinantal equation of the first term

$$| R_{22}^{-1} R_{21} R_{11}^{-1} R_{12} - \lambda I | = 0 \tag{4}$$

is solved for all possible values of λ (up to the lesser of p or q): the characteristic roots. The canonical correlation, R_c, for each root is $\sqrt{\lambda_i}$ which is a measure of the degree that observations referenced by the axes of each set occupy the same relative position in the research space.** For each characteristic root the vectors of the coefficients α and γ are found for the set U and V from the canonical equations

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*See Appendix F for derivation.

**The statistical significance of any root λ_i and therefore the canonical correlation R_c is the Chi-square statistic, where $\chi^2 = -[N-.5(p+q+1)] \ln \Lambda'$; in which $\Lambda' = \prod_{i=r+1}^{q} (1-\lambda_i)$, (see Ref. 6).

$$(R_{22}^{-1} R_{21} R_{11}^{-1} R_{12} - \lambda_i I)\gamma = 0 \text{ , and} \tag{5}$$

$$\alpha = (R_{11}^{-1} R_{12}\gamma)/\lambda_i \text{ ,} \tag{6}$$

where α gives the weighting of each of the socioeconomic variables in the interdependent relationship and γ gives the weighting of each of the behavior variables in the relationship.

To determine the relationship between socioeconomic structure and behavior of the sample set we have 12 variables which can be divided into the two component groups $X^{(1)}$ and $X^{(2)}$ in which the $X^{(1)}$ set consists of:

X_1 = age (AGE),
X_2 = occupation (OCC),
X_3 = car necessity for work (CNEC),
X_4 = car ownership (COWN),
X_5 = income (INC), and
X_6 = availability of car (CARA).

Set $X^{(2)}$ consists of:*

X_8 = residential travel time (TTO),
X_9 = CBD travel time (TFRM),
X_{10} = total travel time (OTT),
X_{11} = out-of-pocket expenses (OPE),

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*X_7 the variable hour end was dropped from this test because of conceptual incompatibility and program limitations that $X^{(1)}$ must be $\leq X^{(2)}$.

X_{12} = out-of-pocket expenses ÷ income (E/INC), and

X_{13} = bus frequency (FREQ).

A canonical analysis was made of the study data using program UBC BMD06M from the UBC library. Tables XVI and XVII show the results of the canonical analysis for the auto group and the bus group respectively. Canonical correlations are significant, and there are two significant roots for each group. A comparison of the two groups on their socioeconomic-behavior interdependence indicates some important differences. First, there is a stronger relationship between socioeconomic structure and behavior among the bus riding group than the car driving group (R_c = .91 vs R_c = .71) on the first canonical variates. This implies that bus riders have the type of socioeconomic constraints which make them dependent upon the attributes of the transportation system, while car drivers have more freedom to choose different combinations of service attributes and therefore are less dependent upon the attributes of the system. The correlation between the two sets of variables denotes a state of equilibrium in which decisions of car ownership, spatial location, and mode choice are interdependent. It supports the idea that those who drive cars, and therefore presumably of a high car ownership category, have a better choice of residence and job location than those who are more dependent upon the transportation services. It also implies that control policies will have a smaller locational effect on

Table XVI

CANONICAL CORRELATION TEST FOR CAR DRIVER GROUP

FIRST CANONICAL VARIATE: $R_c = .71$

VARIABLES OF SET 1	COEFFICIENTS (α)	VARIABLES OF SET 2	COEFFICIENTS (γ)
X_1(AGE)	.0214	X_8(TTO)	-.0543
X_2(OCC)	.0065	X_9(TFRM)	-.1007
X_3(CNEC)	.0758	X_{10}(OTT)	.0367
X_4(COWN)	-.0363	X_{11}(OPE)	1.6829
X_5(INC)	.9880	X_{12}(E/INC)	-1.7666
X_6(CARA)	.1617	X_{13}(FREQ)	.0063

χ^2 TEST FOR SIGNIFICANCE OF ROOTS

ROOT	R_c	λ_i	Λ	χ^2	d.f.	p
1	0.7149	0.5041	0.4734	925.88	36	<.001
2	0.1686	0.0256	0.9638	45.61	25	<.01
3	0.0873	0.0076	0.9893	13.35	16	n.s.

SECOND CANONICAL VARIATE: $R_c = .17$

VARIABLES OF SET 1	COEFFICIENTS (α)	VARIABLES OF SET 2	COEFFICIENTS (γ)
X_1(AGE)	-.5591	X_8(TTO)	-.1770
X_2(OCC)	-.2481	X_9(TFRM)	.2499
X_3(CNEC)	-.4512	X_{10}(OTT)	-.1206
X_4(COWN)	-.5526	X_{11}(OPE)	.0835
X_5(INC)	.1893	X_{12}(E/INC)	.1893
X_6(CARA)	-1.2391	X_{13}(FREQ)	.9740

Table XVII

CANONICAL CORRELATION TEST FOR BUS GROUP

FIRST CANONICAL VARIATE: R_c = .91

VARIABLES OF SET 1	COEFFICIENTS (α)	VARIABLES OF SET 2	COEFFICIENTS (γ)
X_1(AGE)	.0933	X_8 (TTO)	.0168
X_2(OCC)	-.0009	X_9 (TFRM)	-.0344
X_3(CNEC)	-.0000	X_{10}(OTT)	.0184
X_4(COWN)	-.0442	X_{11}(OPE)	.2974
X_5(INC)	.9500	X_{12}(E/INC)	-1.0485
X_6(CARA)	.0341	X_{13}(FREQ)	.0200

χ^2 TEST FOR SIGNIFICANCE OF ROOTS

ROOT	R_c	λ_i	Λ	χ^2	d.f.	p
1	0.9109	0.8299	0.1275	1970.0	36	<.001
2	0.4865	0.2372	0.7480	278.0	25	<.001
3	0.1264	0.0159	0.9800	19.3	16	n.s.

SECOND CANONICAL VARIATE: R_c = .49

VARIABLES OF SET 1	COEFFICIENTS (α)	VARIABLES OF SET 2	COEFFICIENTS (γ)
X_1(AGE)	.0892	X_8 (TTO)	.0083
X_2(OCC)	.0279	X_9 (TFRM)	-.0662
X_3(CNEC)	-.0000	X_{10}(OTT)	-.0998
X_4(COWN)	-1.8093	X_{11}(OPE)	-1.2693
X_5(INC)	.3940	X_{12}(E/INC)	.0762
X_6(CARA)	-2.1340	X_{13}(FREQ)	.9828

this group than on the group who currently use transit. That is, if the disutility of travel becomes unacceptable to this group they may tend to change job or home location to relieve the situation rather than adjust to a controlled change in the existing system.

Secondly, in both groups income and system cost factors are the prime components describing the interrelationship of socioeconomic structure and behavior. It is evident however that parking charges (OPE for car drivers) have much more influence relative to the other system components for the car drivers than fares do for transit passengers (OPE for transit group). Thus, high incomes are associated with high out-of-pocket expenses for both groups but for transit riders this is more or less fixed, modifying its effect. Income and cost modified by the ability to pay (OPE/INC) shows a high interdependence in both groups. However, the evidence is weak because of the substantial intercorrelation between income and out-of-pocket expenses divided by income for the transit group ($r = -0.26$ for car drivers, and $r = -0.86$ for bus passengers) (see Table XVIII).

While the first canonical variate shows interdependence of income and cost, the second canonical variate brings out the positive relationships between the other socioeconomic characteristics and bus frequency. For both groups car availability and bus frequency are related. This can be explained

Table XVIII

MATRIX OF SIMPLE INTERCORRELATIONS OF SOCIOECONOMIC AND BEHAVIOR VARIABLES FOR CAR GROUP AND TRANSIT GROUP

BUS GROUP	CAR GROUP X_1	X_2	X_3	X_4	X_5	X_6	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
X_1		*	*	*	.25	*	*	*	*	*	*	*
X_2	*		*	*	-.43	*	*	*	*	*	*	*
X_3	*	*		*	.21	*	*	*	*	*	*	*
X_4	*	*	*		.33	-.91	*	*	*	*	*	*
X_5	.30	-.59	*	*		*	*	*	*	*	-.26	*
X_6	*	*	*	-.86	.27		*	*	*	*	-.23	*
X_8	*	*	*	*	*	*		*	*	*	*	*
X_9	*	*	*	*	*	*	*		*	*	*	*
X_{10}	*	*	*	*	*	*	*	*		*	*	*
X_{11}	*	*	*	*	*	*	*	*	.35		.84	*
X_{12}	-.34	.50	*	*	-.86	-.26	*	*	*	.32		*
X_{13}	*	*	*	*	*	*	*	*	.23	.64	*	

*$r < .20$

through the car ownership factor since low frequencies would precipitate higher car ownership, which is brought out by a high intercorrelation of car ownership with car availability ($r = -0.91$ for car group and $r = -.86$ for the bus group).

The relatively close link between socioeconomic characteristics and system performance for transit riders has important ramifications for CBD parking policies. If too restrictive pricing or locational planning is imposed it could have the effect of decentralizing automobile oriented activities. If parking costs are taken as a business overhead, either directly or in the form of the wage rate some firms may find it economical to decentralize if the dislocation does not bring other diseconomies. The fact that fewer diseconomies would accrue to car drivers, since they are less dependent on the system, would tend to reinforce decentralization of industries which had a proportionately large number of automobile commuting employees. These may be the fringe industrial and warehousing firms which employ a large number of craftsmen and labourers, a typical car oriented group.

The analysis also appears to support a reciprocal relationship between car ownership and bus service. With the high car ownership rate of the study area the effect is probably related to the multiple commuter households of the West Vancouver apartment complex. The existence of a good bus service would doubtless delay a number of non-family households

(single people living communally) from the purchase of their first car, or the purchase of a second car.

CLASSIFICATION OF MODAL GROUPS BY COMBINED FACTORS

The research question posed is: can a combination of socioeconomic variables and behavioral variables serve to define the classification of the users of the corridor system into a group which drive cars and a group which takes the bus to work, and if so, what is the relative influence of behavioral variables to socioeconomic ones?

Multiple discriminant analysis is used to test the validity of the *a priori* classification of the two client groups and to assess the relevant dimensions of the classificatory criteria. A linear function of that set of variables which define the individual socioeconomic characteristics and behavior profiles is found which best discriminates between the client groups under study. The coefficients of the resultant function determine the degree to which their associated variables adds to the discrimination between the client groups.

Some explanation of multiple discriminant analysis, its assumptions, and how it is used in the present case is in order. (Unfortunately the literature of this technique is rather widely scattered and fragmentary, with few transportation or planning applications. Therefore a brief outline of the technique is considered relevant).

An Outline of Multiple Discriminant Analysis

Discriminant analysis is a statistical criterion for the classification of objects or persons based on measurement of the dimensions or characteristics of the objects or persons to be classified. It was first developed by Fisher[8] to classify anthropological findings. The theory has been extended and further documented by Rao[9] Kendall,[10] Anderson,[11] Rulon *et al*[12] and Hope.[13] Cooley and Lohnes[14] have also presented the technique with computational procedures.

The technique is meant to answer the question: given observations on variables which represent individual measurements (characteristics and scores etc.), to what group is that individual most likely to be a member. Like multiple linear regression analysis discriminant analysis seeks to find the linear function which in some way describes the "best fit" with reference to multiple observations. The line of "best fit" may also reduce the dimensions of the problem, seeking to describe in fewer dimensions the essence of the relationship.

Discriminant analysis starts with *a priori* clusters which are either perceived to be natural or defined theoretically, and finds that characteristic which best discriminates between the classes. Assumptions of the technique are that the classes are mutually exclusive and exhaustive, that the distribution of the variates are multivariate normal, and that

the variance of each class is homogeneous, making the dispersion matrices equal for each class.*

Application of discriminant analysis to the problem of mode choice is by the so-called discrimination-classification model. The discrimination model is designed to test hypotheses about mode group membership. It is a procedure to select an optimal boundary which divides the test space, defined by a set of variables, into two regions. Classification is a procedure for deciding which mode a new individual is likely to choose. It is based on the assignment of a new individual to a particular mode based on a measure of the linear relationship among the attributes of the modal system.

An Outline of the Discriminant Model

Consider two modal groups with p measurements on each individual describing a vector X, consisting of observations on the system attributes of $X_1, X_2, X_3, \ldots, X_p$. The observation X's have two types of variances, (1) that between each group and (2) that within each group. The criterion for discrimination is that the ratio of the square of the differences of means of the observations on the two mode groups to the common variance of each mode group (pooled within group variance) is maximized. That is to maximize:

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*This is the assumption of homoscedasticity.

$$G = \frac{[\sum_{i}^{p} v_i(\bar{X}_{i1} - \bar{X}_{i2})]^2}{\sum_{i}^{p}\sum_{j}^{p} v_i v_j D_{ij}} \qquad \text{where,}$$

p = number of variates,

v = weights or coefficients to be determined,

D = pooled within group variance-covariance, or deviation, matrix, and

$\bar{X}_1, \bar{X}_2$ = means of the variates for the two modal groups.

Differentiating with respect to v_i and making $\frac{\partial G}{\partial v_i} = 0$, we have:

$$\sum_{j}^{p} v_j D_{ij} = \frac{\sum_{i}^{p}\sum_{j}^{p} v_i v_j D_{ij}}{\sum_{i}^{p} v_i(\bar{X}_{i1} - \bar{X}_{i2})} (\bar{X}_{i1} - \bar{X}_{i2})$$

where $v_j \alpha = \sum_{i}^{p} D^{ij*}(\bar{X}_{i1} - \bar{X}_{i2})$, or in vector notation,

$$v = D^{-1}(\bar{X}_1 - \bar{X}_2) \quad \text{when a suitable} \qquad (7)$$

constant is selected. The vector of weights v are coefficients which locate the means of the groups from a new, transformed axis system on the criterion that the new axis system is rotated by an angle θ from the test axis system in such a way that the distance between the means when projected onto the new axis is maximized.**

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*D^{ij} is the inverse of D_{ij}.

**See appendix G for a geometric description of the axis rotation and the vector v.

The generalization of this two group case to more than two groups is made by replacing the vector of the differences of means of the two groups by the vector of the differences between the grand mean (i.e. the mean for all groups combined) and the vector of group means, each taken in turn and weighted by group size. This is normally expressed in matrix algebra to facilitate the computational aspects of the technique. Two pth order matrices define the discriminant criterion: an A matrix (the between group sum of squares and cross products matrix whose elements comprise the cross products of deviation of the group mean from the grand mean), and the W or error matrix whose elements are the within group dispersions, and is a pooled estimate of individual observations from the group mean. A third matrix, T, is the total sum of squares and cross products of deviation from the grand means.* Thus the A matrix is calculated from A = T - W, and the discriminant criterion is to maximize A/W. The discriminant functions are associated with the

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*The elements of A, W, and T are defined as follows:

$$a_{ij} = \sum_{k=1}^{g} N_g(\bar{X}_{ik} - \bar{X}_i)(\bar{X}_{jk} - \bar{X}_j),$$

$$w_{ij} = \sum_{k=1}^{g} \sum_{n=1}^{Ng} (X_{ikn} - \bar{X}_{ik})(X_{jkn} - \bar{X}_{jk}),$$

$$t_{ij} = \sum_{n=1}^{N} (X_{in} - \bar{X}_i)(X_{jn} - \bar{X}_j), \text{ where}$$

g = number of groups

Ng = number of subjects in group g (cont'd)

determinantal equation: $| W^{-1}A - \lambda I | = 0.$ (8)

The scalar $W^{-1}A$ is maximized when the original test axies is rotated through the angle θ so that the matrix equation is

$$[W^{-1}A - \lambda I]v = 0, \qquad (9)$$

expressing the weights v for maximum discrimination for each λ possible. The criterion for discrimination then becomes:

$$\lambda_i = \frac{v_i' A v_i}{v_i' W v_i}, \text{ in which} \qquad (10)$$

v_i is the transformation matrix of the direction cosines of θ. That is, v, is a vector whose elements represent the angles between the original (or test axis) for each variate and the discriminator. The discriminant problem is to find the vector of weights v_i associated with the maximum value of λ_i for any root. Taking the partial derivative of (10) and setting it equal to zero gives:

N = total number of subjects, and i and j run from 1 to p, where p = number of variables,

$\bar{X}_{ik}, \bar{X}_{jk}$ = means of variate i and j for group k,

$\bar{X}_i, \bar{X}_j$ = mean of variate i and j for all groups combined,

X_{ikn}, X_{jkn} = n^{th} score value on variate i (j) for group k, and

X_{in}, X_{jn} = n^{th} score value on variate i(j).

$$\frac{\partial \lambda_i}{\partial v_i} = \frac{2[(v_i W v_i) A v_i - (v_i' A v_i) W v_i]}{(v_i' W v_i)^2} = 0$$

which simplifies to

$$[W^{-1}A - \lambda_i I] v_i = 0. \qquad (12)$$

The relative size of λ's indicate the extent to which the associated discriminant function distinguishes between the groups, and the vector v_i is the vector of coefficients which maximizes the difference between groups. As many vectors as necessary to account for successive between group variance are extracted up to the number of variates or one less than the number of groups.

This form of the analysis is useful to test hypotheses about intergroup differences in the measured variates.*

---

*Group difference is defined by a series of significance tests. Wilk's lambda criterion is used to estimate the discriminating power of the test and is derived as a function of the roots of $W^{-1}A$ (i.e. λ_i) as follows:

$$\Lambda = \prod_{i=1}^{r} \left[\frac{1}{1+\lambda_i}\right], \qquad r = \text{number of roots.}$$

This is converted to the familiar F-test by the following transformation:[14]

$$F^{2r}_{ms+2\lambda} = \left(\frac{1 - \Lambda^{1/s}}{\Lambda^{1/s}}\right)\left(\frac{ms + 2\lambda}{2r}\right), \quad \text{in which}$$

$$s = \sqrt{(p^2q^2 - 4)/(p^2 + q^2 - 5)}, \quad p = \text{number of variates,}$$

$$m = n - (p+q+1)/2, \quad q = g-1, \quad g = \text{number of groups}$$

$$\lambda = -(pq-2)/4, \quad n = N-1$$

$$r = pq/2.$$

(cont'd)

If the between group variance is significantly greater than the pooled within group variances as inferred from a generalized variance ratio, or F-test, we conclude that there is some set of variates on which these two groups can be considered different. The vector of coefficients, referred to as eigenvectors define the relevant dimensions (in terms of the variables chosen to represent the differences) which maximized this difference. The eigenvector when scaled by multiplying each element with the square root of the diagonal elements of the W matrix gives the relative contributions of each of the variates to the discrimination.

An alternate test of Λ in terms of χ^2 can be used:

$$\chi^2 = -[N - .5(p+q+1)] \ln \Lambda' \text{ where}$$

$$\Lambda' = \prod_{i=r+1}^{g} (1 - \lambda_i)$$

A statistic, Mahalanobis D^2, is used to test the significance of group separation in the reduced space. The statistic is to test the null hypothesis that the difference in means are zero. Rao[15] and King[16] give:

$$D^2_{ab} = \sum_{i=1}^{p} \sum_{j=1}^{p} s^{ij} d_i d_j$$

where $d_i = \bar{X}_{ia} - \bar{X}_{ib}$, the difference in the two group centroids on variate i,

$d_j = \bar{X}_{ja} - \bar{X}_{jb}$, for $(i,j=1,2,\ldots,p)$,

$s^{ij} = (s_{ij})^{-1}$, $s_{ij} = (S^{(a)}_{ij} + S^{(b)}_{ij})/(N_a + N_b - 2)$.

D^2 can also be converted to the F-ratio by the following:

$$F = \frac{N_a N_b - p - 1}{p} \cdot \frac{N_a N_b}{(N_a N_b)(N_a N_b - 2)} \cdot D^2_{ab},$$

with p and $(N_a N_b - p - 1)$ degrees of freedom.

The familiar squared multiple correlation coefficient can also be found where: $R^2 = \frac{\lambda}{1+\lambda}$.

When the test axis is rotated through the angle θ the original test variates are projected perpendicularly to the new axis, and the original test values are transformed to so-called discriminant "scores" with one less dimension than the original values. For the case of two modes and two variates the two dimensional space is reduced to a straight line and the discriminant score is the location of an individual along the line. This is shown in the geometrical interpretation of the two group-two variate case as Figure 6, where A and B are the "swarm" of observations on the variates X_1 and X_2 and $\bar{X}_A$ and $\bar{X}_B$ are the group means.

The original test swarm describe an equi-probability ellipse in the test space which reduces to a circle, as projected, when the axis is rotated to maximize the between to within group variance. The line joining the projected means, or parallel to it is the canonical variate, and for the two group case, is synonomous with the discriminator. Rulon has shown that the line passing through the intersection of any two concentric ellipses minimizes the overlap of the two swarms on the discriminator, which is perpendicular to this line. If there are more than two groups there are (g-1) or p canonical variates, and the first canonical variate minimizes the sum of the squared deviations from the projected group means.

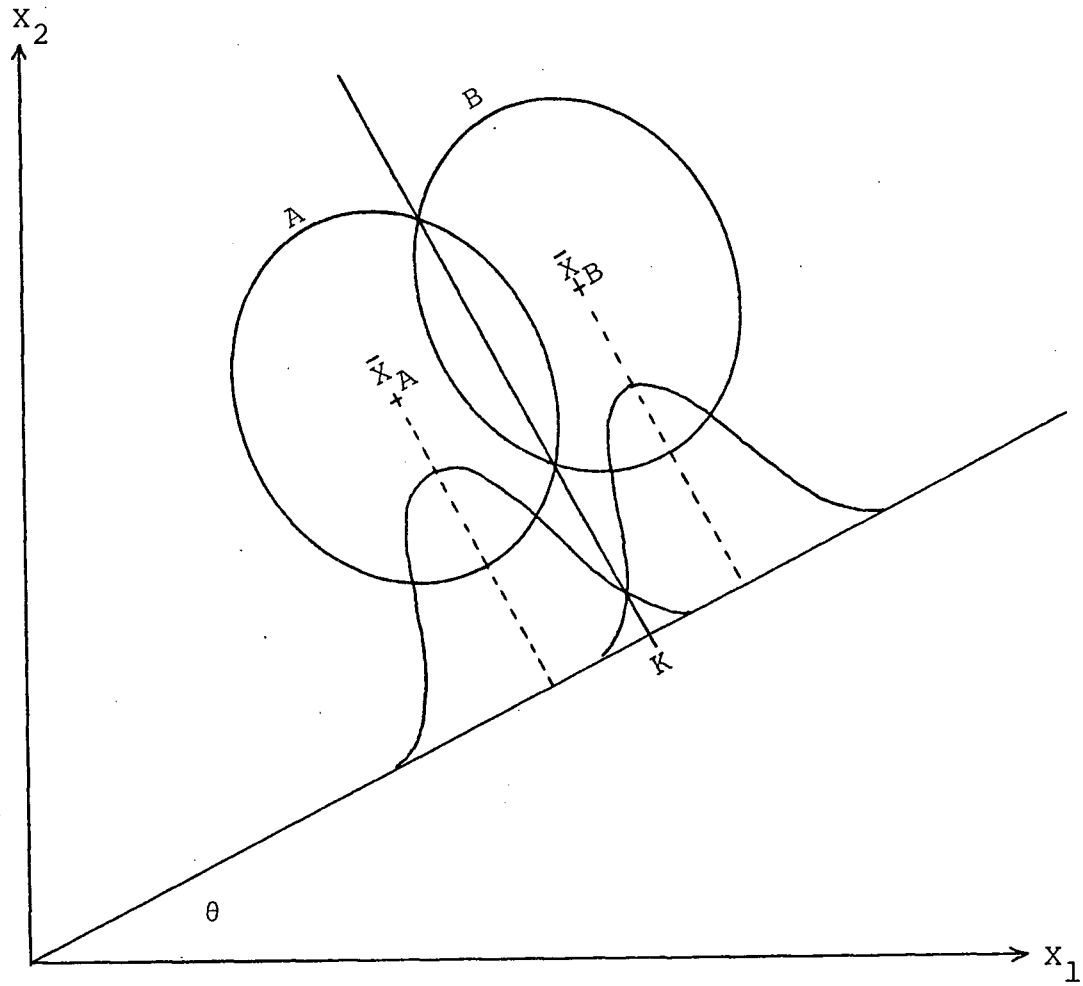

FIGURE 6

ROTATION OF AXIS TO MAXIMIZE BETWEEN TO WITHIN GROUP VARIANCE FOR OBSERVATION CLUSTERS A AND B - GEOMETRIC ILLUSTRATION OF TWO GROUP TWO VARIATE CASE

An Outline of the Classification Model

Besides testing hypotheses about intergroup distances[17] and relevant dimensions of explanatory variables, the technique is used as a mathematical model to assign new individuals to some class based on a set of explanatory variables which in some way characterize the person or subject being classified. The applications of the technique to modal split through the work of Warner and Quarmby have emphasized discriminant analysis as an assignment rule. Discriminant functions are used in a predictive model of mode choice in which the explanatory variables are used to predict the probability of choice. It is convenient to derive linear discriminant functions for each group in the analysis, rather than a single discriminator which serves to separate the groups as above.

The linear discriminant function for a set of observations on X_i, $i=1,2,\ldots,p$ takes the form:

$$v_1X_1 + v_2X_2 + v_3X_3 + \ldots + v_pX_p$$

or

$$\sum_i^p v_iX_i$$

in which v is the vector of weights derived by (7). By substitution of (7) the linear discriminant function becomes

$$\sum_i^p \sum_j^p D^{ij}(\bar{X}_{i1} - \bar{X}_{i2})X_i \ ,$$

or in vector notation $X'D^{-1}(\bar{X}_1 - \bar{X}_2)$. The discriminant function can be evaluated for any individual on his vector of observations, X, and a discriminant "score" determined. The discriminant rule describes a boundary, and if an individual's score is on one side of the boundary he is likely, with some probability, to be a member of one mode group, otherwise he is thought to be a member of the other mode. Prediction thus involves calculating a value for each commuter and assigning him some probability of choosing one mode over the other on the basis of this value.

Consider two modal populations normally distributed, one associated with one set of explanatory variables, and the second with another set. The total test space may be thus divided into two regions in which one region (say R_1) consists of that area of the test space where the density of observations for modal population one is a maximum, and all other observations fall into another region (say R_2). Let q be the a priori probability that an observation is from mode population 1 and (1-q) the a priori probability that an observation is from mode population 2. If an individual is drawn from a mixed population which contains the probability ratio of q/(1-q) of modal population one to modal population two, the probability of wrongly classifying an individual selected at random is q + (1-q)* and the rule which minimizes the probability of

*That is, if the chance of wrongly classifying an individual of the first group is equal to the chance of wrongly classifying an individual of the second group. If the chances of wrongly classifying individuals of their respective groups are α_1 and α_2, this expression becomes $\alpha_1 q + \alpha_2(1-q)$.

wrongly classifying the individual is the relevant classificatory criterion.[18]

If $f_1(X)$ and $f_2(X)$ are the probability densities of mode population one and two respectively where X is the vector of explanatory variables, the two regions of the test space are those in which:

$$R_1 \text{ is defined as: } q\, f_1 \geq (1-q)\, f_2$$

$$R_2 \text{ is defined as: } (1-q)\, f_2 \geq q\, f_1$$

The discriminant rule used to classify an individual is as follows. If

$$f_1(X)/f_2(X) > k$$

classify the individual as belonging to region 1; otherwise classify him as belonging to region 2. The constant, k, therefore defines a boundary, on one side of which the individual belongs to one mode and the other side of which he belongs to an alternative mode. This is a binary choice problem and assumes that only two modes are considered.

The discriminant rule classifies an individual by the method of maximum likelihood. Since $f_1(X)$ and $f_2(X)$ are assumed joint-normal the ratio

$$\frac{f_1(X)}{f_2(X)} = \frac{\frac{1}{\sqrt{2\pi}}\, e^{-[1/2(X-\bar{X}_1)'D^{-1}(X-\bar{X}_1)]}}{\frac{1}{\sqrt{2\pi}}\, e^{-(1/2(X-\bar{X}_2)'D^{-1}(X-\bar{X}_2)]}} ,$$

and

$$\frac{\ln f_1(x)}{\ln f_2(x)} = -1/2\ [X'D^{-1}X - X'D^{-1}\bar{X}_1 - \bar{X}_1'D^{-1}X + \bar{X}_1'D^{-1}\bar{X}_1 - X'D^{-1}X + X'D^{-1}\bar{X}_2 + \bar{X}_2'D^{-1}X - \bar{X}_2'\ D^{-1}\bar{X}_2]$$

$$= X'D^{-1}(\bar{X}_1 - \bar{X}_2) - 1/2\ (\bar{X}_1 + \bar{X}_2)'D^{-1}(\bar{X}_1 - \bar{X}_2)$$

The discriminant rule will assign an individual to mode 1 if

$$\ln \frac{f_1(x)}{f_2(x)} > \ln k\ ,$$

or if $X'D^{-1}(\bar{X}_1 - \bar{X}_2) - 1/2(\bar{X}_1 + \bar{X}_2)'D^{-1}(\bar{X}_1 - \bar{X}_2) > \ln k;$

where $\bar{X}_1$ and $\bar{X}_2$ are the best estimates of the means of modal population one and two respectively, and D^{-1} is the inverse of the (assumed) common dispersion matrix of each of the mode populations. The second half of the above expression is a constant and the function can therefore be written

$$X'D^{-1}(\bar{X}_1 - \bar{X}_2) - a$$

A probability model can be developed to estimate the likelihood of an individual choosing any mode (say mode 1) of two alternatives, based on his discriminant score derived from valuing the discriminant function for both modal groups. Thus, the conditional probability that an observation at X is from mode 1 is

$$P(X) = \frac{qf_1(X)}{qf_1(X) + (1-q)f_2(X)}$$

By taking natural logarithms of both sides and combining constants into one constant, c, and using conventional notation for discriminant scores, z, it can be shown that:

$$P(X) = \frac{e^z}{1 + e^z}, \quad \text{in which}$$

$$z = X'D^{-1}(\bar{X}_1 - \bar{X}_2) - c$$

This relationship is an S-shaped logistic curve. The z-value for each individual can be found from the expression with the degree of discrimination dependent upon the range of z-values. The z-value dictates probabilities between 0 and 1, of an individual with that z-value of choosing each mode. The individual is then assigned to the mode which gives him the highest probability. Test of the model is defined by the number of misclassifications when known individuals are assigned to mode groups on the basis of their posterior probabilities. If the number of misclassifications are sufficiently small the model may be used as a predictive one.

Group Discrimination on Combined Variables

A version of the Cooley Lohnes computer program (DISCRIM),* modified by the author for data tape input and converted to FORTRAN IV, was used to test the *a priori* mode classification on the combined demand variables. Group means

*The program DISCRIM is documented in: William W. Cooley and Paul R. Lohnes, *Multivariate Procedures for the Behavioral Sciences*, John Wiley, New York: 1962, p.127. The author is indebted to Nirmala devi Cherukupalle for her card deck of the original program, as well as her program for the Mahalanobis D^2 test.

and standard deviations are shown on Table XIX. The absolute value of the means have little relevance since they are standardized, but the transformed means allow some insight into the difference between groups. For example, the necessity to have a car for work, car ownership, income, residential travel time, and out-of-pocket expenses are sufficiently different from the overall mean of zero, and with substantial difference between means, that one would expect these variables to be important in group separation. Moreover, the relative values of the means can be used to further support this hypothesis.

Table XX is a summary of the statistical tests of the discrimination hypothesis. Univariate F tests on the 13 variables show that all are significant at $p < .05$. All but CBD travel time are significant at $p < .001$. The result of the test of the null hypothesis of no discrimination produces a variance ratio F_{H2} of 504.69 and an extracted root significant at $p < .001$, as determined by the χ^2 test. Table XXI gives the separation of the group centroids in the reduced (discriminant) space with a Mahalanobis D^2 of 1.99 resulting in an variance ratio (F) of 83.0, which is significant at $p < .001$. The R^2 statistic, or strength of discrimination has been shown, and may be interpreted in the same way as the coefficient of determination used in regression analysis.* The value of .750 denotes strong discrimination between the two modal groups.

*That is, the percent of variation in the data which is explained by the statistical test, and is numerically $\frac{\lambda}{1+\lambda}$.

Table XIX

GROUP MEANS AND STANDARD DEVIATIONS OF MODAL GROUPS FOR COMBINED SOCIOECONOMIC AND PERFORMANCE VARIABLES

(STANDARD SCORES i.e. $\bar{X} = 0.0$ $S = 1.0$)

VARIABLE	CAR DRIVERS	BUS PASSENGERS
	GROUP MEANS	
X_1 (AGE)	.147	-.190
X_2 (OCC)	-.230	.300
X_3 (CNEC)	.720	-.930
X_4 (COWN)	.356	-.458
X_5 (INC)	.415	-.534
X_6 (CARA)	.336	-.421
X_7 (HREND)	-.144	.190
X_8 (TTO)	-.601	.773
X_9 (TFRM)	-.047	.060
X_{10} (OTT)	-.294	.378
X_{11} (OPE)	-.241	.310
X_{12} (E/INC)	-.417	.540
X_{13} (FREQ)	.094	-.121
	GROUP STANDARD DEVIATIONS	
X_1 (AGE)	1.022	1.217
X_2 (OCC)	.883	1.101
X_3 (CNEC)	.826	.016
X_4 (COWN)	1.153	.947
X_5 (INC)	.916	.960
X_6 (CARA)	.733	.990
X_7 (HREND)	1.032	.900
X_8 (TTO)	.681	.910
X_9 (TFRM)	1.182	.777
X_{10} (OTT)	.970	.909
X_{11} (OPE)	1.388	.338
X_{12} (E/INC)	.852	.915
X_{13} (FREQ)	1.148	.758

Table XX

STATISTICAL TESTS OF SIGNIFICANCE FOR DISCRIMINATION OF MODES ON COMBINED SOCIOECONOMIC AND PERFORMANCE VARIABLES

UNIVARIATE F-TEST

VARIABLE	F-RATIO	p
X_1 (AGE)	49.87	<.001
X_2 (OCC)	155.18	<.001
X_3 (CNEC)	3840.37	<.001
X_4 (COWN)	315.99	<.001
X_5 (INC)	559.30	<.001
X_6 (CARA)	426.95	<.001
X_7 (HREND)	63.70	<.001
X_8 (TTO)	1648.84	<.001
X_9 (TFRM)	5.91	<.05
X_{10} (OTT)	275.78	<.001
X_{11} (OPE)	145.83	<.001
X_{12} (E/INC)	642.88	<.001
X_{13} (FREQ)	25.50	<.001

TEST OF DISCRIMINATORS

$\Lambda = .2509$ $\quad F_{H2} = 504.69$

$F_1 = 2r - 13$ $\quad F_p < .001$

$F_2 = ms + 2\lambda = 2197$ $\quad R^2 = .750$

TEST OF ROOT:

Number of Roots	Root (λ_i)	% Root is of Trace	No. of Roots Summed	Sum of Roots	d.f.	χ^2	χ^2_p
1	2.9863	100.0	13	2.9863	13	13,200	<.001

Table XXI

CENTROIDS OF MODAL GROUPS IN REDUCED SPACE AND SIGNIFICANCE TEST OF GROUP SEPARATION ON COMBINED SOCIOECONOMIC AND PERFORMANCE VARIABLES

GROUP	CENTROID
CAR DRIVERS	0.9918
BUS PASSENGERS	-1.2781

TEST OF GROUP SEPARATION

$$D^2 = 1.9926$$

$$F^{13}_{2197} = 83.00$$

$$F_p < .001$$

Interpretation of Discriminant Loading

The interpretation of the test is by the vector loadings or the values of the v coefficients. The coefficients are scaled in the test to give the relative value of the loading for each attribute. The vector loadings show a high degree of dominance of socioeconomic factors for the auto driver group, and a dominance of behavioral ones for the transit group (Table XXII). The intensity of the need for a car at work is the major contributor to its use for the journey to work as well as household car ownership and income of the commuter. These findings generally support the literature, although

Table XXII

DISCRIMINATOR VECTOR LOADINGS ON COMBINED SOCIOECONOMIC AND PERFORMANCE VARIABLES

VARIABLE	SCALED VECTOR LOADING*
X_1(AGE)	0.34
X_2(OCC)	-1.31
X_3(CNEC)	21.53
X_4(COWN)	6.29
X_5(INC)	3.75
X_6(CARA)	-4.76
X_7(HREND)	-3.62
X_8(TTO)	-18.16
X_9(TFRM)	6.23
X_{10}(OTT)	-5.25
X_{11}(OPE)	1.63
X_{12}(E/INC)	-6.43
X_{13}(FREQ)	6.86

*The discriminator vector, v, is scaled by multiplying it by the square root of the diagonal elements of the W matrix. Thus, the relative contribution of each variable to the discriminator is shown.

the relatively small contribution of income is surprising. This may be due to a relative homogeneity of income in the study area. But it also may show the relatively small effect of income on choice due to system factors. Zupan in his study of the New York region concluded that income was a factor in

whether the mode choice decision was primarily based on environmental factors ("variables that measure the characteristics of the home and work locations") or on those factors which measured the characteristics of the transportation system. Low income groups were more susceptible to environmental factors and high income groups to transportation system factors.[19] It may be that the effect of income here is dissipated throughout the behavioral factors by its correlation with environmental factors, since income is highly correlated with car availability (r = .93) and also with the out-of-pocket expenses to income ratio (r = .64) (Table XXIII). Income is seen to be much more important when its effect alone is considered as shown by its univariate F ratio, a fact which also infers that when all variables are considered as a system the income effect is distributed through other variables.

Behavioral factors associated with the car driver group include CBD travel time and bus frequency in the residential zone. The relatively large contribution of CBD travel time is surprising since univariate measures do not show it to be important, nor is it intercorrelated with other variables. It does show that when the combined system is considered CBD travel time is a factor in classifying auto drivers separately from transit riders. The effect is probably due to the very short walking distances of about 17 percent of all car drivers (see Table XIV). The contribution of bus frequency is as expected since the frequency of buses available to auto drivers is one

Table XXIII

CORRELATION MATRIX OF COMBINED SOCIOECONOMIC AND PERFORMANCE VARIABLES

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
X_1	1.00												
X_2	*	1.00											
X_3	*	-.25	1.00										
X_4	*	*	.35	1.00									
X_5	.31	-.55	.44	.24	1.00								
X_6	.32	-.54	.40	*	.93	1.00							
X_7	*	*	*	*	*	*	1.00						
X_8	*	*	-.52	-.23	-.33	-.28	*	1.00					
X_9	*	*	*	*	*	*	*	*	1.00				
X_{10}	*	*	-.27	*	*	*	.38	.30	*	1.00			
X_{11}	*	*	*	*	*	*	*	*	*	*	1.00		
X_{12}	-.26	.38	-.41	*	-.64	-.70	*	.34	*	.24	.67	1.00	
X_{13}	*	*	*	*	*	*	*	*	*	.23	*	*	1.0

* = r < .20

minute less than that to bus passengers, with means of 17.6 and 16.6 minutes respectively. The major contribution to this difference occurs in the remote western part of West Vancouver where auto use is high relative to transit use and bus frequencies are very low.

Behavioral factors mainly contribute to the separation of transit riders. Residential travel time is the primary one, and represents the very great difference between the almost negligible time to get to a car to start the journey compared to the time distance to the bus stop. The residential travel time does not include waiting time at the bus stop nor transfer time which are considered by the author to be different in concept from walking time to the bus stop, and are uniquely a part of transit use with no comparative disutilities in the car mode. If these were included the effect of residential travel time would be more prominant. Overall travel time is also an important consideration in separating car drivers from transit passengers, and shows the effect of the greater travel times for the latter group. The ratio of expenses to income also contributes heavily to the separation of the transit group. This might be expected where transit passengers, even those with a choice as defined here by having come from a household with at least one car, are relatively sensitive to cost factors, especially when it is related to their ability to pay. Existing parking charges show only small effects in separating

auto drivers, probably because of the comparatively low rates in Vancouver, and the number of auto drivers who enjoy free parking.

The time of arrival at the destination has some influence for transit riders as hypothesized. The availability of a car also contributes to separation of the transit group. However, this was found to be highly correlated with income ($r = 0.91$).

MODE CHOICE AS A FUNCTION OF POLICY VARIABLES

Loadings on Policy Discriminator

Only those variables amenable to parking policy were tested to determine the effects separate from structural influences, because the effects of policy are central to this investigation and also because of substantial intercorrelations between some variables within the socioeconomic set of variables. For example, income and car availability are highly intercorrelated with smaller but substantial intercorrelation of occupation and income and occupation and car availability, and between car necessary for work and these variables. Moreover, very substantial intercorrelation exists between income and car availability and cost factors and between car necessary, income and residential travel time (Table XXIII).

Group means of the variables show substantial differences in residential travel time, although bus passengers

have a mean walking distance of less than 3 minutes (Table XXIV.

Table XXIV

GROUP MEANS AND STANDARD DEVIATIONS FOR MODAL GROUPS ON POLICY VARIABLES

(RAW SCORES)

VARIABLE	CAR DRIVERS	BUS PASSENGERS
X_8 (TTO)	1.332	2.760
X_9 (TFRM)	3.058	3.196
X_{10} (OTT)	31.278	37.399
X_{11} (OPE)	.488	.622
X_{12} (E/INC)	.173	.369
X_{13} (FREQ)	17.588	16.634
	GROUP STANDARD DEVIATIONS	
X_8 (TTO)	.707	.946
X_9 (TFRM)	1.534	1.009
X_{10} (OTT)	8.832	8.284
X_{11} (OPE)	.436	.106
X_{12} (E/INC)	.175	.188
X_{13} (FREQ)	5.079	3.354

Approximately 6 minutes separate the bus group from the car group. About one minute in bus frequency separates the two groups. The relatively small spread between these means, as a percentage of the total travel time and frequency indicates that if these variables are critically important in the choice of mode, relatively small decreases are needed so that the service by bus is equal to that by car. This has implications

for mode shift to be discussed later.

The significance tests in Table XXV show that discrimination is well defined, with an R^2 of .530. However, a redistribution of the contributory factors takes place when the structural effects are removed. The vector loadings emphasize the contribution of behavioral variables for the transit group, ranking 1,2,3 in order of magnitude (Table XXVI). The new loadings dramatically re-enforce the effects of the ratio of expenses to income and overall travel time, as well as the residential travel time influence. Likewise, zonal bus frequencies, CBD travel time and parking charge increase in importance. The largest increases in influence by eliminating the structural effects is in the cost factors, parking charges for auto drivers, fares, and the expenses over income proxy. This result appears to infer that parking charge and transit fare changes would be more effective for a homogeneous population, while these factors decrease in overall importance when the variability of structural characteristics is considered. This means that these effects will have more impact on some socio-economic groups than others.

Modal Group Assignment by Policy Discriminator

To predict mode split, and to simulate the results on mode split of changes in policy it is necessary to determine the validity of the policy discriminator in prediction. A stepwise discriminant test was performed by a UBC revised edition

Table XXV

STATISTICAL TESTS OF SIGNIFICANCE FOR DISCRIMINATION OF MODES ON SIX POLICY VARIABLES

UNIVARIATE F-TEST

VARIABLE	F-RATIO	p
X_8 (TTO)	1648.84	<.001
X_9 (TFRM)	5.91	<.05
X_{10} (OTT)	275.78	<.001
X_{11} (OPE)	145.83	<.001
X_{12} (E/INC)	642.88	<.001
X_{13} (FREQ)	25.50	<.001

TEST OF POLICY DISCRIMINATORS

$\Lambda = .46801$ $\quad F_{H2} = 417.55$

$F_1 = 2r - 6$ $\quad F_p < .001$

$F_2 = ms + 2\lambda = 2204$ $\quad R^2 = .530$

TEST OF ROOT

No. of Roots	Root λ_i	% Root is of Trace	No. of Roots Summed	Sum of Roots	d.f.	χ^2	χ^2_p
1	1.1367	100.0	6	1.1367	6	4950	<.001

Table XXVI

VECTOR LOADINGS ON POLICY DISCRIMINATOR

USING SIX VARIABLES

VARIABLE	SCALED VECTOR
X_8 (TTO)	-28.91
X_9 (TFRM)	7.43
X_{10} (OTT)	-11.42
X_{11} (OPE)	4.79
X_{12} (E/INC)	-17.67
X_{13} (FREQ)	10.32

of the BMD07M program. This program performs a multiple discriminant analysis in a stepwise manner in which at each step one variable is entered into the set of discriminating variables according to its F value. A variable is deleted if its F value become too low. The criterion set for entering and deleting a variable is $F_p < .05$.

The first run was made on all 6 variables included in the policy discriminator. The results showed all 6 accounted for significant variation in the separation of the two groups. However, some correlation existed between the out-of-pocket expense variable and that measuring out-of-pocket expenses divided by income (i.e. X_{11} with X_{12}). Therefore out-of-pocket expense variable (X_{11}) was removed since it contributes very little to the separation of the two groups. The resulting

discriminant functions for the car group and bus group respectively which were used to calculate the discriminant scores for each case are:

$$z_c = -14.675 + 1.132X_8 + 1.695X_9 + 0.284X_{10} + 0.998X_{12} + 0.773X_{13}$$

$$z_b = -20.009 + 3.208X_8 + 1.431X_9 + 0.351X_{10} + 6.732X_{12} + 0.659X_{13}$$

These functions used to value each observation at X_{ij} resulted in a z score for each individual, and this score was used to determine the posterior probability of group membership by means of the assignment model outlined above. The posterior assignment of all individual resulted in a 12.6 percent misclassification (Table XXVII). This is a measure of the effectiveness of the model to classify individual into modes based on the policy discriminator. Another measure of the goodness of overall fit of the discriminator is the canonical correlation, R_c, in the reduced space. A first canonical variate, synonomous with the discriminator in the two group case, is the line of closest fit to the means of the groups on the variates in the reduced space, and is fitted in such a way that the sum of deviations of the group means from the line is a minimum. The canonical correlation coefficient is a measure of the goodness of fit of the line and in this case $R_c = .73$. The "fit" can also be given by the more familiar square of the multiple correlation coefficient, R^2, and in this case resulted in $R^2 = .535$.

Table XXVII

PREDICTED CLASSIFICATION VERSUS ACTUAL MODE USED

FOR FIVE SIGNIFICANT POLICY VARIABLES*

		NUMBER PREDICTED TO BE IN GROUP			MISCLASSI-FICATIONS
		CAR	BUS	TOTAL	
ACTUAL NUMBER IN GROUP	CAR	1134	110	1244	110
	BUS	168	799	967	168
				2211	278*

*Percent misses 278/2211 = 12.6%

TEST OF SIGNIFICANCE OF FIVE POLICY VARIABLES

$F_{H2} = 496.85$

$F_p < .001$

$R_c = .73$

$R^2 = .535$

COMPARATIVE ANALYSIS OF RESULTS

Comparison with Similar Studies

There are three known studies similar to this analysis which uses the discrimination-classification technique on similar instrumental variables.* These are, Quarmby, Warner

*A fourth analysis by McGillivary contains no comparable tests in the published version of his paper.

and Bock's investigations. Table XXVIII shows the variables tested for car versus transit samples in each study, the R^2, and posterior misclassifications compared with the present study.

Table XXVIII

COMPARISON OF RESULTS OF DISCRIMINANT-CLASSIFICATION ANALYSIS OF MODE CHOICE FOR CAR AND TRANSIT SAMPLES WITH THREE PREVIOUS STUDIES

	VARIABLES TESTED	R^2	PERCENT POSTERIOR MISCLASSI-FICATION
QUARMBY (Sample Size = 542)	TRAVEL TIME DIFFERENCE EXCESS TIME DIFFERENCE COST DIFFERENCE	.523	23.6
WARNER (Sample Size - 931)	ln COST RATIOS ln TIME RATIOS CAR AVAILABILITY SEX	.167	38.0
BOCK (Sample Size - 470)	TIME DIFFERENCE COST DIFFERENCE CAR OWN. X TIME DIFF. INCOME X TIME DIFF. INCOME X COST DIFF.	.207*	30.9
BROWN (Sample Size - 2211)	RES. TRAVEL TIME CBD TRAVEL TIME TOTAL TRAVEL TIME OPE/INCOME BUS FREQUENCY	.535	12.6

*R^2 calculated by the author from Bock's published results of F ratio and D^2.

Quarmby's best results of several tests using variable ratios, differences and logs of ratios were for the difference measurement as reproduced here. He also tested several additional variables from those shown here including cost/income, use of car for work, ownership of car by firm, and a variable he named car demand ratio (number of drivers licences in household to number of cars). The extension of his three "difference" variables by these additional ones produced the same R^2 value.

Warner's comparable test using auto traffic and city mass transit (it is not clear whether subway trips are included in this category), using natural logarithms of time and cost ratios, car availability, and sex, produces a relatively small R^2, although it was significant beyond the .01 level. He attributes the relatively small value (in comparison with least squares problems) as resulting from individual data instead of aggregated averages and from the unsystematic influences in the nature of the problem.

Bock's results are between Quarmby's and Warner's using time and cost differences and including modifications of those by car ownership and income measures.

The results of the present study compares favourably with Quarmby's analysis (with which it is the most similar). The results produce a slightly better discrimination on the

canonical variate as well as fewer misclassification on the posterior assignment.

Two significant conclusions emerge from the comparison of these analyses. First, the present study differs from the others in that variables are measured in absolute terms with no reference to the alternative service levels. This infers that analysis can be accomplished without a direct measure of competitive services for each individual. This is important in terms of data collection, reducing the survey to measurements of actual travel behavior, without the necessity to measure objectively the alternative service (a difficult task since the perceived alternatives may not be obvious) or to determine them subjectively (an equally difficult problem). Secondly, the results tend to point to the validity of considering micro-level policy variables in the analysis. Quarmby has done this with his excess travel time differences (walk and waiting times), and they have been further subdivided in the present analysis to residential walk time and CBD walk time. The justification for this rests on the fact that these are of importance separately since residential travel time is the major influence in mode choice behavior while CBD travel time has a minor influence. The separate influence of these variables have major implications for policy design.

PRINCIPAL FINDINGS

The analysis has demonstrated that each modal group can be conceived to occupy a unique socioeconomic space, which depends upon the type of transportation service available, and which in turn is dependent upon the service which exists. For the car group there is a strong interdependency between income and the cost of parking, with a secondary interdependency between age and car ownership with frequency of bus service. Therefore, changes in parking cost would be expected to influence different income groups differently with lower income groups being affected in such a way that they would either shift mode or to relocate home or job. Also changes in bus frequency may affect future car ownership, in that for example, a commuter with one car used for work may decide to relinquish it to the family for other uses if a bus with satisfactory frequency was available.

Income and fares are also interdependent influences for transit riders. This interdependency between income and cost is stronger than that for car drivers. This is probably due to the generally lower incomes of transit riders and therefore increased sensitiveness to cost of travel. Car ownership and availability are linked also with fares and bus frequency and show the same influences as observed in the car group, but for transit riders these factors weigh more heavily than for the more affluent car drivers.

Factors relating to socioeconomic structure and the performance of the transportation system acting in concert discriminate the users of one mode from the users of the other mode. Among the combined factors the necessity of a car at work is predominant followed by residential travel time. The need to have a car at the workplace has been cited by many investigators to be a major factor in the decision to drive the car to work. While this is self evident, there are severe difficulties in interpreting what this means. No objective measure of this necessity has been made, with all results of test on the variable related to the subjective evaluation of the need for a car at work. The survey upon which this analysis is based attempts to scale the degree of necessity of a car for work. In this manner, the frequency with which a car is felt to be needed shows up as a prime indicator; that as the frequency increases the use of the car increases. Unlike most studies of socioeconomic influences on mode split, income and car ownership do not appear to be important. This may be explained by the high income, high car ownership rates of the sample, and infers that one does not need to be a "captive" rider before using the bus.

The analysis of the discriminator of policy variables has shown that five variables will successfully reproduce mode choice behavior. The most important of these are residential travel time, overall travel time, out-of-pocket expenses/ income and bus frequency. The walking time at the CBD has not

shown the influences expected. The analysis substantiates the hypothesis that the system factors are the significant ones in their influence on mode split behavior.

CHAPTER V

PROPENSITY OF CAR DRIVERS TO SHIFT MODE

Mode Split Planning Objectives

The planning objective is to study means of creating a modal split which will help achieve public goals. In practice this involves the prediction of mode split based on user preferences and subsequent behavior, and the development of the means to study changes in behavior on the system to conform to externally pre-determined, but flexible, societal objectives. Presumably one such objective could be to rationalize the flows on the transportation system so that public objectives could be met, while at the same time meet as much as possible, individual user preferences. A manifestation of this is that some car drivers are encouraged to shift to some other mode, or combination of modes.*

This means of rationalizing mode balance infers that either a multimodal system, or a pure transit system is feasible and could increase social welfare while at the same time provide users with no more total disutility of travel than perceived

*It is also possible that a valid objective may be to shift the demand from non-remunerative passenger transit systems to automobiles. Homburger suggests that Britain may in fact be pursuing implicitly such a policy by abandoning unremunerative bus and rail services while increasing fares, while at the same time carrying out a policy of increased freeway construction (see Ref. 1).

benefits of travel, and preferably to achieve a lower level of individual disutility. It is postulated that there is some level of transportation service at which car commuters with particular preference patterns will shift to a new system because the perceived disutility on the new system will equal or drop below that of driving a car. The manipulation of the disutilities of the system can be accomplished in 3 ways: (1) increasing the disutility of driving a car while the alternative remains the same, (2) decreasing the disutility of the alternative while leaving the car alternative the same, and (3) adjust both. The degree that (1) will have on decreasing individual welfare will depend upon the surplus of benefits over disutility (or generalized cost) of travel. A large consumer surplus will allow substantial increases in generalized cost before benefits are exceeded. If generalized cost exceeds benefits with increase in disutility a commuter would shift to transit as long as some consumer surplus remains with this alternative, otherwise he would forego travel or leave the system by changing the spatial relationship of home and job, thus decreasing system demand.

One way to study these forces is by way of an extension of the analysis of the previous chapter: behavior on the system is observed in conjunction with a set of explanatory variables which in some way are associated with the choice of mode. Ideally, this would be extended with mode choice and system behavior analysed through different time periods and

extrapolated as a prediction of mode choice based on simulated changes in the predictive model. Some of the problems of this approach have been discussed. An alternative method is to question commuters on the system about changes which would be necessary to have them shift mode. If they would change mode at all they would do so only if a system could be devised which would provide them with at least the same or less disutility than currently experienced. It remains only to observe how many commuters would shift under a specific change in system components, and the socioeconomic characteristics of these commuters to predict mode split, and the modal population structure.

However, fully accurate prediction is only possible if the individuals who said they would shift mode under certain conditions actually do so if those conditions are met. Given the existing state of the art and minimal understanding of the relationship between statements measuring preference patterns and subsequent behavior the most we can assert is that any individual will have some tendency or predisposition to act in accordance with his stated preferences. Therefore, the model which describes the probability that an individual will shift to a new modal system should more accurately be viewed in terms of propensity to shift rather than in a predictive sense. For this reason the analysis to follow is in terms of propensity to shift from car mode to a new modal system, whether it is a multimodal or pure transit system.

Outline of the Shift Propensity Model

It is hypothesized that each user chooses that mode which he perceives to have the least disutility of all modes available to him. Also it is postulated that his perception of a mode is in terms of its intrinsic characteristics, or attributes, and not of its institutionalized characteristics. That is, the mode choice is based on perceived performance characteristics of the system, and not because of a name or its institutional connotations. If we further assume that the total disutility of a mode is linear and an additive function of its attributes as perceived by any user, k, we can state that the decision to take a particular mode is because

$$U_k^1 < U_k^2 \quad \text{where:}$$

U_k^1 = total disutility of accepted mode (i.e. mode 1)

U_k^2 = total disutility of rejected mode (i.e. mode 2)

But each mode is an abstraction of some combination of modal attributes so that,

$$\sum_{i=1}^{p} U_{i,k}^1 < \sum_{i=1}^{p} U_{i,k}^2 \quad \text{where:}$$

$U_{i,k}^j$ = disutility of attribute i for mode j as perceived by user k, and

p = total number of attributes considered in the choice decision.

Each disutility term $U_{i,k}^{j}$ can be conceived to consist of two components: that which is a variable measure of the attribute, and a parameter which weighs that attribute in relation to all other attributes considered in respect to the relative value placed on the attribute in the mode choice decision. That is; disutility for any attribute is the product of a weighting coefficient and the number of units of the attribute experienced, or

$$U_{i,k}^{j} = V_i X_{i,k}^{j} \text{ where:}$$

V_i = value user k places on attribute i

$X_{i,k}^{j}$ = measure of attribute i of mode j as perceived by user k.

Consequently, mode 1 is accepted and mode 2 is rejected when

$$\sum_{i=1}^{p} V_i X_{i,k}^{1} < \sum_{i=1}^{p} V_i X_{i,k}^{2} \qquad \text{or}$$

$$\sum_{i=1}^{p} V_i (X_{i,k}^{1} - X_{i,k}^{2}) < 0.$$

Several aspects of this disutility function are noteworthy. First, the function is described in terms of relative disutilities of two alternatives (i.e., a binary choice problem). The function has been derived here using differences between attributes of the two modes, but the form of the inequality remains the same if ratios are used (i.e., the right hand side

would be < 1 for ratios, rather than < 0). Secondly, the function applies only to a single individual. Individual utilities are not comparable.[2] That is, the function describes the relative disutilities of each attribute for the mode choice decision, but the strength of acceptance of a mode by one individual cannot be compared with the strength of another individual's acceptance and therefore individual total disutilities are not additive.* However, if the vectors X are treated as random vectors a probability distribution can be determined which will be a statistical description of the aggregation of individual k, where k=1,N. A third aspect of the disutility function is that the inequality suggests the connection between individual disutility functions and discriminant functions. The relative disutility function postulates an inequality, or a boundary, on one side of which one mode is chosen and on the other side of which the other mode is chosen. Comparing individuals in terms of which side of the boundary condition they fall is the problem of multiple discriminant analysis, and the discriminant analysis gives a boundary condition which separates the modal groups on the basis of their average disutility, as measured by the parameter values and variables of the discriminant function. The disutility value

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*Furthermore if more than two modes were considered (the mode choice decision has always, to date, been handled as a binary choice problem) we cannot say that aggregated individual utilities are transitive, i.e. rational. That is, if a majority of people prefer mode 1 to mode 2 and mode 2 to mode 3 we cannot say that a majority prefers mode 1 to mode 3: (see Ref. 2, pp.2-3).

weighting V for the individual is analogous to the vector of parameters v of the discriminant function. Lastly, note also that disutility is described in terms of perceived differences between modal attributes. Utility (disutility) is purely subjective and depends on subjective values for the variables of the disutility function. One disadvantage of this approach is possible interdependence between the subjective measure given through interview of the system attributes and the psychological value attached to that attribute. That is, if an individual places great value on travel time, he may estimate his actual travel time to work much greater than it actually is (i.e., by objective measurements) or than he would estimate it to be if his value of travel time was less. There may also be some intercorrelation between the existing level of service and subjective evaluation of ideal levels of service preferred. These problems are discussed later.

The shift propensity schema may be outlined in terms of indifference curve analysis using stated preferences as follows.

Consider I_k, I_k, the indifference curve for individual k, which is the locus of all combinations of two system attributes (say overall travel time and overall travel cost) which describes his preferences within the context of his budget constraints and the modes available to him (Figure 7). U_k^1 is the point at which the time-cost combination gives him least

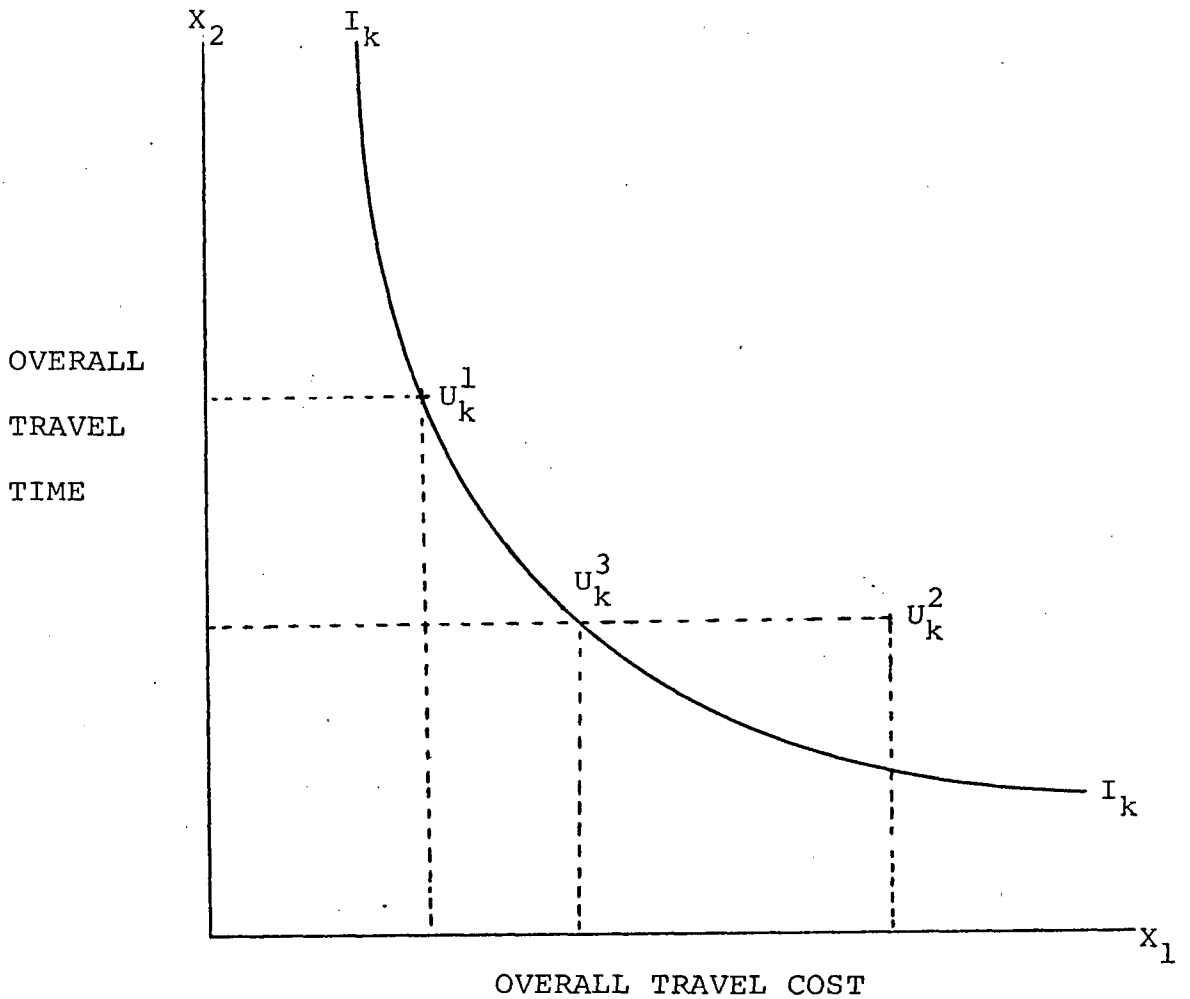

FIGURE 7

INDIFFERENCE CURVE ILLUSTRATING DISUTILITY OF COMBINATIONS OF TIME AND COST OF TWO MODES FOR A HYPOTHETICAL INDIVIDUAL k

dissatisfaction, and therefore represents the disutility of the characteristics of mode used, if we assume the modal attributes are continuous. On the other hand, U_k^2 represents the characteristics of the mode rejected and is always to the right of $I_k I_k$ since the disutility of this combination is greater than that of the mode used. However, the characteristics of U_k^2 can be changed in such a way that individual k will be indifferent to whether he continues to use the existing mode or shifts to the alternative. This point is shown at U_k^3 which in this illustration results from decreasing the cost of the alternative.

The relative attribute values (X) of U_k^3 to U_k^1 define a relative disutility function for the individual, and describes his propensity to shift mode. These relative values can then be plotted in (this case) two dimensional space representing the location of that individual vis-a-vis all other individuals. Assume that U_{k1} represents (for these two attributes) the cluster of propensity (disutility) measures for those individuals of one socioeconomic group (say low income) while U_{k2} represents the cluster of propensity measures for another mutually exclusive group (say high income) (Figure 8). If there is sufficient differentiation between the clusters representing the within group variation we may say that for these attributes there exists a different combination of attributes at which low income groups would shift to transit than that combination at which high income groups would shift. The

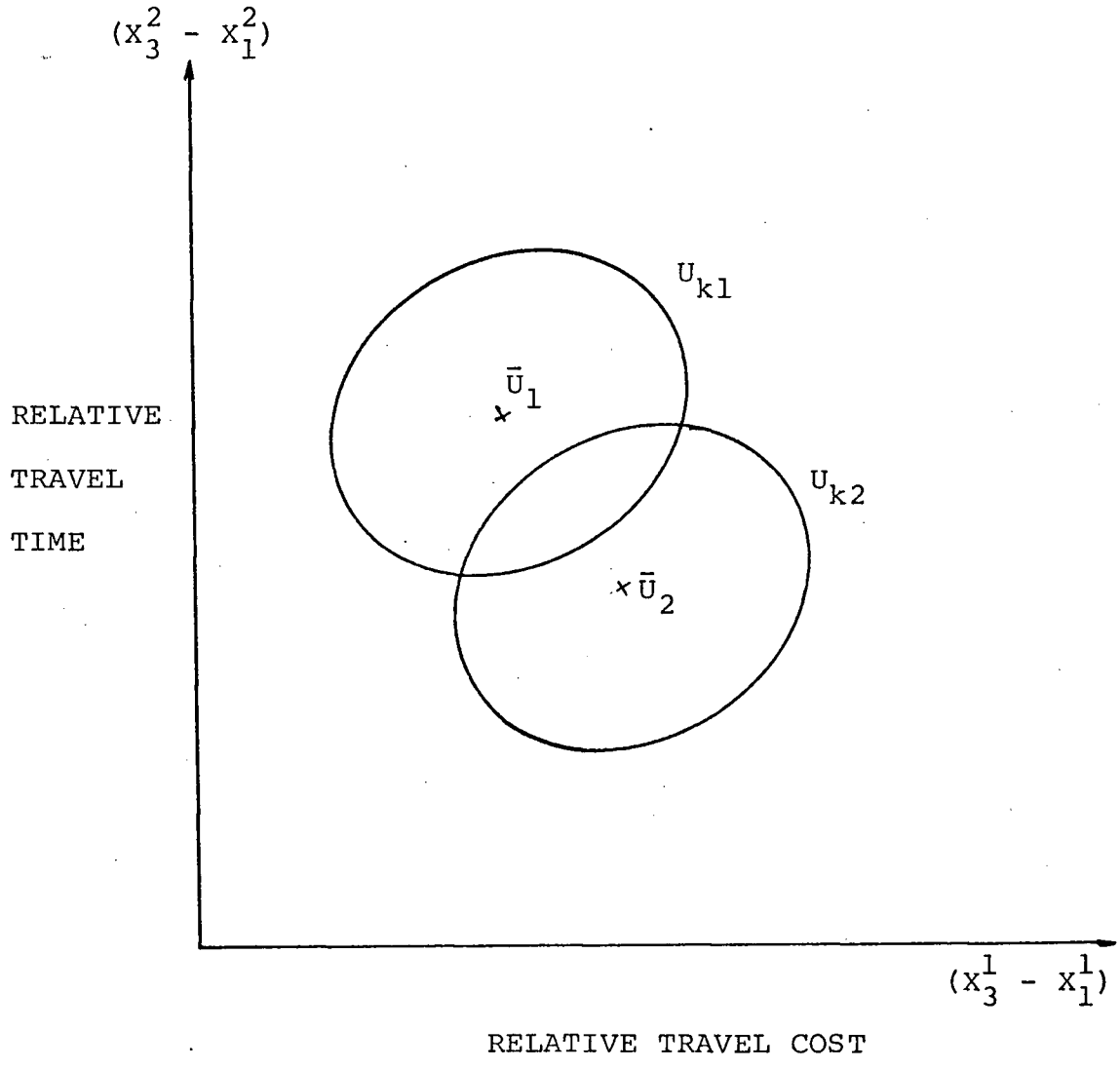

FIGURE 8

CLUSTERS OF OBSERVATIONS ON RELATIVE DISUTILITY VALUES FOR INDIVIDUALS OF TWO HYPOTHETICAL SOCIOECONOMIC GROUPS

distance between the means of the clusters and the overlap of values gives a statistical measure of the degree this differentiation exists, and is found by the use of discriminant analysis. A discriminant function can be found for each group or sub-group which quantitatively describes any group or sub-group's tendency to shift mode.

When a group discriminant function is valued it can be used to predict the propensity to shift mode. That is, the z value of any individual can be found and his group identified. Since the z value is a function of systems attributes and individual value orientations (which here are assumed stable i.e., as parameters) any change in the system attributes will change the z value. If any individual's z value changes enough it will transfer him from the region of mode 1 to the region of mode 2. At some extreme change in system attributes all z values change sufficiently that all members of the region of mode 1 are transferred to the region of mode 2. For any given policy change, the probability of an individual remaining a car driver, or shifting to a new mode can be determined. Conversely, the probability of an individual shifting mode can be stated as:

$$P(X) = \frac{e^z}{1+e^z}$$

in which z is the discriminant function value (or discriminant score) for each individual as a car driver and in his potential group as a new mode user. The discriminant rule will assign

him to the new mode if his z value is "closer" to the mean of the new mode group than to the mean of the car group; otherwise the rule will leave him a member of the car group.

The method presumes some restrictive preconditions. Assumption are (1) that every individual is aware of the potential alternatives, (2) that his preferences are rational in terms of the utility postulate of maximizing satisfactions (3) that his behavior and stated preferences are coincident and (4), related to (3), that his perception of a preferred system is independent of the existing level of service.

Assumption (1) and (2) present no particular problem since these are intrinsic assumptions of any analysis using utility theory. Assumption (3) is important to practical application of the model as a device for making transportation decisions, and therefore deserves some discussion. The congruence of stated preferences and behavior is tied to the relationship between an individual's value system as manifested in specific attitudes and behavioral response. Early behavioralists who believed in the mechanistic behaviorist system of stimulus-response and resulting habit patterns felt that attitudes were redundant in explaining social phenomena. Later, however, it was recognized by social behaviorists (e.g., F.H. Allport) that the concept of attitude was needed to give reality to the idea of the mechanistic model of man. This concept was first introduced into the behavioristic system as a predisposition to

respond, and later in terms of the subjective meaning the attitude had for the individual.[3] Modern definitions of the attitude concept as it affects behavior range from a "tendency or disposition to evaluate an object" by Katz and Stollard[4] with an implicit behavioral component, to "tendencies to react" by Lambert and Lambert[5] with its explicit behavioral component. The current concensus is that attitudes and behavior are interrelated although the relationship may go from a very weak connection to a very strong one. In the present case it is postulated that individuals can articulate their evaluation of the transportation systems attributes in terms of preferences, and that if these attributes are included in a new arrangement there will be a tendency to react accordingly.

Assumption (4) presupposes that individual travellers can perceive a transportation system independently of the existing level of service. No systematic study is available on this point, but the validity of this assumption is examined later.

The shift propensity model is meant to serve as the basis for a control mechanism in the context of forward seeking, goal oriented, incremental planning. By simulating policy in the model, the number of car drivers who shift can be estimated. Because policy options are incremental in character, the actual results of such changes can be observed in the field. If the field results do not conform to expectations as derived from the model, the model can be changed accordingly.

SHIFT PROPENSITY OF NORTH SHORE COMMUTERS

The planning model as outlined above was empirically tested using a sample of the car driving population of the commuters from the North Shore communities to the CBD of Vancouver to study the impact of (1) a simulated park and ride system, and (2) changes in the use of transit if parking costs were increased.

The performance dimensions are those which define the relative values of a preferred level of service to actual level of service by car. The explanatory variables were those which defined the preferred level of service if a shift was to occur and those which defined the actual level of service experienced at the time of the trip. Car drivers were asked to indicate on a categorized scale the minimum quality of service desired if he were to use a park and ride system, and the maximum charge he would accept for parking before he would use transit. (See questionnaire, Appendix B). The preferred measure is the explanatory variable for the individual as a hypothetical transit rider and the actual measure is the explanatory variable for the individual as a car driver. The performance dimensions of the test space are therefore the relative value of these variables. A description of the dimensions used follows.

Relative Overall Travel Time: (ROTT)

The door-to-door journey time by park and ride in 5 minute increments compared to that by car was indicated by the respondent. This value was then converted to absolute travel time preferred, and this value compared to the actual travel time by car. This process was carried out so that both differences and ratios could be used as relative disutility measures.

Relative Out-of-Pocket Expenses: (ROPE)

The maximum two way combined bus fare and parking charge that the respondent would insist upon before shifting, compared to the actual parking charge levied.

Relative Residential Travel Time: (RTTO)

The walking duration from the parking location to the transit vehicle preferred in a park and ride system, compared to the actual walking distance from residence to car at the trip origin.

Relative Frequency of Service: (RFREQ)

The frequency of transit vehicles leaving the park and ride terminal in minutes compared with the actual frequency of bus service in the zone of origin of the car driver.

Relative Parking Charge: (RPKCHG)

The parking rate at which the respondent said he would switch to transit if the parking rates were substantially increased in downtown Vancouver, compared to actual parking charge experienced at the time of the journey.

If the preferred service was provided each car driver willing to shift mode could, under the preferred conditions, be considered a user of the multimodal system. The existing car driving population actually tested, and the hypothetical users of the new system then define two groups in two regions of the test space. These would in the statistical sense be matched pairs with each member of each pair (i.e., group) being located as two points on an indifference surface. For example, at points U_k^1 and U_k^3 in Figure 7 for the case of two dimensions. The problem is to find that discriminant function which maximally separates the two groups, and those dimensions which define the separation. The significant discriminant function variates give a definition to those policy changes which would encourage car drivers to shift mode. The number of persons which would be classified as a multimodal or "transit-only" user at any level of change in the system, can be determined.

Since some people would shift only under the most extreme conditions, and because the critical factor(s) to encourage a shift, or a wide enough upper or lower limit on

the scale may have been missing, a follow up question was asked to determine if the respondent would definitely switch if the quality of service he specified as preferring was actually provided. Those who answered no to this question were eliminated from the sample, leaving a total of 465 respondents who said they would in fact switch if the service they desired was provided. Discriminant analysis was then used to test: (1) if actual individual behavior profiles of the original "anchor" group (i.e., actual car drivers) were significantly different from those of the "shift" group (i.e., hypothetical transit or multimodal user's profiles based on that combination of attributes which they said would cause them to shift); (2) what dimensions serve to define the separation between car drivers as car drivers and car drivers as hypothetical transit users, and (3) the validity of the linear discriminant functions for a predictive model of mode shift propensity.

The central tendencies of the observations of the two groups give a general indication of the preference pattern of the car driving population to divert (Table XXVIIIa). If the distribution of both groups is normal, the results of the table describe those measures needed to bring about a shift of one-half the car group. The other half would be those who required changes which locate them below the mean. This shift would occur with a decrease in mean travel time of about 5 minutes. Total out of pocket expenses would have to decrease, but not

Table XXVIIIa

MEANS AND STANDARD DEVIATIONS FOR CAR GROUP AND SHIFT GROUP, FOR A PROPOSED MARK AND RIDE, AND AN INCREASE IN PARKING CHARGES

VARIABLE	CAR DRIVERS	SHIFT GROUP	
	GROUP MEANS		AVERAGE
X_1(ROTT)	30.849	25.806	28.328
X_2(ROPE)	.549	.533	.541
X_3(RTTO)	.669	2.022	1.345
X_4(RFREQ)	17.409	4.503	10.956
X_5(RPKCHG)	.549	1.011	.780
	GROUP STANDARD DEVIATION		AVERAGE
X_1(ROTT)	8.381	8.799	8.951
X_2(ROPE)	.420	.328	.377
X_3(RTTO)	1.554	.953	1.455
X_4(RFREQ)	4.870	2.192	7.478
X_5(RPKCHG)	.420	.532	.532

substanially. The overall walking time from the parking lot of a park and ride station to the bus compared with the existing time at the residential end of the journey (for all practical purposes this is nill) would have to be about 2 minutes. This infers that drivers would tolerate some walking at the residential end of the trip (as they in general do at the CBD end)

if other desirable characteristics are provided. One characteristic which shows up very dramatically is a large reduction in the frequency of public transit vehicles within the multimodal system compared with the frequency of the buses the respondent perceives at his home location. The average car driver, who is a potential "shift" patron would require about 4.5 minute headway between buses compared with the more than 17 minutes he perceives at present.

Some caution is necessary in the interpretation of these data. First, large standard deviations for the out-of-pocket cost factor results from a few extreme observations; those who pay a very high parking cost at present, and those who demand a very low total expense for the shift condition. Many respondents indicated they desired a system with no out-of-pocket expenses. Secondly, the spread between existing frequency and that preferred may be dramatized by the way these were measured. Recall that the existing frequency is a rush period average for the zone of origin for each driver and may not represent the combination of extremely high or extremely low existing frequencies with extremely low or extremely high preferred frequencies on the individual basis. If precise frequencies were used for the hour of departure the spread in means would decrease, and the effect of this factor would be expected to moderate somewhat.

The parking charge needed, by itself, to effect the shift would be from about an average of $.55 to about $1.00 per day.

Statistical tests (Table XXIX) show an overall discrimination between the two groups for both a park and ride system of $R^2 = .762$, and in terms of the raising of parking fees an $R^2 = .175$. Both R^2 values are significant. The relatively large R^2 value for discrimination between what exists now and a new combination of characteristics in a park and ride system shows a realizable multimodal system to be perceived. However, substantial changes in service levels are perceived necessary. The univariate F-test shows the scale of changes needed for a shift considering each attribute by itself. For the park and ride system, the frequency of buses at the terminal, the distance to walk to the terminal from parking location are critical factors as well as the overall elapsed travel time. The change in parking charges also is effective in discriminating between the groups at the $p < .001$ significance level, indicating that an increase in parking charges will cause car drivers to shift to the bus. In the reduced space the group means show significant separation for both the multimodal system and parking fee charges.

The vector loadings on the discriminator show that bus frequency dominates the preference pattern of the "shift" group (Table XXX). This reflects the differences found between

TABLE XXIX

STATISTICAL TESTS ON PROPENSITY OF MODE SHIFT FOR THE CAR GROUP AND SHIFT GROUP FOR A PROPOSED MULTIMODAL SYSTEM AND FOR A TRANSIT SYSTEM BASED ON INCREASED PARKING CHARGES

UNIVARIATE F-TESTS

VARIABLE	F-RATIO	F_p
X_1(ROTT)	80.09	<.001
X_2(ROPE)	.47	n.s.
X_3(RTTO)	256.03	<.001
X_4(RFREQ)	2715.61	<.001
X_5(RPKCHG)	215.20	<.001

SIGNIFICANCE OF DISCRIMINATOR AND GROUP SEPARATION

MULTIMODE		TRANSIT	
DISCRIMINATOR	GROUP SEPARATION	DISCRIMINATOR	GROUP SEPARATION
Λ = .2369	D^2 = 147.45	Λ = .8118	D^2 = .213
F_1 = 4.0		F_1 = 1	
F_2 = 925.0	F_{D2} = 685.0	F_2 = 928.0	F_{D2} = 49.8
F_{H2} = 744.90	F_p .001	F_{H2} = 215.20	F_p <.001
F_p < .001		F_p < .001	
R^2 = .762		R^2 = .175	

SIGNIFICANCE OF ROOT

No. of Roots	Root (λ_i)	% of Trace	No. of Roots Summed	Sum of Roots	d.f.	χ^2	χ^2_p
			MULTIMODE				
1	3.2212	100.0					
1	3.2212	100.0	4	3.2212	4	312.5	<.001
			TRANSIT				
1	.2319	100.0	1	.2319	1	430.0	<.001

Table XXX

VECTOR LOADINGS ON DISCRIMINATORS

VARIABLE	SCALED VECTOR
X_1 (ROTT)	-17.85
X_2 (ROPE)	.43
X_3 (RTTO)	-11.48
X_4 (RFREQ)	108.13
X_5 (RPKCHG)	14.61

the frequency preferred for each trip against that averaged by zone and averaged over the rush period. Overall travel time followed by residential travel time also contribute substantially to the separation. No serious intercorrelation exists, although some correlation is evident between actual overall travel time and bus frequency (Table XXXI). This is to be expected since bus frequency in the more remote areas is low while auto travel time is high, particularly in the western portion of West Vancouver.

The discriminant functions of the anchor group for the multimodal system and the transit system respectively are:

$$z_{am} = -10.761 + 0.401X_2 + 1.221X_4$$

$$z_{at} = -0.657 + 2.390X_5$$

Table XXXI

CORRELATION MATRICES FOR CAR GROUP AND SHIFT GROUP ON MULTIMODAL VARIABLES

		ROTT	ROPE	RTTO	RFREQ		
CAR	ROTT	1.00	.12	.11	.15	ROTT	SHIFT
GROUP	ROPE	.09	1.00	.12	.15	ROPE	GROUP
	RTTO	-.01	.05	1.00	.17	RTTO	
	RFREQ	.32	-.05	-.05	1.00	RFREQ	

Those for the "shift" group are respectively:

$$z_{sm} = -1.940 + 1.216X_2 + 0.316X_4$$

$$z_{st} = -2.222 + 4.397X_5$$

In the stepwise procedure using an acceptance-rejection criterion of $F_p \leq .05$ overall travel time drops out of consideration and the discriminant scores are calculated on the basis of residential travel time and frequency. This increases the F-ratio from F = 744.90 to F = 1484.74 for the park and ride scheme. The canonical correlation, $R_c = .87$, resulting in an R^2 of .76 indicate good discrimination on these two variables (Table XXXII). The posterior classification by the discriminant functions results in less than one percent misclassification (Table XXXIII). Using only parking charge as a variable in the model produces only moderately successful results. This may be

Table XXXII

SIGNIFICANCE OF DISCRIMINATOR USING ONLY THOSE VARIABLES REMAINING SIGNIFICANT IN THE STEPWISE PROCEDURE

MULTIMODE			TRANSIT		
F_{H2}	=	1484.74	F_{H2}	=	215.20
R_c	=	.873	R_c	=	.434
R^2	=	.760	R^2	=	.189

Table XXXIII

PREDICTED CLASSIFICATION VERSUS ACTUAL GROUP MEMBERSHIP FOR THE TEST ON THE MULTIMODAL SYSTEM AND TRANSIT SYSTEM

MULTIMODAL

		NUMBER PREDICTED TO BE IN GROUP			
		CAR GROUP	SHIFT GROUP	TOTAL	MISSES
ACTUAL NUMBER IN GROUP	CAR	457	8	465	8
	SHIFT	0	465	465	0
				930	8

% MISCLASSIFICATION = 0.9%

TRANSIT

		NUMBER PREDICTED TO BE IN GROUP			
		CAR GROUP	SHIFT GROUP	TOTAL	MISSES
ACTUAL NUMBER IN GROUP	CAR	409	56	465	56
	SHIFT	249	216	465	249
				930	305

% MISCLASSIFICATION = 32.8%

partially due to a relatively crude breakdown in the parking charge categories.

To determine how many car drivers would shift to transit for any given policy change, it is only necessary to change the variable value for each individual and note the new z values. This then is evaluated by the model and a new probability found for each function. He is then assigned to that group for which he has the largest P(X) value. It is evident from the vector loadings that a given percentage change in frequency will have more effect on transferring auto drivers to a park and ride system than will the same percentage change in residential travel time.

Validity of Preference Patterns

The mode shift described here is based on an analysis of what people say they would do under a given hypothetical situation. To improve validity only those respondents who stated a second time that they would shift if there preferences were met were analysed. A question still remains as to whether the respondents would in fact shift if their desires were met. Some attempt was made to further understand the preference structure and to estimate the validity of stated preference as a tool to analyse mode shift.

It was reasoned that if an individual's preferences were independent of the level of existing service it was likely

that the propensity was good that a shift would in fact occur. Consequently, a test of the independence of preferences from the existing system attributes was carried out using canonical analysis. Table XXXIV shows the correlation coefficients for the 4 variables representing existing attributes and the 5 variables representing preferred attributes.* Simple intercorrelation exists between preferred travel time (X_5) and actual travel time (X_1). Using the rule of thumb that an $r = .65$ is not serious intercorrelation it is observed that all other variates are independent between the sets.

However, the canonical correlation between the sets is significant. Two roots with $R_c = .68$ and $R_c = .60$ are both significant at $p < .001$. The inference is that the two sets of variates can be combined in such a way to produce correlation between what an individual prefers in the way of transportation service and the existing alternatives available.

The coefficients of the two sets for the 1st canonical variates are:

X_1	(0.881)	X_5	(0.952)
X_2	(0.280)	X_6	(0.025)
X_3	(-0.135)	X_7	(-0.138)
X_4	(0.121)	X_8	(-0.089
		x_9	(0.229)

*Preferred parking charges (X_9) is compared with actual parking charge (X_2) to account for the extra variate in the second set.

Table XXXIV

CANONICAL TESTS OF INDEPENDENCE OF PREFERRED ATTRIBUTES WITH ACTUAL ONES

CORRELATION MATRIX

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	1.00								
X_2	-.09	1.00							
X_3	-.01	.05	1.00						
X_4	.32	-.05	-.05	1.00					
X_5	.65	.10	-.08	.27	1.00				
X_6	.04	.19	-.06	.04	.12	1.00			
X_7	-.02	-.02	.10	-.07	.11	.12	1.00		
X_8	.03	.03	.07	-.00	.15	.15	.17	1.00	
X_9	.09	.60	.02	.01	.13	.17	-.08	-.00	1.00

SIGNIFICANCE OF CANONICAL ROOTS

Root	Canon. Corr. (R_c)	λ_i	Λ'	χ^2	d.f.	χ^2_p
1	.678	.4597	.3405	493.5	20	.001
2	.595	.3528	.6400	202.0	12	.001
3	.155	.0240	.9750	11.7	6	.05

These indicate the factor contributing most to the intercorrelation is the relationship between actual travel time and that which is preferred. The second canonical variates have the following coefficients:

X_1	(-0.355)	X_5	(-0.381)
X_2	(0.967)	X_6	(0.140)
X_3	(0.038)	X_7	(0.087)
X_4	(0.008)	X_8	(0.052)
		X_9	(0.951)

This variate brings out the remaining intercorrelations: that between actual parking cost and that preferred. The results indicate that as far as travel time and parking cost factors are concerned, car drivers do not envision very radical changes to be possible. However, indications are that other attributes such as transit fares, residential travel time, and service frequency can be changed in a way very much different from that which is currently experienced.

At present no way exists to determine the degree to which stated preferences, or the value given to systems attributes, and behavior are interrelated. This analysis therefore stops short of a predictive model, but does indicate very definitely a propensity to shift mode based on the factors studied. It has been shown that practical increases in parking charges in the CBD by whatever manner, will significantly affect mode split; and that the residential travel time, frequency of

buses leaving the park and ride terminal location and overall travel time can be used as instrumental factors in a mode shift policy.

INFLUENCE OF SOCIOECONOMIC CHARACTERISTICS IN MODE SHIFT PROPENSITY

The propensity for car drivers to shift mode is likely related to the socioeconomic structure of the individual. Since it is reasonable to assert that each individual's relative disutility will depend on such socioeconomic factors as age, car ownership, income, and occupation, each of these will relate to mode shift propensity through different disutility dimensions. That is, it would be expected that age categories, for example, may influence the propensity to shift through a different set of attributes than another socioeconomic characteristic. If the dimensions which distinguish between socioeconomic characteristics can be found, and if they are significant in classifying the various characteristics we can then assert that changes in the system will differentially affect the various groups that have a propensity to shift mode. For example cost changes may have more influence on separating the different income categories and therefore will encourage, say more low income workers to shift than high income ones.

A series of tests were performed to determine the relative disutilities of the car driving group. No agreement exists in the literature as to the best way to express relative

disutility. Some investigators have used differences between car and transit attributes, some ratios, and some have found transformations of the raw measures more useful. Preliminary tests using both difference measures and ratio measures were conducted to attempt to resolve this dilemma. The tests showed that ratios produced better discrimination between groups with more of the variables proving significant. This finding plus the fact that most of the transportation study research has used ratios resulted in the decision to use ratios in this analysis as the measure of relative disutility. The shift variables were then expressed as a ratio of actual state of the system as perceived by the individual divided by the preferred state of the system before a mode shift would occur. That is:

X_1 = actual overall travel time ÷ preferred overall travel time.

X_2 = actual charge paid for parking ÷ preferred out-of-pocket expenses for both transit fare and parking.

X_3 = actual walking time from origin to vehicle ÷ preferred walking time at park and ride terminal.

X_4 = actual frequency of bus at origin zone ÷ preferred frequency of transit vehicle leaving park and ride terminal.

X_5 = actual charge paid for parking ÷ parking charge that would cause a mode shift.

These ratio variables may be interpreted in terms of satisfaction with the existing level of service in the following manner: for the park and ride service (X_1 to X_4), if $X \leq 1$ the individual

is not satisfied with his service and would need an improved level of service (decreased disutility) in a new system. For CBD parking policy, X_5 is always less than one because the ratio presumes some change upward in parking fees is necessary to cause a shift.

A matrix of relative disutility scores was developed and a program written to punch the variables on cards for the 465 car drivers who stated they would switch to a new mode if certain changes were made (See Appendix H).

Age as a Factor in Propensity to Shift Mode

Best results were achieved when the age groups were split into those under 40 and those over 40. For all attributes those over 40 require a relatively higher level of service on the multimodal system before shifting mode than those under 40, as shown by the lower values for relative disutility ratios for the over 40 group (Table XXXV). Statistical tests are shown on Table XXXVI. The univariate F tests show that travel time and frequency are the dimensions through which age is an influence in the mode shift. Group discrimination on all attributes and group separation in the reduced space are both significant. When the vector is scaled (Table XXXVII), out-of-pocket expenses also show important influences, which is hidden otherwise by the large standard deviation of this variable. The assignment test using only travel time and frequency dimensions produced an F probability of $p < .001$ and a canonical correlation

Table XXXV

AGE GROUP MEANS AND STANDARD DEVIATIONS

FOR THOSE UNDER 40 AND THOSE OVER 40

VARIABLE	UNDER 40*	OVER 40**	
	GROUP MEANS		AVERAGE
X_1(OTT)	1.090	.959	1.022
X_2(OPE)	3.256	2.068	2.633
X_3(TTO)	.379	.377	.378
X_4(FREQ)	4.878	3.910	4.370
X_5(PKCHG)	.613	.561	.586
	GROUP STANDARD DEVIATION		AVERAGE
X_1(OTT)	.604	.535	.572
X_2(OPE)	12.227	9.288	10.790
X_3(TTO)	.807	.818	.812
X_4(FREQ)	3.057	2.761	2.942
X_5(PKCHG)	.726	.641	.683

*Sample = 221
**Sample = 244

Table XXXVI

STATISTICAL TESTS OF THE PROPENSITY OF AGE GROUPS TO SHIFT MODE

UNIVARIATE F TESTS FOR AGE GROUPS

VARIABLE	F-RATIO	F_p
X_1(OTT)	6.20	<.05
X_2(OPE)	1.41	n.s.
X_3(TTO)	.00	n.s.
X_4(FREQ)	12.87	<.001
X_5(PKCHG)	.68	n.s.

SIGNIFICANCE OF DISCRIMINATOR AND GROUP SEPARATION

Λ	=	.9613	D^2	=	.5814
F_1	=	5.0	F^5_{459}	=	13.4
F_2	=	459.0			
F_{H2}	=	3.695	F_p	<	.001
F_p	<	.01			
R^2	=	.029			

SIGNIFICANCE OF ROOTS

No. of Roots	Root λ_i	% Root is of Trace	No. Possible Roots	Σ Roots	d.f.	χ^2	χ^2_p
1	.0403	100.0	5	.0403	5*	37.3	<.001

*Includes PKCHG

Table XXXVII

VECTOR LOADINGS ON DISCRIMINATOR

VARIABLE	SCALED VECTOR
X_1(OTT)	5.98
X_2(OPE)	37.67
X_3(TTO)	-.56
X_4(FREQ)	47.46
X_5(PKCHG)	2.12

of R_c = .19, with an equivalent R^2 = .03, with no reduction from the test with all variables (Table XXXVIII).

Table XXXVIII

SIGNIFICANCE OF DISCRIMINATOR USING ONLY SIGNIFICANT VARIABLES

F^2_{462}	=	8.80
F_p	<	.001
R_c	=	.19
R^2	=	.028

Discriminant functions derived from the linear discriminant functions are for under 40 and over 40 respectively:

$$z_{u40} = -2.987 + 3.135X_1 + 0.524X_4, \text{ and}$$

$$z_{o40} = -2.144 + 2.777X_1 + 0.415X_4.$$

The posterior classification using these functions in the shift model resulted in 40.6 percent misclassification (Table XXXIX).

Table XXXIX

PREDICTED CLASSIFICATION VERSUS ACTUAL GROUP MEMBERSHIP FOR UNDER 40 AND OVER 40

		NUMBER PREDICTED TO BE IN GROUP			
		U40	o40	TOTAL	MISSES
ACTUAL NUMBER IN GROUP	U40	113	108	321	108
	o40	81	163	344	81
				465	189

% MISCLASSIFIED = 40.6%

The tests show that age should be considered in the prediction of who would shift to a new system, with those in the younger age groups more likely to shift than those in the older age groups, with incremental changes in system performance. Bus frequency at the park and ride terminal is particularly important for those over 40 as is overall travel time. When the eigenvector is scaled to account for the large variance in out-of-pocket expense ratio for these ages, this variable increases in its role in explaining the difference between groups, showing that the over 40 age group would require a larger increase in transit fare and parking costs than those under 40.

It appears that changes in the CBD parking rates would not have a differential effect according to age category, with those in the older age group as likely to shift with a given change as those in the younger age group.

Car Ownership as a Factor in Propensity to Shift Mode

This variable was dichotomized into a single car ownership category, and multiple car ownership one.

As one would expect the propensity to shift mode decreases as car ownership increases (Table XL). For the park and ride system the relevant dimensions which separate single ownership from those families owning two or more cars are overall travel time and residential travel time with overall travel time the most important dimension in the separation (Table XLI). Although the test shows a significance at $p < .05$ in overall discrimination, group separation in the reduced space is not significant (as shown by $D^2 = .025$ with an F ratio of .575). The scaled discriminant vectors show that, taken as a system, the relative importance of out-of-pocket expenses and residential travel time increases (Table XLII). Although the level of significance is low, it appears that all factors but bus frequency are important. This supports the idea that bus services and car ownership are negatively related.

The linear discriminant functions for single car ownership and for the multiple car ownership groups respectively, are:

Table XL

CAR OWNERSHIP GROUP MEANS AND STANDARD DEVIATIONS FOR SINGLE AND MULTIPLE CAR OWNERSHIP CATEGORIES

VARIABLE	SINGLE*	MULTIPLE**	
	GROUP MEANS		AVERAGE
X_1(OTT)	1.110	.943	1.022
X_2(OPE)	3.008	2.302	2.633
X_3(TTO)	.467	.300	.378
X_4(FREQ)	4.394	4.348	4.370
X_5(PKCHG)	.576	.594	.586
	GROUP STANDARD DEVIATIONS		AVERAGE
X_1(OTT)	.620	.515	.572
X_2(OPE)	13.055	8.307	10.790
X_3(TTO)	.937	.676	.812
X_4(FREQ)	2.592	3.225	2.942
X_5(PKCHG)	.721	.649	.683

*Sample = 218
**Sample = 247

Table XLI

STATISTICAL TESTS OF THE PROPENSITY OF CAR OWNERSHIP GROUPS TO SHIFT MODE

UNIVARIATE F-TESTS FOR CAR OWNERSHIP

VARIABLE	F-RATIO	F_p
X_1(OTT)	10.04	.001
X_2(OPE)	.50	n.s
X_3(TTO)	4.90	.05
X_4(FREQ)	.03	n.s
X_5(PKCHG)	.08	n.s

SIGNIFICANCE OF DISCRIMINATOR AND GROUP SEPARATION

Λ	=	.9704	D^2	=	.02512
F_1	=	5.0	F^5_{459}	=	.575
F_2	=	459.0			
F_{H2}	=	2.801	F_p	=	n.s
F_p	<	.05			
R^2	=	.029			

SIGNIFICANCE OF ROOTS

Root	λ_i	% of Trace	No. of Roots Possible	Σ of Roots	d.f.	χ^2	χ^2_p
1	.0305	99.99	5	.0305	5	28.3	.001

Table XLII

VECTOR LOADINGS ON DISCRIMINATOR

VARIABLE	SCALED VECTOR
X_1(OTT)	9.73
X_2(OPE)	8.92
X_3(TTO)	8.52
X_4(FREQ)	-0.52
X_5(PKCHG)	-2.06

$$z_s = -1.920 + 3.460X_1$$

$$z_m = -1.387 + 2.940X_1$$

These are relatively ineffective in classifying car ownership group with 46.4 percent misses (Table XLIII). The F ratio of

Table XLIII

PREDICTED CLASSIFICATION VERSUS ACTUAL

GROUP MEMBERSHIP

		NUMBER PREDICTED TO BE IN GROUP			
		SINGLE	MULTIPLE	TOTAL	MISSES
ACTUAL NUMBER IN GROUP	SINGLE	28	190	218	190
	MULTIPLE	21	226	247	21
				465	211

% MISCLASSIFIED = 46.4%

10.04 for the single overall travel time in the reduced space is significant at $p < .002$ but $R_c = .15$ and $R^2 = .02$ show that stratification by car ownership for mode shift propensity is for all practical purposes unnecessary (Table XLIV).

Table XLIV

SIGNIFICANCE OF DISCRIMINATOR USING ONLY SIGNIFICANT VARIABLES

F^1_{463}	=	10.04
F_p	<	.002
R_c	=	.15
R^2	=	.021

In view of these results it was felt that a stratification into 3 groups would be more relevant. Therefore the *a priori* groups tested were those with one car, two cars and three or more cars. Table XLV shows the results, and indicates that the dichotomy into single and multiple is valid, although adding the third group (three or more cars) increases the importance of residential travel time, thereby showing some reluctance of the three car families to shift unless parking is very closely integrated with the transit station in the park and ride system.

Table XLV

TESTS ON CAR OWNERSHIP USING 3 GROUPS

COEFFICIENTS OF DISCRIMINANT FUNCTIONS

VARIABLE	ONE CAR*	TWO CARS**	THREE OR MORE CARS***
X_1 (OTT)	3.399	2.864	3.131
X_3 (TTO)	.520	.242	.572
CONSTANT	-2.008	-1.362	-1.747

SIGNIFICANCE OF FIRST CANONICAL VARIATE

$F^2_{462} = 5.50$

$F_p < .005$

$R_c = .19$

$R^2 = .03$

PREDICTED CLASSIFICATION VERSUS ACTUAL GROUP MEMBERSHIP

		NUMBER PREDICTED TO BE IN GROUP				
		ONE	TWO	THREE+	TOTAL	MISSES
ACTUAL NUMBER IN GROUP	ONE	28	146	44	218	190
	TWO	16	160	33	209	49
	THREE	5	25	8	38	30
					465	267

% MISCLASSIFIED = 57.7%

*Sample = 218
**Sample = 209
***Sample = 38

Income as a Factor in Propensity to Shift Mode

Four categories of income were tested: very low (>$4,000), low ($4-8,000), medium ($8-12,000), and high (<$12,000)

The tests show significant separation of the four groups on the dimensions of overall travel time, residential travel time, and out-of-pocket expenses. Observation of the variate means for overall travel times show that a 7-10 percent decrease in overall travel time would be sufficient to cause a shift below incomes of $12,000 (Table XLVI). The mean for high incomes (<$12,000) at an index less than 1 shows that this group would tolerate, on the average, greater overall travel times if, presumably, other characteristics make up for it. In this case it appears this group would demand a more frequent service as a trade-off. The higher income group would also demand lower overall out-of-pocket costs, as would the medium income group. On the other hand, medium and higher income groups would tolerate some walking between parking lot and transit vehicle, in contrast to the lower income groups.

On the other hand, for the parking charge variable the very low income groups are sensitive to increased parking charges in that only small increases would cause a shift. Low income groups group shift with a doubling of the parking fee as would middle income groups, whereas high income groups would be somewhat more sensitive.

Table XLVI

INCOME GROUP MEANS AND STANDARD DEVIATIONS
FOR VERY LOW, LOW, MEDIUM, AND
HIGH INCOME CATEGORIES

VARIABLE	VERY LOW*	LOW**	MEDIUM***	HIGH****	
		GROUP MEANS			AVERAGE
X_1(OTT)	1.105	1.071	1.082	.899	1.022
X_2(OPE)	1.313	1.787	3.136	2.940	2.633
X_3(TTO)	.714	.605	.291	.243	.378
X_4(FREQ)	3.579	4.206	4.427	4.544	4.370
X_5(PKCHG)	1.043	.553	.529	.621	.586
		GROUP STANDARD DEVIATIONS			AVERAGE
X_1(OTT)	.567	.524	.646	.503	.572
X_2(OPE)	1.029	6.677	14.518	9.159	10.790
X_3(TTO)	1.043	1.035	.688	.634	.812
X_4(FREQ)	2.835	2.473	2.978	3.266	2.942
X_5(PKCHG	1.301	.530	.588	.766	.683

*Sample = 19
**Sample = 126
***Sample = 171
****Sample = 149

The statistical tests show an overall discrimination at $p < .001$ with all three roots significant (Table XLVII). Most important variables are overall travel time, out-of-pocket expenses (as shown by the scaled vector loadings) and residential travel time (Table XLVIII). Parking charge is also significant in the explanation of the differences between the income classes. All groups are separated from each other on these dimensions as shown by the D^2 matrix and its accompanying F_{D^2} ratios (Tables XLIX and L). The following linear discriminant functions for very low, low, medium and high incomes respectively are used to calculate the discriminant scores and the posterior classifications. These are, respectively:

$$z_{v\ell} = -3.150 + 3.133X_1 + 0.934X_3 + 2.080X_5$$

$$z_{\ell} = -2.194 + 3.145X_1 + 0.761X_3 + 1.009X_5$$

$$z_m = -2.043 + 3.242X_1 + 0.263X_3 + 0.950X_5$$

$$z_n = -1.592 + 2.660X_1 + 0.223X_3 + 1.180X_5$$

The resulting posterior classification with 62.2 percent misses appears very crude (Table LI). However, since the assignment is based on the group with the highest probability of membership with no allowance for suspended judgment, the more groups there are the lower expectation of accurate classification. Under these circumstances the accuracy is considered reasonable.

Table XLVII

STATISTICAL TESTS OF THE PROPENSITY OF INCOME GROUPS TO SHIFT MODE

UNIVARIATE F-TESTS FOR INCOME

VARIABLE	F-RATIO	F_p
X_1(OTT)	3.46	<.05
X_2(OPE)	.52	n.s
X_3(TTO)	6.61	<.001
X_4(FREQ)	.78	n.s
X_5(PKCHG	3.53	<.05

SIGNIFICANCE OF DISCRIMINATORS

$\Lambda = .9013$

$F_1 = 15.0$

$F_2 = 1262.0$

$F_{H2} = 3.227$

$F_p < .001$

$R^2 = .096$

SIGNIFICANCE OF ROOTS

No. of Roots	λ_i	% of Trace	No. Possible Roots	Σ Roots	d.f.	χ^2	χ^2_p
1	.0674	63.27	5	.1065	15	198.0	<.001
2	.0291	27.30	4	.0391	8	72.5	<.001
3	.0100	9.43	3	.0100	3	18.6	<.001

Table XLVIII

VECTOR LOADINGS ON DISCRIMINATORS

VARIABLES	SCALED VECTORS		
	I	II	III
X_1(OTT)	-3.50	-7.82	8.25
X_2(OPE)	104.71	-28.06	52.06
X_3(TTO)	-14.38	.36	-7.88
X_4(FREQ)	12.14	1.75	-20.97
X_5(PKCHG)	-3.80	11.72	6.99

Table XLIX

SIGNIFICANCE OF GROUP SEPARATION

D^2 MATRIX

	VLO	LO	MED
LO	.1133		
MED	.3456	.1178	
HI	.3431	.1218	.2116

F-RATIO MATRIX

	VLO	LO	MED
LO	5.23		
MED	16.00	5.41	
HI	15.90	5.63	9.78

$F_p < .001$ in all cases

Table L

SIGNIFICANCE OF DISCRIMINATORS USING

ONLY SIGNIFICANT VARIABLES

$F^{3}_{459} = 4.42$

F_{p} .001

F-PROB MATRIX

	VLO	LO	MED
LO	.031		
MED	.003	.010	
HI	.004	.000	.017

CANONICAL CORRELATION FOR EACH ROOT

$R_{c1} = .22$

$R_{c2} = .17$

$R_{c3} = .09$

Table LI

PREDICTED CLASSIFICATION VERSUS ACTUAL GROUP MEMBERSHIP

	PREDICTED					
ACTUAL	VLO	LO	MED	HI	TOTAL	MISSES
VLO	7	4	4	4	19	12
LO	23	21	39	43	126	105
MED	15	17	70	69	171	101
HI	10	18	43	78	149	71
					465	289

% MISCLASSIFICATION = 62.2%

Occupation as a Factor in Propensity to Shift Mode

Six occupation groups were examined: managerial, professional, secretarial, clerical, sales and other (Table LII). Overall discrimination was significant in the 5 variables studied with 4 roots significant at least at $p < .01$ (Table LIII).

Large variations in the values for out-of-pocket expenses show that managers and professional employees demand substantial reduction in expenses while secretaries and clerks are reasonably satisfied with the existing cost of service (i.e., parking cost). Sales employees and other employees which include craftsmen and labourers show a substantial desire to have expenses very much lower than they currently experience. However, these variances do not prove to be significant because of the extreme values within some groups. The standard deviations for the latter two groups is very high as well as substantial deviations within the managerial and professional classes.

Some occupational groups appear to be prepared to walk substantially greater distances at the terminal, particularly secretaries and sales people. Craftsmen and labourers are unwilling to walk very much further than at present while managers and professional workers will walk some increased distance.

Secretaries are the most sensitive to increases in parking fee increases, while clerks are the least sensitive.

Table LII

OCCUPATION GROUP MEANS AND STANDARD DEVIATIONS FOR MANAGERS, PROFESSIONALS, SECRETARY, CLERICAL, SALES, AND OTHER OCCUPATIONAL CATEGORIES*

VARIABLE	MANG.	PROF.	SEC.	CLER.	SALES	OTHER	
			GROUP MEANS				AVERAGE
X_1(OTT)	1.006	1.040	1.176	1.114	.904	.879	1.022
X_2(OPE)	2.276	2.849	1.267	1.037	4.778	4.867	2.633
X_3(TTO)	.346	.319	.299	.515	.195	.836	.378
X_4(FREQ)	4.097	4.787	4.176	4.023	5.238	3.636	4.370
X_5(PKCHG)	.622	.516	.969	.407	.658	.760	.586
			GROUP STANDARD DEVIATIONS				AVERAGE
X_1(OTT)	.619	.497	.529	.690	.539	.545	.572
X_2(OPE)	7.965	11.351	1.057	1.087	16.119	21.596	10.790
X_3(TTO)	.782	.669	.585	1.121	.510	1.221	.812
X_4(FREQ)	2.842	3.169	2.675	2.387	3.491	2.369	2.942
X_5(PKCHG)	.778	.501	1.021	.348	.389	1.058	.683

*Sample Sizes:
Mang. = 176
Prof. = 174
Sec. = 17
Cler. = 44
Sales = 21
Other = 33

Table LIII

STATISTICAL TESTS OF THE PROPENSITY OF OCCUPATION GROUPS TO SHIFT MODE

UNIVARIATE F-TESTS

VARIABLE	F-RATIO	F_p
X_1(OTT)	1.13	n.s
X_2(OPE)	.75	n.s
X_3(TTO)	2.89	<.05
X_4(FREQ)	1.94	n.s
X_5(PKCHG)	2.66	<.05

SIGNIFICANCE OF DISCRIMINATORS

Λ = .9050
F_1 = 25.0
F_2 = 1691.75
F_{H2} = 1.84
F_p < .01
R^2 = .091

SIGNIFICANCE OF ROOTS

No.	λ_i	%	Possible Roots	$\Sigma\lambda_i$	d.f.	χ^2	χ^2_p
1	.0508	49.98	5	.1017	20	235.0	<.001
2	.0266	26.14	4	.0509	12	118.0	<.001
3	.0197	19.41	3	.0243	6	56.5	<.001
4	.0045	4.46	2	.0045	2	10.4	<.01
5	.0000	.01	1	.0000	-	-	n.s

Labourers, sales people, and managers are all above average in sensitivity to parking fee increases.

The scaled vector associated with the first root shows that bus frequency followed by parking cost and residential travel time are important considerations for the various occupation groups to shift mode (Table LIV).

Table LIV

VECTOR LOADING ON DISCRIMINATORS

VARIATES	SCALED VECTORS				
	I	II	III	IV	V
X_1(OTT)	-3.51	3.59	-7.73	-5.63	-5.77
X_2(OPE)	-12.11	-62.33	110.88	18.50	-192.14
X_3(TTO)	11.43	7.98	4.53	-8.19	3.87
X_4(FREQ)	-28.64	-14.09	26.06	-39.17	26.49
X_5(PKCHG)	7.04	-10.79	-5.12	-3.79	1.85

Mahalanobis D^2 and the associated F probability show that the separation of all groups is significant at $p < .001$ (Table LV).

The discriminant functions are respectively:

$$z_m = -0.514 + 0.533X_1 + 1.357X_5$$

$$z_p = -0.369 + 0.492X_1 + 1.126X_5$$

$$z_{sec} = -1.093 + 0.459X_1 + 2.115X_5$$

$$z_c = -0.386 + 0.790X_1 + 0.887X_5$$

$$z_{sles} = -0.503 + 0.300X_1 + 1.438X_5$$

$$z_o = -1.169 + 1.291X_1 + 1.656X_5$$

Table LV

SIGNIFICANCE OF GROUP SEPARATION

D^2 MATRIX

	MANG.	PROF.	SEC.	CLER.	SALES
PROF.	.31				
SEC.	.71	1.80			
CLER.	1.06	2.37	.05		
SALES	4.55	2.60	8.71	9.92	
OTHER	4.68	3.06	9.02	10.15	.48

F-RATIO MATRIX

	MANG.	PROF.	SEC.	CLER.	SALES
PROF.	14.35				
SEC.	32.80	83.20			
CLER.	49.00	110.00	2.32		
SALES	210.00	120.50	404.00	460.00	
OTHER	217.50	141.50	418.00	470.00	27.20

$F_p < .001$ in all cases

Using these functions the posterior classification shows 79.8 percent misclassifications (Table LVI). Again, the number of groups affects this poor assignment, but it must be concluded that occupation has a very weak influence on an individuals

propensity to shift modes. The significance of the discrimination using only the significant variables in the discriminant functions is shown in Table LVII.

Table LVI

PREDICTED CLASSIFICATION VERSUS ACTUAL GROUP MEMBERSHIP

		PREDICTED						
		MANG.	PROF.	SEC.	CLER.	SALES	OTHER	MISSES
ACTUAL	MANG.	4	46	33	8	56	29	172
	PROF.	-	65	36	10	36	27	109
	SEC.	-	6	4	1	3	3	13
	CLER.	-	19	6	2	9	8	42
	SALES	-	6	4	0	8	3	13
	OTHER	-	10	6	4	2	11	22
								371

% MISCLASSIFIED = 79.8%

Table LVII

SIGNIFICANCE OF DISCRIMINATORS USING ONLY SIGNIFICANT VARIABLES

$$F^2_{458} = 2.77$$
$$F_p < .05$$

F-PROBABILITY MATRIX

	MANG.	PROF.	SEC.	CLER.	SALES
PROF.	.331				
SEC.	.126	.031			
CLER.	.077	.223	.010		
SALES	.707	.534	.348	.120	
OTHER	.004	.001	.048	.018	.015

CANONICAL CORRELATION FOR FIRST TWO ROOTS: $R_{c1} = .185$
$R_{c2} = .156$

PRINCIPAL FINDINGS

It was postulated that one public objective to rationalize modal balance is to decrease the use of automobiles and increase the use of some more efficient system from the criterion of public welfare. A planning tool in the form of a quasi-predictive model was developed which would allow an assessment of the results of creating a park and ride system, and the increase of parking costs in the CBD on the modal balance of the corridor; specifically the number of car drivers who would shift to a new system. The model also allows us to determine what socioeconomic groups would be more sensitive to changes in the transportation system. The analysis has shown that incremental policy changes regarding the supply, location, and charges for parking, along with an integrated transit facility in the corridor may have dramatic effects on changing the mode split. Although this analysis was of the development and feasibility of the model and planning approach, and not of simulation tests, some of the effects can be inferred.

The results justify the concern of transportation planners with travel time. If a park and ride system could be developed which would reduce the overall travel time by only a modest amount it would have a significant effect on the number of persons who would shift to the system. The results in the

corridor studied here are probably conditioned by the fact that the North Shore population do not seem adverse to bus travel if the service is competitive, as it is for many persons in this area. In practice this decrease in travel time would be very difficult to achieve under all circumstances. This is further compounded by the fact that any multimodal system would need to be almost time-continuous without a substantial wait for a transit vehicle. Transit frequency within the overall system was shown to be the most important factor in a consideration of this type of system. However, the frequencies demanded for a substantial shift are not unrealistic with a frequency of 4.5 minutes achieving substantial success. Subway headways in larger cities are usually less than half of this value in rush periods, and therefore given a sufficient capacity in the feeder system (roads, parking, and feeder buses) such a system appears feasible.

The tests show that drivers will tolerate some walking in the system. The mean walking distances preferred for a shift of just over 2 minutes is well within the usual walking distances most motorists face in other circumstances. For large cities up to 5 minutes at the destination end, and somewhat less than 10 minutes at the origin end, although little is known about this aspect of a motorists walking tolerance. It is highly likely that if these were put together, however, that the total of 15 minutes is intolerable, although, in Chapter III it was shown that almost 32 percent of those going by car walked

10 or more minutes at the trip destination. One factor to consider in this analysis is that the tolerable walking distance at the destination is unknown, and this, if it had been asked might have involved a trade-off with the residential walking distance and thereby decreased the latter. Judging by the results of Table XIV, Chapter III, which shows substantial numbers of car drivers walking more than 5 minutes at trip destination and that transit passengers are in general deposited closer to destination (as would the park and ride system), it seems likely that a two minute walking distance at the parking-transit interface would not cause a problem in encouraging the use of the system.

The insensitivity of out-of-pocket costs in the manner of combined bus fare and parking cost is difficult to interpret. Most studies have shown transit fare decreases to have little effect on diverting car drivers. On the other hand, parking cost is usually found to be a sensitive factor. One explanation is that the respondent perceived this expense more in the manner of an over the road cost (which is usually not a strong incentive to shift), as he would vehicle operating cost or transit fare. In practice this is not an unrealistic explanation since some park and ride systems have a fee which is paid on parking, but which includes the transit portion of the fare (for example, the Toronto Transit Commission). The driver may see this as an integrated trip fare.

As expected parking charges in the CBD would be an effective means of balancing the mode split. Whether the charge is levied as a fee increase or as a tax would not affect the results since the important aspect of the factor is that it is not a hidden cost, such as vehicle operating costs. This appears to be a fruitful area in which to pursue ways of rationalizing mode balance.

An important finding of this chapter is that socio-economic structure exerts a significant influence on what dimensions an individual will place relative value in his sensitiveness to shift mode. In general those over 40, from families with more than one car, with middle to higher incomes, in the non-professional occupations would be more resistant to shift than the population as a whole. The age factor influences mode shift propensity through out-of-pocket expenses and frequency of service. Car ownership is an influence because of overall travel time and residential walking time. This is probably a spatial effect as well with car ownership increasing as distance from the CBD increases, thereby pointing up the trade-off between travel time and owning another car. Income influences are varied. The lower income groups are more time sensitive than the high income groups, although the latter group are more sensitive to transit frequencies and out-of-pocket costs. On the other hand, lower income groups would tolerate less walking than the higher income groups, and are more sensitive to parking charge increases.

The result of occupation as an influence on shift propensity is not conclusive, although some tendencies emerge. Sales people and the lower status groups are sensitive to cost factors, while secretaries and clerks are not. Unexpectedly managerial and professional employees also appear to be cost sensitive. Paradoxically secretaries and clerks are parking charge sensitive, the explanation is presumably that again fare and parking cost combined is perceived as a line travel cost while parking is not.

CHAPTER VI

MAJOR CONCLUSIONS, IMPLICATIONS OF FINDINGS, AND FURTHER RESEARCH

There appears to be a rationale for planning an appropriate mix of transit and highway facilities to rationalize flows on the system, which will reduce undesirable social consequences. Commuters make mode choice decisions according to their socioeconomic status which also determines the relative value given by individual trip makers to time, cost, and convenience factors. The appropriate mix of facilities is that which optimizes the travel habits and preferences of the users. The planning of such a mix is predicated on understanding the relationship between socioeconomic structure and travel preferences and thereby adjusting the system so that public benefits are maximized. This criterion assumes that each trip maker will have available that combination of services which he desires. While it is not possible that this range of choice can be provided, some optimization can be achieved by adjusting the service levels of each mode. However, to provide for an increased level of satisfaction for all commuters may increase social costs. For example, if in the extreme case all commuting was done by automobile the level of satisfaction of users may be increased, but at substantial

social costs. Therefore, the primary criterion for mode split adjustment is that travel demands be met, but within a limiting constraint provided by social objectives.

Recent concern for the revitalization of public transportation has been for the purpose of creating increased public benefits by way of more efficient land use patterns, economic efficiency, and social conditions of an urban region. If there are no relative changes in system flows there will be no changes in these public benefits. Traditional analyses of mode split have shown that we can expect little shift from automobile commuting to public transportation with the simple improvement of line haul transit systems. Rapid transit improvements where they have been carried out in North America have a history of operating successfully only at the expense of the rest of the transit system, rather than as an attraction for automobile commuters. In Toronto for instance, while subway revenue passengers increased from 35.2 million in 1955 (its first full year of operation) to 75.8 million in 1967,* the ratio of transit revenue passengers to metro population decreased from 240 to 167 during that period.[1] The subway (serving the CBD) increase was accompanied by a decrease in total transit patronage, while the number of persons coming downtown by automobile increased.[2] These trends in Toronto and the absence of substantial projections of a shift from

*Including the Bloor-Danforth line.

automobiles to the new rapid transit system in San Francisco* has prompted Zettel to remark that:

> BARTS impacts will depend...on conscious policy action.[3]

The conclusion Zettel reaches is that BART will not "inexorably" cause changes but rather that BARTS existence will stimulate public action.

The thesis of this study is that successful public policies to affect the balance between automobile travel and public transportation must contend with two factors; the incidence of effects of policy options, and some mechanism to successfully control demand. Several conclusions about the incidence of effects of policies have come from the analysis.

INCIDENCE OF EFFECTS OF MODE SHIFT POLICIES

It has been shown that the socioeconomic characteristics of commuters to the CBD are different from non-CBD commuters. Therefore parking policies oriented to changing the structure of parking in the CBD will affect the mode split differently than those policies for non-CBD locations. The differences in these has not been examined in any depth in the study except as a framework to study CBD oriented trips.

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*Zettel concludes from the studies done for BART that "BARTS main source of patronage will be riders who have been diverted from other transit systems" although there will be an estimated 3200 automobiles removed from the trans Bay crossings in the peak hour in 1975. (See Ref. 3).

However, in changing the mode split by means of policies in the CBD the resultant decrease in congestion on the streets may encourage more through traffic. On the other hand CBD users may find that they can leave home closer to a desirable time thus creating a peak hour as sharp, but not as prolonged as previously. This would tend to discourage generated through traffic and increase benefits to users. Because of these unknown factors it is not feasible to estimate the relative impact of a shift on CBD vs non-CBD travel, nor the differential social effects resulting from this.

The analysis of CBD travel shows that high status occupational groups are not adverse to using the bus mode. This might be expected in the case study situation. Trip lengths are relatively short, bus service is good, and traffic congestion is heavy. The Bridge traffic is a well recognized rush hour problem in Vancouver and the rationalization of these facts appear to encourage many professionals to use the bus. On the other hand the low status occupations appear to be willing to put up with congestion to be able to drive downtown.

Another factor in the study was the apparent dichotomy within the so-called "choice" rider category. It appears that automobile drivers can be classified into those who have analysed (to some extent) the advantages of bus travel, and those who have never considered it as an alternative. This latter group may be highly susceptible to transit marketing strategies or such negative controls as parking fee changes.

A policy mechanism will affect users in different ways depending on the relative values of the system. Simple solutions such as lowering fares (or raising them) to rationalize the mode split should consider the incidence of the effects of the controls. The study has shown an interdependence between the socioeconomic structure of the trip maker and the way in which the system attributes are valued. Consequently any changes in the system will not only effect the number of users of the system and the mode split, but also the characteristics of the client group who use each mode.

Correlation tests showed a strong interdependency between level of income and travel expenses when the correlation between structure and system attributes is maximized. Those of higher incomes have an ability to select the more expensive alternative. This is as expected and has been seen in the increased ownership and use of automobiles as the general level of societal incomes has increased. Of more interest is the interdependencies of other structural variates with system performance. Car ownership and availability are related to excess travel times and the frequency of bus service. This follows intuitive reasoning. The decision to extend bus lines into new areas follows development of these areas when there is a sufficient demand perceived to justify these extensions.* If car ownership is high demand for bus service is low and

*Some experimentation with providing full service to relatively undeveloped suburban areas has been carried out. (See Ref. 4).

therefore service is only provided when those who have no transportation choice become a significant group to warrant transit service either from political pressure or economic incentives. On the other hand where transit service is already good, the need for a second or third car diminishes. Inferences are that if a high quality transit service is provided to a developing area (such as the North Shore communities) the demand for such a service would cause a switch away from multicar ownership. This however would require a change in the "pay as you go" philosophy of transit decision making and would require subsidization of capital and operating expenses until demand increased to economic levels.

Moreover, changes in the transportation service will have an impact on the structure of the influence area of the system. If certain restrictive changes are made some people will, in the long run, move out of the influence area (i.e., relocate) rather than face the increased disutilities of travel. On the other hand, others who find the new set of circumstances advantageous may locate to take advantage of the new service. In the long run therefore equilibrium will occur between the socioeconomic structure of a corridor and the transportation system serving it. This study has assumed a fixed demand for travelto concentrate on the relationship between structure and modal balance. Further research however is needed to trace the impact, not only on the mode split but on the changes

in socioeconomic composition of those using the system. The expectation is that different corridors defined by transportation service would have different socioeconomic structure. That is, a corridor served primarily by arterials and bus will have different socioeconomic characteristics than one served by freeways and rapid transit. The extension of the type of analysis carried out here would require the measurement over time of changes occurring with transportation policy inputs.

The introduction of a multimode park and ride system into a transportation corridor is shown here to be valid in terms of reducing the amount of automobile traffic entering the CBD. If the proper combination of walk times, transit frequencies, and an overall reduction in travel time was feasible a conclusion of this study is that substantial shifts would occur. (However, since the shift to transit would relieve congestion and thereby, perhaps substantially, decrease disutilities of car driving, a countervailing tendency would be to increase the use of the corridor by generated traffic).* The increase in overall travel time needed to effect a shift would probably require a rapid transit link so that by increasing substantially the line-haul speed, some impact on overall time was effected. The major difficulty, however, appears not

*There seems no easy solution to this problem. McGillivray has suggested an analytical procedure by estimating the interdependencies between variables and attempting to assess the effects due to simultaneous changes in two or more variables. That is, for example, test a 30 percent decrease in transit fares concurrently with an implied 5 percent increase in road travel time. (See Ref. 5).

to be in terms of transportation efficiency but rather in the institutional structures needed to bring about the necessary changes in policy.

PUBLIC INTEREST BENEFITS AND SYSTEM PERFORMANCE

The social objective of policies to rationalize the mode split or specifically to create a shift to transit, is to increase public interest benefits. This implies balancing demand with the capacity of the facilities by optimizing the use of the system. This analysis has suggested a framework and mechanism which will effect a balanced system providing the criteria for such a balance are determined outside the model.

Current interest among transport economists is on a price mechanism to get a more effective use of transport facilities. This concern is divided between the use of price to ration the use of highways, and pricing to make transit more attractive. The economic premise behind pricing to ration the use of road space is that the traffic flows most beneficial to traffic as a whole are those levels at which the cost of road use to each individual is that which takes into account not only the cost to the individual but also the cost he imposes on the whole traffic stream by contributing to congestion of the stream. When this total cost (i.e., cost of operation of his vehicle due to congestion plus the increased cost to other vehicles due to his incremental contribution to congestion) equals benefits the stream will become stabilized and total benefits will be maximized.

Two problems however are extant in a pricing mechanism for mode split adjustment. First, no practical means of implementing charges has been found. Suggestions for congestion pricing have been vehicle meters with computer billing, external meters charging traffic for the length of time in certain areas such as the CBD, and a parking charge or tax. While parking charges are not particularly satisfactory to control congestion (because of vehicles going through the limited area where congestion pricing is in effect) this method appears to have the most promise for mode split adjustment because of its imposition at the terminal of the journey. The second problem with pricing is the apparent insensitivity of many to cost of travel. Consequently, mode split adjustment requires a mechanism which goes beyond pricing.

The present study extends pricing ideas to include non-economic as well as economic influences and to consider incidence of effects. If the mode choice is a function of system attributes as demonstrated here then maximum social benefits are gained when the use of the system is such that each trip maker is at the margin where his benefits (or satisfaction levels) are just equal to the costs (or disbenefits) incurred on the system. Given a level of demand for total trip making and a continuous supply function there will be an adjustment between modes so that everyone using the system will maximize his benefits relative to his costs. Releasing the restriction

of a given demand for travel, trip making will increase until maximum social benefit is realized.

The quandry faced by transit management of uneconomic levels of demand stems from a mis-interpretation of this economic premise. The pressure to lower fares as a method of attracting riders follows the law of supply and demand. However, it appears that non-economic factors such as a comfortable ride is an important determinant of demand for transit, and lowering the price of transit invariably decreases revenues in the long run, or does not increase them enough to provide a better service level. Therefore fare decreases are self defeating. As Lisco points out the lack of demand for transit is not because fares are too high but precisely because they are too low, thus causing underinvestment in transit facilities and a consequent decline in quality of service.[6] Quality of service which includes comfort and convenience factors as well as time and cost factors is thereby a primary focus of any control mechanism which is designed to adjust demand.

PARKING POLICY AS AN INCREMENTAL CONTROL MECHANISM

It has been demonstrated that parking factors are influential in the mode choice decision. Parking policies may therefore have substantial effects on adjusting the mode split. The behavioral model of mode split shows that residential distribution time, CBD distribution time and parking rates have important influences on mode choice. These are all

factors which could be included in a municipal parking policy, particularly a policy which includes residential distribution in conjunction with a rapid transit line haul system.

Parking and Residential Distribution

Residential distribution is a central determinant in mode choice. Few studies have been done on the micro-aspects of this problem, that is, aspects such as walking distance to the bus stop, frequency of buses, deterrants to comfort and convenience in making the walk portion of the trip wait times, shelters etc.* Furthermore, it may be that automobile drivers have never considered these factors. Lansing and Hendricks

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*Several demonstration projects have examined some of these:

The Skokie Swift demonstration project provided a high speed, non-stop rapid transit line to a suburban community of Chicago and included 522 parking spaces at the terminal and feeder bus services. Some 18 percent diversion of automobile drivers to the system was reported. (See Ref. 8).

Grand River Bus Route Study in Detroit showed over 12 percent increase in average daily patronage with headways decreased from 3 1/2 - 2 minutes at peak periods. However, only about 1/2 of this increase was new bus riders. A demonstration project in Boston on Bus and Rail Service and Fare studies concluded that frequency of service was "a more important factor than lower fares in increasing passenger volumes." (See Ref. 9, 10).

An 18 month study of a commuter park and ride terminal on the Pennsylvania Railroad in which a 300 car free parking lot was established 1 1/2 miles from downtown Brunswick N.J. showed an increase as much as 123 percent for the average week-day patronage. (See Ref. 11).

In late 1968 the Metropolitan Toronto Planning Board's survey of the effects of two parking lots on the Bloor-Danforth Subway line on commuters showed that 54.0 percent and 42.8 percent respectively of those parking on the two lots had previously driven all the way before the lots were opened. Park and ride passengers accounted for 10.5 percent and 5.6 percent of all passengers entering the two terminals. (Besides this 23.1 and 42.1 percent of all patrons were via bus and ride.) (See Ref.12).

show for example that car drivers do not consider a bus being available if it is more than 10 minutes away.[7]

The findings here show that a critical factor in parking and mode choice is the existence of a convenient parking and transfer arrangement at the residential end of the commuter trip. Residential travel time (excluding waiting times) has a high loading on the discriminator between transit riders and auto drivers. It is also shown to have a major influence on the encouragement of a shift. In this case the travel time factor is that between the parking area and loading point of the line haul system. The conclusion is that to be effective not only must parking be an integrated part of the terminal but also must seem so to the user.

Parking and City Centre Planning

Congestion of motor vehicles in the centre of the city has long been a concern of planners. Some method appears to be needed to reduce congestion, either by restricting entry of the people who drive cars or by encouraging them to use transit, on the assumption the latter will have less deleterious effects than the motor car. This study has proposed an alternative to congestion: parking policy as an incremental means to help accomplish the end of shifting more people to transit. It has been shown that parking charges would be effective in causing some persons to shift mode. It was hoped that policies related to removing worker parking supply from the CBD to peripheral areas would induce more transit riders. However, the

analysis of behavior showed this generally not to be a factor in mode choice, and therefore on the basis of the evidence it must be concluded that such a policy would not deter many from driving downtown to work. However, further research on this is needed, specifically to attempt to include a CBD walking factor in the shift propensity analysis.

Insufficient analysis to date has been given to the concept of "metering" road traffic. Beesley's and Roth's work stand out in attempting to develop the concept of congestion road pricing and the implementation of a means to collect the revenues from such a concept. Both authors produce arguments against CBD parking policy as a metering mechanism. Arguments against parking policy as a control mechanism to meter traffic and to adjust mode split are first, that charging those who park in the CBD increased rates in effect subsidizes through traffic because their disutility is less due to the decreased numbers of cars downtown; and secondly, that there is insufficient public ownership of parking facilities to have any effect on competitive rates. The first difficulty may be alleviated if parking supply and location are tied to the capacity of the street system serving the downtown. It has been shown that it is possible to adjust the use of streets by parking methods.* A planning objective for centre city

*The author has carried out simulation studies of traffic entering downtown Toronto for the purpose of estimating the effect on street flows of adjusting the location of parking supply. Total volumes entering the core, as well as volumes on individual streets could be changed by varying the configurations of parking supply.[13]

planning, with the concept of transportation corridors, is to impose an upper limit on the total amount of street capacity and therefore parking supply, to serve this capacity by corridors, and when the capacity of the corridor is in danger of being exceeded to encourage by public policy the transfer of activity generated to an improved transit system. Since CBD activity appears to also have an upper limit as the metropolitan area grows, an effective decrease in congestion would occur.

Parking Policy Criteria

These findings indicate the need for parking policies to be designed around several basic criteria. First, it is necessary to view parking as an integral part of the transportation system. As roads and streets are public resources it is logical that the protection of investment in these facilities is related to the terminal capacity. Therefore a strong argument exists to include parking capacity as part of this system. By municipal control of parking supply, the demand for and use of the public road resource can be controlled. While a simple requirement, the institutional framework in most cities mitigate against public control by viewing parking operations as a use of land to be controlled by market forces in the traditional manner.

The attitude is generally held that parking policy is directed to providing a service to the public. The parking

problem of the CBD is invariably seen in terms of parking "needs" for the continued vitality of downtown or other such service objectives. Only when this service is not being provided effectively by private enterprise, is it held by the current philosophy that "municipal agencies concerned with the welfare of downtown may be justified in assuming the role of parking developer."[14] Successful mode split planning by a parking mechanism is predicated on parking operations being institutionally integrated with streets and transit.

Secondly, if street capacity, parking supply and transit flows are in balance the concept of public control of parking can include its effect on transit whether it is publicly owned or not. However, any adjustment of the balance between auto use and transit use must include incentives as well as disincentives. Parking restrictions by price or supply controls must also be accompanied by transit improvements if the overall public benefit is to be maximized. It would be desirable that transit was therefore also subject to public ownership or control. To achieve an optimization of transportation service (considering only the journey to work), a publicly owned transit system with ownership of residential terminals including parking rates and supply combined with public control over commuter parking at the distribution end of the trip appears necessary. Thus, the transit authority with parking fees and line haul quality directed to the provision of incentives, and municipal

parking policy which would support a given mode split, could be used as instruments of public policy.

The third criterion of parking policy is that it provide for incremental policy adjustments. The major advantage of using parking policy as a control mechanism is its inherent incremental investment nature. A change of a few spaces, or a minor adjustment in rate structure can be implemented quickly and its results studied. In this manner public objectives can be reached in incremental steps with largely non-capital investment decisions. Parking policies should exploit the incremental nature of this control mechanism and through gradual, and incremental, changes achieve public ends.

Operational adjustment such as rate increases, a parking tax, rate structure controls; as well as investments in facilities are more or less reversible. Parking lot operation is largely considered commercially as a holding use of land, in which a parking lot becomes a temporary revenue producer awaiting change over to a more profitable use. Therefore, the temporary nature of parking operations can be used to advantage by testing operational changes without large capital commitments. (The commitments here, even for say a municipally owned parking garage, are nothing like those of street widenings in built up areas, downtown freeway construction, or rapid transit).

Parking policy options however face important barriers to successful implementation of a mode shift. The study has shown that a great number of car drivers park free. Therefore rate structure changes will not affect these people. Also most of these employees have sufficient leverage to demand on-site parking thus also effectively making themselves immune from location policies. There are also people who use their cars during the day and would not, in any case, be able to shift. These two groups represent the irreducible minimum car population in the CBD.

THE PROPENSITY MODEL

A primary significance of the study was the development of a propensity model to study mode shift. The model appears to be a feasible tool for analysis and tests of a control mechanism. The model tests show for example that a modest decrease in travel time would effect a significant shift to a park and ride type multimodal system. In practice such a reduction in travel time would be difficult because of the multimodal concept incorporating vehicle transfers, and the necessity for almost time-continuous travel including very frequent service. However, neither the time constraints nor frequencies are unrealistic and with design and planning features mentioned elsewhere have possibilities.

The tests show that drivers will tolerate some walking in the system. It appears that existing walking distances in the CBD of Vancouver are relatively great and may

account for the relative insensitivity to walking. There is no doubt that both residential times and CBD walking times are considered jointly by the trip maker, and must be considered in one policy set.

Unexpectedly parking cost when combined with transit fare did not assume as much importance in encouraging a shift as anticipated. It may be that the trip maker views these combined costs as a single journey cost. Parking cost by itself however did appear to be a significant factor in the shift model.

The model substantiates the hypothesis that socio-economic structure has a significant influence on the value placed on different dimensions of the system and sensitiveness to mode shifts. As expected the more affluent and established groups would resist a shift, but unexpectedly professional occupations would be shift-sensitive. This conforms to the findings elsewhere in the study and indicates potential shift patrons among this group.

NEW TECHNOLOGICAL FACTORS IN MODE SPLIT PLANNING

Of major importance is the travel time from residence to the bus stop. All tests showed this. This finding emphasizes the importance of the multimodal concept as opposed to a policy of single technological improvements to the line haul system. No line haul system, regardless of the service

provided on the line haul will be successful in attracting patronage unless the residential travel time perceived is desirable by the user. Current experiments are being conducted which may hold promise in proving a viable dial-a-bus system for this service. Feeder bus routes can serve a park and ride system with line haul provided by express buses or by rapid rail transit. One application is the bus-freeway in which buses and cars are metered onto a freeway in the mix which provides rapid bus transit during peak periods.[15] This system has the potential of a single mode from home to work with buses providing both local and rapid transit service. The bus-freeway is being experimented with in three locations, and although the effect on mode split is still unknown the inference is that if the residential distribution system can be successfully implemented mode split adjustments will occur.

Findings show also that better bus frequencies are critical to mode shift and any feeder bus system would need to provide better than existing average frequencies. This would probably imply smaller buses and in turn would probably necessitate subsidization, since the cost of labor is a major operational cost of a transit system.* The reduction of the pay load with smaller buses is a serious bottleneck to system rationalization. Equally, this factor also is predominant

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*For example driver costs of the Toronto Transit Commission amounts to between 60-65 percent of the systems operations cost.

in the downtown distribution system, which although not shown in this analysis to be an important determinant of shift, does have some impact. The Minibus of Washington D.C. is considered successful for shopping trips and a similar system may be effective for work trips. However, the findings here indicate no substantial effect on mode split for work trips.

This research has reduced the modes to abstractions of time, cost, convenience factors and in this manner has attempted to relate demand to the attributes of possible modes rather than to the modes themselves. This has been effective in showing the modal characteristics which need to be incorporated into new technological changes. Recently many suggestions have become extant and some of these hold promise in the light of the findings of this research. The dial-a-bus feeder system, the dual mode system in which a private vehicle is transferred to an automated line haul system are possibilities. However, this research has led to the conclusion that a conventional express bus combined with a park and ride feeder system could be made successful without radical innovations. However its success is dependent upon the convenient transfer from automobile to bus and the reduction of terminal waiting times.

The findings of this study indicate little substantial shift from the car mode unless transfer and waiting times by an alternative mode be reduced or eliminated. (An alternative philosophy may be to decrease line haul times enough

to "swamp" the importance of waiting and transfer times). The only practical method of providing a nearly continuous journey downtown is the combination of automobile parking and a fast line haul system. This combination of modes has the most promise in cutting down on residential trip times, in-trip transfers and waiting times. A commuter can control his transfer time by his departure time from home to arrive at the terminal at the last possible moment. By integrated design of parking facilities and boarding platforms the distance of the transfer can conceivably be very short. The reduction of time and distance, as well as very frequent line haul service, would appear to satisfy substantial numbers of commuters.

LIMITATIONS OF STUDY AND FURTHER RESEARCH

The data required substantial reduction and reformatting to put them in a form to be analysed by multivariate methods. Consequently it is difficult to assess the interpretations of the analysis in view of the assumptions inherent in the tests, and the population variances. Interval scaled variables would be desirable throughout. Because of the categorical nature of the responses to the questionnaire the resulting scale was a high level ordinal one, and based on the results produced appear to be reasonably representative of population statistics. New tests of this nature, however, should be conducted to refine the scaling procedures at the survey level. This is a problem in virtually all mode choice research.

A problem in the tests of subjective responses is validity of the response as a base for public decision making. Some would argue that measures of behavior only are valid means of identifying mode choice and preference. There have been no studies in transportation planning on the relationship between responses on hypothetical behavior and subsequent action. Meanwhile such tests as have been carried out in this study are necessary until better data collection methods can be used to incorporate checks on this type of question. An argument is also being carried out in mode choice research as regard using perceived as opposed to objective measures of variables. Most recent studies have used subjective measures. Quarmby tested subjective and objective responses and found good correlation with regard to walking time reported and actual distance measured on a map. A study is currently being carried out at Northwestern University on the perceived-objective question.[16] Preliminary results imply that perceived measures may fairly replicate objective measures for habitual travel patterns, such as the work trip. The present study is based on perceived variables with evidence that in some cases the measures vary significantly from objective ones. The author is convinced that this type of response is a valid one in mode choice research as a method to simulate the variables objectively. A great amount of analysis of this question is still necessary.

The planning mechanism used to explore mode split demand adjustment was a discrimination-classification model

which can be used to simulate intermodal demand with changes in performance levels of the system. The mechanism consists of two sub-models: one an empirical generalization of intermodal demand based on system behavior, and a theoretical utility model of the inferred propensity to shift mode based on subjective preferences for changes in the system.

The discrimination-classification approach has been used several times to predict mode choice since Warner's initial effort in 1962. This type of model has two major advantages over the multiple linear regression type. Firstly, it allows a disaggregation of the data into individual behavior units, thereby avoiding problems of ecological fallacy and spuriousness. Linear regression models depend on a continuous distribution for its dependent variable. Thus, investigators use a series of traffic zones as the basic behavioral unit to meet this assumption. The individual mode choice problem is however discontinuous. A change in, say, travel time may make an individual switch from car to transit but it cannot make him less of a car user than at present. The discriminant criterion postulates a dichotomous dependent variable (mode choice) and the assignment of an individual is to one or the other side of a discriminant boundary depending upon the characteristics of the mode selected. It is therefore appropriate to the problem as to whether an individual in a certain population takes either transit or auto. That is, the dependent variable is binary valued instead of continuous.

The second advantage of the discrimination-classification approach is that the discriminant functions are analogous to the aggregation of utility functions for each individual and therefore can be related to a theoretical framework. The discriminant function is a linear boundary separating groups as an envelope enclosing groups on the criterion that the variance of observations within the group is statistically less than variance between groups. The discriminant score, as the quantitative value of the discriminant function is a relative quantitative measure of a linearized value function. The coefficients of the function are the relative contributions of each variable under study, and is thereby a relative measure of the utility of that factor in the mode choice decision. The combination of being able to predict group membership, thereby allowing a stratification of the mode choice decision into as many strata as possible; and its relationship to utility theory makes the discriminant-classification approach useful for the study of mode choice. Its value however lies in classification, not in prediction.

The models developed and tested here produce the antecedents to a more complete analysis using a wider range of variables, and tested on further data. Further research is needed to carry out simulation tests using a wider range of both socioeconomic and transportation system data. Some authors have also experimented with other probability models such as probit analysis and logit analysis. Lisco, for one, claims

better predictive ability for these models. Further studies are needed on both the relative advantages of discriminant function and other models to fully analyse this.

This study was an analysis of a given data base collected for another purpose. The analysis provides some insight into the problem of determinants for a parking model to study mode shift, and the incidence of parking policy on mode choice. Part of the results of the study was to point out those variables, and means of measurement, which should be studied in more depth. Principally among these is the concept of travel comfort which has not been analysed in any study. Comfort factors appear to be a prime consideration in travel consumption. Therefore further research efforts are needed to define the dimensions of comfort and to attempt means of measurement and quantification.

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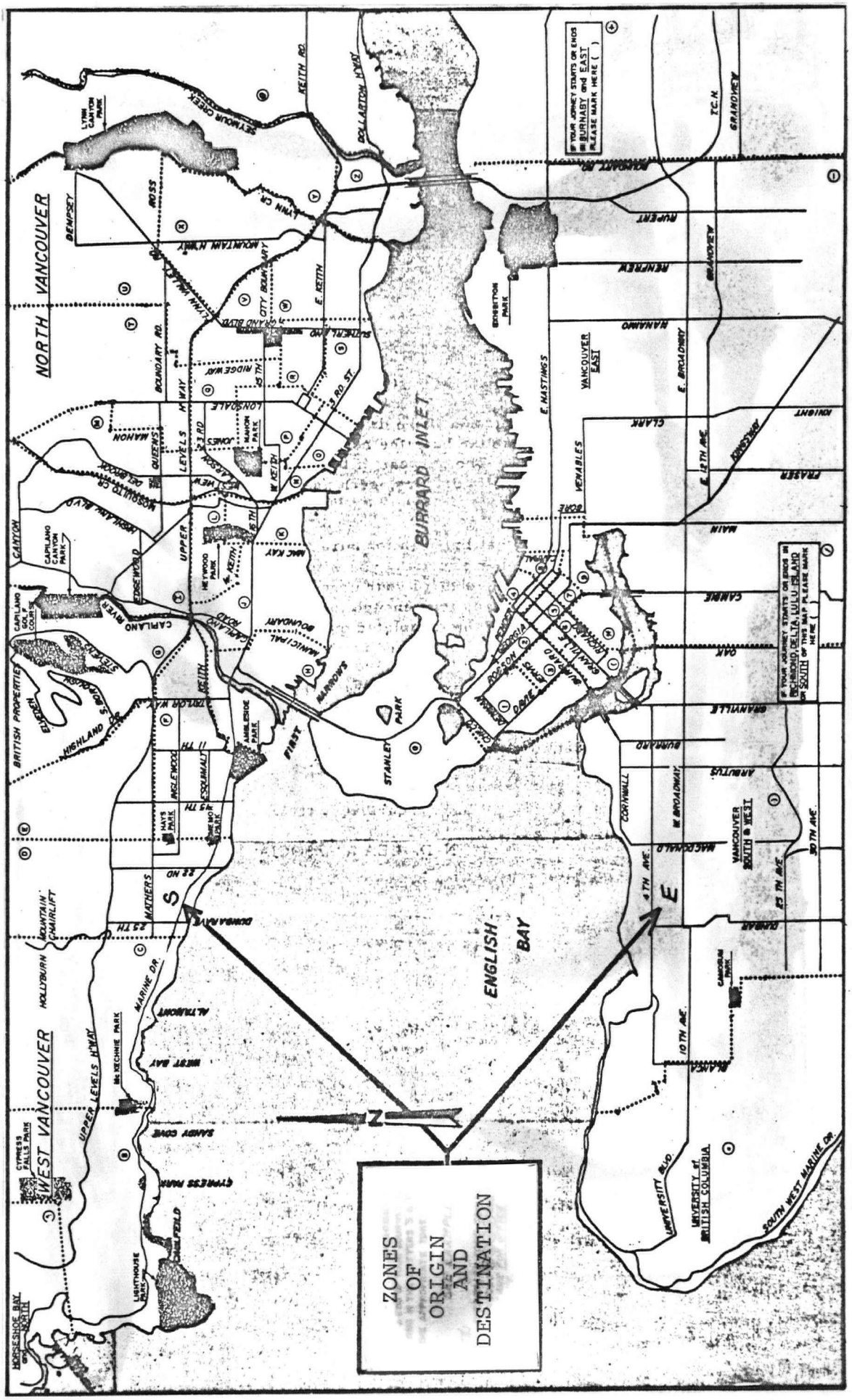
A P P E N D I C E S


ZONES
OF
ORIGIN
AND
DESTINATION
NORTH VANCOUVER
WEST VANCOUVER
BURRARD INLET
ENGLISH BAY
STANLEY PARK
VANCOUVER EAST
VANCOUVER SOUTH & WEST
UNIVERSITY OF BRITISH COLUMBIA
IF YOUR JOURNEY STARTS OR ENDS IN BURNABY and EAST PLEASE MARK HERE ( )
IF YOUR JOURNEY STARTS OR ENDS IN RICHMOND DELTA, WHITE ROCK OR SOUTH OF THIS MAP PLEASE MARK HERE ( )
N
S
E
W

FIRST NARROWS TRANSIT PLANNING STUDY
for the
British Columbia Department of Highways
March, 1967

This survey is designed to supply information regarding the existing bus system and to provide guidance for future transit planning across the First Narrows Bridge. Your assistance by completing and returning this form on or before Friday, March 17, 1967, will be appreciated. NO SIGNATURE OR POSTAGE IS REQUIRED.

Since the answers to these questions will be processed by electronic computer, please check only one square ☑ to each question unless otherwise requested. Use of a pencil is preferred.

1. Questions 1(a) to 1(g) are intended to provide information concerning your door-to-door journey, not just your car trip. The actual journey you choose to report on should be a typical week-day journey, in either the morning or evening peak period. (i.e. 7-9 a.m. or 4-6 p.m.)

1(a) On the map opposite please mark with an "S" and "E" the zones where you "START" and "END" your door-to-door journey.

1(b) When did you start your door-to-door journey?

__:__AM
or __:__PM on_____
(Day of Week)

1(c) How long does it take you to travel:

(Time in Minutes)

	0	1-3	3-5	5-10	10 or more
(i) from start of journey to your car?	☐	☐	☐	☐	☐
(ii) from your car to end of journey?	☐	☐	☐	☐	☐

1(d) When did you door-to-door journey end?

__:__ AM or __:__ PM

1(e) How long is your door-to-door journey in minutes?.....

1(f) Purpose of your journey was to travel to or from:

☐ Work
☐ Personal Business
☐ Shopping
☐ Social or Recreation
☐ School or University
☐ Other (specify).....

1(g) How many persons (including driver) were in the car?

☐ One
☐ Two
☐ Three
☐ Four
☐ Five
☐ Six or more

2. Are you a member of a regular car pool?

☐ Yes ☐ No

3. Do you normally cross First Narrows Bridge in the peak period? (7-9 a.m. and 4-6 p.m.)

☐ Yes ☐ No

4. If there was no congestion on the bridge at any time, at what time would you prefer to cross it? (Please give both morning and evening times)

__ __ AM and __:__PM

5. Are you the driver of the car?

☐ Yes ☐ No

If "Yes", please answer questions 5(a) through 5(c)

5(a) What do you now pay for parking? (Check one only in the appropriate section, monthly or daily).

☐ Monthly	OR	☐ Daily
☐ Free		☐ Free
☐ Less than $10.00		☐ Less than $.50
☐ $10.01 - $20.00		☐ $.51 - $1.00
☐ $20.01 - $30.00		☐ $1.01 - $1.50
☐ $30.01 - $40.00		☐ $1.51 - $2.00
☐ More than $40.00		☐ More than $2.00

5(b) Do you normally park your car for more than seven hours (i.e. a working day) in downtown Vancouver?

☐ Yes ☐ No

5(c) How often is it absolutely necessary to use your car during the day?

☐ Never
☐ Very Seldom
☐ Once a week
☐ Frequently
☐ Other (specify).....

6. Do you ever travel by bus instead of car?

☐ Never
☐ Occasionally
☐ Most of the time
☐ Other (specify).....

7. How does the door-to-door journey time by bus compare to that by car?

☐ Bus more than 15 min. faster (specify).....
☐ Bus 11 - 15 min. faster
☐ Bus 6 - 10 min. faster
☐ Bus 1 - 5 min. faster
☐ Bus same
☐ Bus 1 - 5 min. slower
☐ Bus 6 - 10 min. slower
☐ Bus more than 10 min. slower (specify).....
☐ Do not know

8. Factors influencing the quality of the normal bus service are listed below. Please indicate the minimum quality of service you would desire for your journey if you were to use a normal bus service.

8(a) The distance from the start of your journey to the bus stop should be less than:

- ☐ 500' (approx. 1 city block, or 2 min. walk)
- ☐ 1000' (approx. 2 city blocks, or 4 min. walk)
- ☐ 1500' (approx. 3 city blocks, or 6 min. walk)
- ☐ 1/2 mi. (approx. 5 city blocks, or 10 min. walk)

8(b) For your journey, the frequency of service should be better than one bus every:

- ☐ 2 minutes
- ☐ 5 minutes
- ☐ 10 minutes
- ☐ 15 minutes

8(c) Your door-to-door journey by bus compared to that by car should be:

- ☐ Bus more than 15 min. faster (specify) .....
- ☐ Bus 11 - 15 min. faster
- ☐ Bus 6 - 10 min. faster
- ☐ Bus 1 - 5 min. faster
- ☐ Bus same
- ☐ Bus 1 - 5 min. slower
- ☐ Bus 6 - 10 min. slower
- ☐ Bus more than 10 min. slower (specify) .....

8(d) Would you want to be guaranteed a seat on every bus trip?

☐ Yes ☐ No

8(e) Would you want weather protected bus stops?

☐ Yes ☐ No

8(f) For the quality of normal bus service you have specified above, what is the maximum one-way daily fare you would be prepared to pay?

- ☐ Free
- ☐ $.01 - $.20
- ☐ $.21 - $.40
- ☐ $.41 - $.60
- ☐ $.61 - $1.00
- ☐ $1.01 - $1.50
- ☐ More than $1.50
- ☐ Do not know

The following questions are being asked to give information concerning a park and ride bus service between the North Shore and downtown Vancouver. With a park and ride service, the commuter would park his car in a North Shore parking lot, walk to a sheltered bus stop, and board an express bus which would transport him with a minimum of delay to within two blocks of his downtown destination. Bus passengers would be guaranteed a comfortable seat.

9. Factors influencing the quality of the park and ride bus service are listed below. Please indicate the minimum quality of service you would desire, if you were to use a park and ride system.

9(a) The distance from the parking space to the bus loading area should be less than:

- ☐ 200' (1 min. walk)
- ☐ 500' (2 min. walk)
- ☐ 1000' (4 min. walk)

9(b) Frequency of service should be one bus every:

☐ 2 min. ☐ 4 min. ☐ 6 min. ☐ 10 min.

9(c) The door-to-door journey time by park and ride bus service compared to that by private car should be:

- ☐ More than 15 min. faster (specify) .....
- ☐ 11 - 15 min. faster
- ☐ 6 - 10 min. faster
- ☐ 1 - 5 min. faster
- ☐ Same
- ☐ 1 - 5 min. slower
- ☐ 6 - 10 min. slower
- ☐ More than 10 min. slower (specify) .....

9(d) For the quality of service you have specified above, what is the maximum two-way combined bus and parking fare you would be prepared to pay?

- ☐ Free
- ☐ $.01 - $.50
- ☐ $.51 - $1.00
- ☐ $1.01 - $1.50
- ☐ $1.51 - $2.00
- ☐ $2.01 - $2.50
- ☐ $2.51 - $3.00
- ☐ More than $3.00

10. If you were using a park and ride bus service how would you probably travel between the North Shore end of your journey and the bus loading area? (The bus loading area would be located less than one mile from the bridge head).

- ☐ Car
- ☐ Walk
- ☐ Feeder bus
- ☐ Dropped off by car not parked at the loading area
- ☐ Taxi
- ☐ Bicycle
- ☐ Other (specify) .....

11. If the quality of bus service you have specified as desirable were provided (questions 8 and 9), would you in fact switch from your car to the bus?

☐ Yes ☐ No

If "Yes", which bus service would you prefer?

- ☐ Normal bus service
- ☐ Park and ride bus service

If "No", would a rail rapid transit service having a similar quality of service as you have specified for a park and ride bus service, cause you to change your mind?

☐ Yes ☐ No

If "Yes", please give reasons why?

12. If you continue to travel by car, how long will you consistently wait in a queue at the First Narrows bridge before considering transit?

- ☐ 0 - 15 min.
- ☐ 16 - 30 min.
- ☐ 31 - 45 min.
- ☐ 46 - 60 min.
- ☐ More than 1 hour

13. If parking rates in downtown Vancouver increase substantially at what parking rate would you consider switching to transit? (Do not answer if you are a passenger).

- ☐ Less than $10.00 per mo.
- ☐ $10.00 - $20.00 per mo.
- ☐ $21.00 - $30.00 per mo.
- ☐ $31.00 - $50.00 per mo.
- ☐ $51.00 - $75.00 per mo.
- ☐ More than $75.00 per mo.

14. In order to correlate results, your filling in of the following personal data would be appreciated.

14(a) ☐ Male ☐ Female

14(b) Age?

- ☐ 0 - 20 yrs.
- ☐ 21 - 40 yrs.
- ☐ 41 - 60 yrs.
- ☐ Older than 60 yrs.

14(c) Occupation?

- ☐ Managerial Work
- ☐ Professional Work
- ☐ Secretarial Work
- ☐ Clerical Work
- ☐ Sales Work
- ☐ Other Work (Type)
- ☐ Student
- ☐ Housewife
- ☐ Retired
- ☐ Other (specify)

14(d) How many cars in household?

- ☐ None
- ☐ One
- ☐ Two
- ☐ Three or more

14(e) If working, your annual income is:

- ☐ Less than $4,000
- ☐ $4,001 - $8,000
- ☐ $8,001 - $12,000
- ☐ More than $12,000

In the space below, please give us any information, suggestions or criticisms which you believe will be helpful to us in planning for a First Narrows transit system.

FIRST NARROWS TRANSIT PLANNING STUDY
for the
British Columbia Department of Highways
March, 1967

3805

This survey is designed to supply information regarding the existing bus system and to provide guidance for future transit planning across the First Narrows Bridge. Your assistance by completing and returning this form on or before Friday, March 17, 1967, will be appreciated. NO SIGNATURE OR POSTAGE IS REQUIRED.

Since the answers to these questions will be processed by electronic computer, please check only one square ☑ to each question unless otherwise requested. Use of a pencil is preferred.

1. Questions 1(a) to 1(h) are intended to provide information concerning your complete door-to-door journey, not just your bus trip. The actual journey you choose to report on should be a weekday journey in the morning rush hour period, that is 7-9 a.m.

1(a) On the map on the back of this form, please mark with an "S" and "E" the zones where you start and end your door-to-door journey.

1(b) At what time did you start your door-to-door journey?

__ __ : __ __ A. M. on..... (Day of Week)

1(c) How did you get from the start of your journey to the bus stop?

☐ Walk ☐ Auto ☐ Taxi ☐ Other (specify).....

1(d) How did you get from the bus to the end of your journey?

☐ Walk ☐ Auto ☐ Taxi ☐ Other (specify).....

1(e) How long does it take you to: (Time in Minutes)

	0	1-3	3-5	5-10	10 or more
(i) Travel from start of journey to bus stop?	☐	☐	☐	☐	☐
(ii) Wait for bus? (an average)	☐	☐	☐	☐	☐
(iii) Wait at transfer point (an average) (if applicable)	☐	☐	☐	☐	☐
(iv) Travel from bus to end of journey?	☐	☐	☐	☐	☐

1(f) At what time did you arrive at the end of your door-to-door journey?

__ __ : __ __ AM

1(g) How long is your door-to-door journey in minutes?.....

1(h) The purpose of your trip was to travel to or from:

☐ Work ☐ Personal Business ☐ Shopping ☐ Social & Recreation ☐ School or University ☐ Other (specify).....

2. Please indicate in order of preference which of the following you feel need improvement. (i.e. Mark 1, 2, 3, etc.)

☐ Frequency of service
☐ Bus route closer to home or work
☐ Lower fares
☐ Shelters provided at bus stops
☐ All passengers seated
☐ Express routes providing faster service
☐ Better lighting and air conditioning
☐ Faster travel time along Georgia in evening
☐ Other (specify).....
☐ Other (specify).....

3. If you have switched from car to bus, why? (check the prime reason.)

☐ Reduce costs
☐ Save time
☐ Avoid bridge delay
☐ Car required by another person
☐ Avoid driving in congested traffic
☐ Parking too difficult in downtown Vancouver
☐ Other (specify).....

4. How does the door-to-door journey time by bus compare to that by car? (if known)

☐ Bus more than 15 min. faster (specify).....
☐ Bus 11-15 min. faster
☐ Bus 6-10 min. faster
☐ Bus 1- 5 min. faster
☐ Same
☐ Bus 1- 5 min. slower
☐ Bus 6-10 min. slower
☐ Bus 11-15 min. slower
☐ Bus more than 15 min. slower (specify).....
☐ Do not know.

5. In order to correlate results, your filling in of the following data would be appreciated.

5(a) ☐ Male ☐ Female

5(b) Age? ☐ 0-21 yrs. ☐ 21-40 yrs. ☐ 41-60 yrs. ☐ older than 61 yrs.

5(c) How many cars in household? ☐ None ☐ One ☐ Two ☐ Three or more

5(d) Do you have a drivers licence? ☐ Yes ☐ No ☐ Under 16 yrs. old

5(e) Occupation? ☐ Managerial Work ☐ Professional Work ☐ Clerical Work ☐ Sales Work ☐ Secretarial Work ☐ Student ☐ Housework ☐ Retired ☐ Other (specify) .....

5(f) If working, annual income of: ☐ Less than $4,000 ☐ $4,001 - $8,000 ☐ $8,001 - $12,000 ☐ more than $12,000

In the space below, please give us any information, suggestions or criticisms which you believe will be helpful to us in planning for a First Narrows transit system.

_____
_____
_____
_____

Thank you

COMPUTER PROGRAM FOR DATA CONVERSION

```
C NORTH SHORE DATA CONVERSION
C CONVERT CC CODES TO VARIABLE VALUES
C TWO DECKS OF DATA   DK#1=CARS , DK#2=BUS
C INPUT=CODES
C OUTPUT=INTEGER OR REAL VALUES
      DIMENSION   IA(80),I6(256),I8(256),R10(256),R19(256),R13(10),R14(1
     1      0),I20(256),R29(10),R34(10),I35(10),R39(10),I40(10),I41(10),
     2      R43(10),I48(10),R49(10),RB15(10),RB16(10),RB17(10),RB18(10)
      INTEGER BLANK
      DATA BLANK/Z00000040/
      DATA I6/250*0/,I8/256*0/,R10/256*0./,R19/256*0./,R13/0.00,0.01,2.0
     10,4.00,7.50,10.00/,R14/0.00,0.01,2.00,4.00,7.50,10.00/,I20/256*0/,
     2R29/0.00,0.01,5.00,15.00,25.00,35.00,-40.00/,R34/0.0,2.0,4.0,6.0,1
     30.0/,I35/0,2,5,10,15/,R39/0.00,0.01,0.20,0.60,1.00,1.60,2.50,-2.50
     4,-9.00/,I40/0,1,2,4/,I41/0,2,4,6,10/,R43/0.00,0.01,0.25,0.75,1.25,
     51.75,2.25,2.75,-2.75/,I48/00,15,30,45,60,-1/,R49/0.00,5.00,15.00,2
     65.00,40.00,62.50,-75.00/,RB15/0.00,0.01,2.00,4.00,7.50,10.00/,RB16
     7/0.00,0.01,2.00,4.00,7.50,10.00/,RB17/0.00,0.01,2.00,4.00,7.50,10.
     800/,RB18/0.00,0.01,2.00,4.00,7.50,10.00/
      C=5./60.
      N=99
      DO 100 I=193,201
      N=N+1
100   I6(I)=N
      DO 200 I=209,217
      N=N+1
200   I6(I)=N
      DO 300 I=226,233
      N=N+1
300   I6(I)=N
      I6(64)=0
      J=0
      DO 400 I=241,249
      J=J+1
400   I8(I)=J
      I8(64)=0
      I8(77)=10
      I8(92)=11
      I8(240)=20
      I8(75)=21
      I8(93)=22
      I8(97)=23
      I8(96)=24
      I8(78)=25
      I8(91)=26
      I8(110)=27
      X10=6.5
      X19=6.5
      DO 500 I=241,249
      R10(I)=X10
      R19(I)=X19
      X10=X10+C
500   X19=X19+C
      DO 600 I=193,201
      R10(I)=X10
```

```
      R19(I)=X19
      X10=X10+C
600   X19=X19+C
      DO 700 I=209,217
      R10(I)=X10
      R19(I)=X19
      X10=X10+C
700   X19=X19+C
      DO 800 I=226,233
      R10(I)=X10
      R19(I)=X19
      X10=X10+C
800   X19=X19+C
      R10(124)=X10+C
      R19(124)=X19+C
      R10(74)=X10+C
      R19(74)=X19+C
      R10(64)=0.0
      R19(64)=0.0
C READ CARD DK#1
10    CALL READC (IA)
      IF(IA(80).EQ.241) GO TO 23
      IF((IA(15)).EQ.64.AND.(IA(16)).EQ.64.AND.(IA(17)).EQ.64.AND.(IA(18
     1)).EQ.64) IWAY=1
      IF((IA(15)).NE.64.OR.(IA(16)).NE.64.OR.(IA(17)).NE.64.OR.(IA(18)).
     1NE.64) IWAY=2
      DO 900 I=1,80
      IF(IA(I).EQ.BLANK) IA(I)=240
900   CONTINUE
      GO TO (11,12), IWAY
 11   IORIG =I6(IA(6))
      IDEST =I8(IA(8))
      MODE  =1
      HRST  =R10(IA(10))
      HREND =R19(IA(19))
      TTO=R13(IA(13)-240+1)
      WAIT=0.00
      TRNSF=0.00
      TFROM=R14(IA(14)-240+1)
      IF(IA(20).GE.240) IOTT=(IA(20)-240)*5+10
      IF(IA(20).EQ.78) IOTT=-55
      MPASS =(IA(22)-240)
      MDRIV =(IA(27)-240)
      PKCHG=R29(IA(29)-240+1)
      NECC  =(IA(31)-240)
      MBUS  =(IA(32)-240)
      IJ=(IA(33)-240)
      IF(IJ.LT.1) MROT=IJ
      IF(IJ.EQ.1) MROT=-1
      IF(IJ.GT.1) MROT=IOTT-25+IJ*5
      IF(IJ.EQ.8) MROT=-8
      IF(IJ.EQ.9) MROT=-9
      TTOP=R34(IA(34)-240+1)
      MFRQP=I35(IA(35)-240+1)
      IK=(IA(36)-240)
```

```
      IF(IK.LT.1) MROTP=IK
      IF(IK.EQ.1) MROTP=-1
      IF(IK.GT.1) MROTP=IOTT-25+IK*5
      IF(IK.EQ.8) MROTP=-8
      MSEAT=(IA(37)-240)
      MPRO =(IA(38)-240)
      FAREP=R39(IA(39)-240+1)
      KTTO=I40(IA(40)-240+1)
      MFRQK=I41(IA(41)-240+1)
      IM=(IA(42)-240)
      IF(IM.LT.1) KROT=IM
      IF(IM.EQ.1) KROT=-1
      IF(IM.GT.1) KROT=IOTT-25+IM*5
      IF(IM.EQ.8) KROT=-8
      FAREK=R43(IA(43)-240+1)
      MOTOR=0
      MOFMB=0
      MOTOK=(IA(44)-240)
      NSWCH=(IA(45)-240)
      NORK =(IA(46)-240)
      NRAIL=(IA(47)-240)
      NQUE=I48(IA(48)-240+1)
      SWCHG=R49(IA(49)-240+1)
      IMFRQ=0
      IMCON=0
      LOFARE=0
      IMPRO=0
      IMCRWD=0
      MEXP=0
      LAC=0
      JEXP=0
      MCHNG=0
      MSEX =(IA(50)-240)
      MAGE =(IA(51)-240)
      MOCC =(IA(52)-240)
      MCARS=(IA(53)-240)
      INCOM=(IA(54)-240)
      MLIC=0
      GO TO 21
C READ  DK#2
12    IORIG =I6(IA(6))
      IDEST =I8(IA(8))
      MODE =2
      HRST =R10(IA(10))
      HREND=R19(IA(19))
      TTO=RB15(IA(15)-240+1)
      WAIT=RB16(IA(16)-240+1)
      TRNSF=RB17(IA(17)-240+1)
      TFROM=RB18(IA(18)-240+1)
      IF(IA(20).GE.240) IOTT=(IA(20)-240)*5+10
      IF(IA(20).EQ.78) IOTT=-55
      MPASS=0
      MDRIV=0
      PKCHG=00.00
      NECC=0
```

```
      MBUS=0
      IN=(IA(31)-240)
      IF(IN.LT.1) MROT=IN
      IF(IN.EQ.1) MROT=-1
      IF(IN.GT.1) MROT=IOTT-25+IN*5
      IF(IN.EQ.8) MROT=-8
      IF(IN.EQ.9) MROT=-9
      TTOP=0.00
      MFRQP=00
      MROTP=00
      MSEAT=0
      MPRO=0
      FAREP=0.00
      KTTO=00
      MFRQK=00
      KROT=00
      FAREK=0.00
      MOTOB =(IA(13)-240)
      MOFMB =(IA(14)-240)
      MOTOK=0
      NSWCH=0
      NORK=0
      NRAIL=0
      NQUE=00
      SWCHG=00.00
      IMFRQ =(IA(22)-240)
      IMCON =(IA(23)-240)
      LOFARE=(IA(24)-240)
      IMPRO =(IA(25)-240)
      IMCRWD=(IA(26)-240)
      MEXP  =(IA(27)-240)
      LAC   =(IA(28)-240)
      JEXP  =(IA(29)-240)
      MCHNG =(IA(30)-240)
      MSEX  =(IA(32)-240)
      MAGE  =(IA(33)-240)
      MOCC  =(IA(36)-240)
      MCARS =(IA(34)-240)
      INCOM =(IA(37)-240)
      MLIC  =(IA(35)-240)
21    WRITE (6,22) IORIG,IDEST,MODE,HRST,HREND,TTO,WAIT,TRNSF,IFROM,IOTT
     1       ,MPASS,MDRIV,PKCHG,NECC,MBUS,MROT,TTOP,MFRQP,MROTP,MSEAT,MPR
     2       O,FAREP,KTTO,MFRQK,KROT,FAREK,MOTOB,MOFMB,MOTOK,NSWCH,NORK,N
     3       RAIL,NQUE,SWCHG,IMFRQ,IMCON,LOFARE,IMPRO,IMCRWD,MEXP,LAC,JE
     4       XP,MCHNG,MSEX,MAGE,MOCC,MCARS,INCOM,MLIC
22    FORMAT (1X,I3,I2,I1,6F5.2,I4,2I2,F6.2,2I2,I4,F5.2,I3,I4,2I2,F5.2,2
     1       I2,I4,F5.2,1X,6I1,I3,F6.2,1X,15I1)
      GO TO 10
23    STOP
      END
```

APPENDIX D

COMPUTER PROGRAM FOR SCORE MATRIX 1

```
C SCORE MATRIX 1B
C INPUT=*NSDATA* OUTPUT=SCORE MATRIX 1B
      DIMENSION          X(50),FARE(30),IASOCS(10),IBSOCS(10),PERS(30)
      DIMENSION IOWK(10),IDWK(10),XTO(10),XFROM(10)
      DIMENSION MFREQ(30)
      DATA          X/50*0./,FARE/1.08,0.96,0.64,0.56,0.64,0.50,0.64,0.4
     10,18*0.70/,IASOCS/2,1,4,5,3,5*6/,IBSOCS/2,1,5,3,4,4*6/,PERS/3.5,3.
     25,3.5,4.0,4.0,2.7,4.0,2.7,3.8,3.8,3.2,3.8,3.2,3.8,3.2,3.2,3.2,3.2,
     33.2,3.8,3.8,3.2,3.2,3.8,3.8,3.8/,IOWK/0,1,2,3,4,5/,IDWK/0,1,2,3,4,
     45/,XTO/0.00,0.01,2.00,4.00,7.50,10.00/,XFROM/0.00,0.01,2.00,4.00,7
     5.50,10.00/,MFREQ/2*30,20,12*15,2*20,2*15,20,6*15/
      XID=0.0
      CALL SETBLK (5,3750,125)
4     READ (5,2,END=99) IORIG,MODE,HREND,TTO,WAIT,TRNSF,TFROM,IOTT,MDRIV
     1,PKCHG,NECC,MAGE,MOCC,MCARS,INCOM
2     FORMAT (1X,I3,2X,I1,5X,5F5.2,I4,2X,I2,F6.2,I2,67X,4I1)
      IF(IOTT.LT.1.OR.MCARS.EQ.1.OR.NECC.EQ.5) GO TO 4
      IF(MODE.EQ.1.AND.NECC.EQ.0) GO TO 4
      IF(MAGE.EQ.0.OR.MOCC.EQ.0.OR.MCARS.EQ.0.OR.INCOM.EQ.0.OR.HREND.EQ.
     10.0.OR.TTO.EQ.0.0.OR.TFROM.EQ.0.0) GO TO 4
      IF(MODE.EQ.1.AND.PKCHG.EQ.0.0) GO TO 4
      IF(MODE.EQ.1.AND.MOCC.GT.6) GO TO 4
      IF(MODE.EQ.2.AND.MOCC.EQ.6.OR.MOCC.EQ.7.OR.MOCC.EQ.8) GO TO 4
      IF(MODE.EQ.1.AND.MDRIV.EQ.2) GO TO 4
      J=IORIG-100+1
      X(1)=MODE
      X(2)=MAGE
      L=MOCC
      IF(MODE.EQ.1) X(3)=IASOCS(L)
      IF(MODE.EQ.2) X(3)=IBSOCS(L)
      IF(MODE.EQ.1) X(4)=NECC
      IF(MODE.EQ.2) X(4)=1
      X(5)=MCARS-1
      X(6)=INCOM
      X(7)=(PERS(J)*ALOG10(X(6)*4000))/X(5)
      X(8)=HREND
      DO 90 K=1,6
      IF(TTO.EQ.XTO(K)) GO TO 20
90    CONTINUE
      GO TO 99
20    TTO=IOWK(K)
      X(9)=TTO
      DO 91 K=1,6
      IF(TFROM.EQ.XFROM(K)) GO TO 21
91    CONTINUE
      GO TO 99
21    TFROM=IDWK(K)
      X(10)=TFROM
      X(11)=IOTT
      IF(MODE.EQ.1) X(12)=PKCHG/20
      IF(MODE.EQ.2) X(12)=FARE(J)
      X(13)=X(12)/X(6)
      X(14)=MFREQ(J)
      XID=XID+1
      WRITE (6,8) XID,(X(I),I=1,6),(X(I),I=7,14)
```

```
8       FORMAT (F5.0,1X,6F2.0,1X,8F6.2)
        GO TO 4
99      STOP
        END
```

COMPUTER PROGRAM FOR STANDARDIZING SCORE MATRIX 1

```
C ZSCORS1
C STANDARDIZED SCORES, SMRX-1
      DIMENSION  X(20),XBAR(15),SDC(15),Z(20)
      DATA XBAR/0.0,2.498,2.644,2.171,1.514,2.678,3.449,8.292,1.956,3.11
     $8,33.960,0.5642,0.2584,7.835/,SDC/0.0,0.5622,1.5550,1.2650,0.5226,
     $0.9310,0.2010,0.4094,1.0392,1.2980,9.1140,0.3145,0.2051,8.0670/
      CALL SETBLK (5,2550,85)
1     READ (5,2,END=99) (X(I),I=1,14)
2     FORMAT (1X,14F6.2)
      Z(I)=0.0
      DO 100 I=2,14
      Z(I)=Z(I)+((X(I)-XBAR(I))/SDC(I))
100   CONTINUE
      WRITE (6,7) X(1),(Z(I),I=2,14)
7     FORMAT (1X,F6.2,13F8.4)
      GO TO 1
99    STOP
      END
```

APPENDIX F

MAXIMIZATION OF CORRELATION BETWEEN A LINEAR SET $U = \alpha' X^{(1)}$ and $V = \gamma' X^{(2)}$

Anderson has shown that ΣUV is maximized when

$$\begin{bmatrix} -\lambda R_{11} & R_{12} \\ R_{21} & -\lambda R_{22} \end{bmatrix} \begin{bmatrix} \alpha \\ \gamma \end{bmatrix} = 0.$$

Using Lagrange multipliers λ and μ the problem is to maximize:

$$\psi = \alpha' R_{12} \gamma - \frac{1}{2}\lambda(\alpha' R_{11} \alpha - 1) - \frac{1}{2}\mu(\gamma' R_{22} \gamma - 1).$$

Set $\frac{\partial \psi}{\partial \alpha}$ and $\frac{\partial \psi}{\partial \gamma} = 0$ for maximization; where

$$\frac{\partial \psi}{\partial \alpha} = R_{12}\gamma - \lambda R_{11}\alpha = 0 \qquad (1)$$

$$\frac{\partial \psi}{\partial \gamma} = R'_{12}\alpha - \mu R_{22}\gamma = 0 \qquad (2)$$

Multiplying (1) by α' and (2) by γ' gives

$$\alpha' R_{12} \gamma - \lambda \alpha' R_{11} \alpha = 0$$

$$\gamma' R_{12} \alpha - \mu \gamma' R_{22} \gamma = 0$$

Since variants of U^2 and V^2 are normalized to unity, and therefore:

$$\alpha' R_{11} \alpha = 1 \quad \text{and}$$

$$\gamma' R_{22} \gamma = 1, \quad \text{and}$$

$$\lambda = \mu = \alpha' R_{12} \gamma$$

(1) and (2) can be written as:

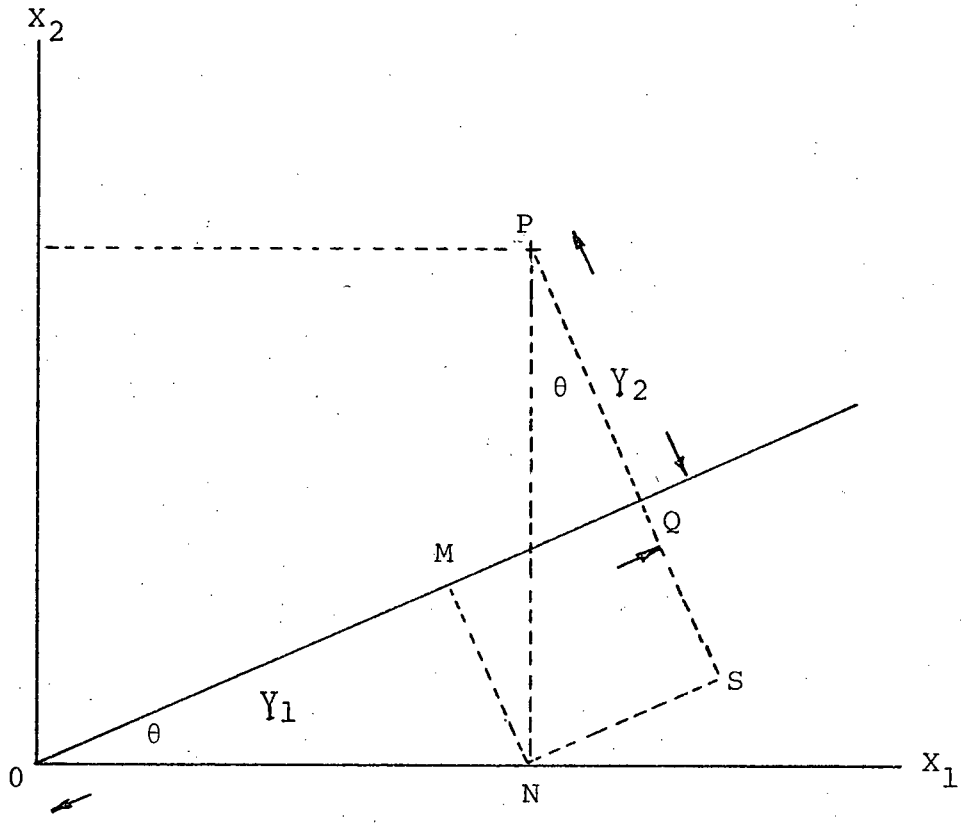
$$-\lambda R_{11} \alpha + R_{12} \gamma = 0$$

$$R_{21} \alpha - \lambda R_{22} \gamma = 0 \quad \text{or}$$

$$\begin{bmatrix} -\lambda R_{11} & R_{12} \\ R_{21} & -\lambda R_{22} \end{bmatrix} \begin{bmatrix} \alpha \\ \gamma \end{bmatrix} = 0.$$

APPENDIX G

GEOMETRIC ILLUSTRATION OF AXIS ROTATION AND VECTORS, v, FOR DISCRIMINANT ANALYSIS



Consider an observation (individual) P with coordinates X_1 and X_2. From the diagram:

$$Y_1 = OM + MQ$$

Now $\quad OM = X_1 \cos\theta$

and $\quad MQ = NS = X_2 \sin\theta$

Therefore $\quad Y_1 = X_1 \cos\theta + X_2 \sin\theta$

Similarly, $\quad Y_2 = PS - SQ$

But $\quad PS = X_2 \cos\theta$

and $\quad SQ = MN = X_1 \sin\theta$

Therefore,

$$Y_2 = X_2 \cos\theta - X_1 \sin\theta$$

$$= -X_1 \sin\theta + X_2 \cos\theta.$$

Combining the expressions in matrix form,

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

The analysis can be generalized for any number of individuals and any number of groups.

The first expression on the right side of this equation is a vector v whose elements are the cosines of the angles between the original axes and the new axes.

APPENDIX H

COMPUTER PROGRAM FOR SCORE MATRIX 2

```
C SCORE MATRIX 2A
      DIMENSION A(50),X(30),MFREQ(30),IA(50)
      EQUIVALENCE (IA(1),A(1))
      DATA X/30*0.0/,MFREQ/2*30,20,12*15,2*20,2*15,20,6*15/
      CALL SETBLK (5,3750,125)
      N=0.0
4     READ (5,10,END=99) (A(I),I=1,16)
10    FORMAT (1X,I3,2X,I1,10X,F5.2,15X,I4,2X,I2,F6.2,29X,2I2,I4,F5.2,10X
     $,F6.2,10X,5I1)
      J=IA(1)-100+1
      DO 100 I=1,16
      IF(IA(I).EQ.0.OR.A(I).EQ.0.) GO TO 4
100   CONTINUE
      IF(IA(2).EQ.2) GO TO 99
      IF(IA(4).LT.1) GO TO 4
      IF(IA(5).EQ.2) GO TO 4
      IF(IA(9).LT.1) GO TO 4
      IF(A(11).LT.1.) GO TO 4
      X(1)=IA(4)-IA(9)
      X(2)=(A(6)/20)-A(10)
      X(3)=A(3)-IA(7)
      X(4)=MFREQ(J)-IA(8)
      X(5)=(A(6)/20)-(A(11)/20)
      X(6)=IA(4)/IA(9)
      X(7)=(A(6)/20)/A(10)
      X(8)=A(3)/IA(7)
      X(9)=MFREQ(J)/IA(8)
      X(10)=(A(6)/20)/(A(11)/20)
      N=N+1
      XID=N
      WRITE (6,11) XID,(X(I),I=1,10),(IA(I),I=12,16)
11    FORMAT (F5.0,10F7.3,5I1)
      GO TO 4
99    STOP
      END
```