TRANSIT TRAVEL TO THE URBAN CORE OF GREATER VANCOUVER

by

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April, 1970
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ABSTRACT

This thesis examines spatial patterns of transit travel to the downtown core of Greater Vancouver. The study is placed within the context of earlier case studies of Vancouver's urban structure and also draws on notions of spatial interaction. In this context, the study qualifies the functional relevance of traditional models of urban spatial structure and urban transportation, which provide a basis for understanding movement to the core of the modern city.

Cartographic analysis found transit travel patterns to the downtown core to be structured by distance from the core, with friction-free inner zone of 3 to 5 miles generating high per capita trips to the core and a rapid drop-off in trips per capita beyond this zone; and by socio-economic variation in radially organized residential areas within this inner zone or "core ring". It was also demonstrated that sub zones of the downtown core were directionally oriented to socially defined residential sectors within the "core ring". This confirms findings of earlier case studies of the spatial structure of Greater Vancouver and the functional role and relationships of the downtown urban core. However, the initially identified relationships were only partly supported by subsequent statistical analysis. This suggested problems resulting
from the unsuitability of using aggregate data collection unit information (traffic zones) to model functional associations underlying spatial interaction; this indicates a direction for further research.

It is also suggested in conclusion that the 'core ring' model of Greater Vancouver deserves more study, particularly in view of its implications to transportation planning in this metropolitan area.
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CHAPTER I

TRAVEL BY TRANSIT TO THE DOWNTOWN CORE:
BACKGROUND TO THE PROBLEM

1) Urban Transportation in Perspective

In many North American cities transportation to the downtown core is under review, and large expenditures will be necessary within the next decade to meet travel demands to core areas. Many plans are being advanced to solve problems of congestion on routes leading to, from and within the core. These plans often seem to be based upon assumptions of a city system which is radially organized around a homogeneous core, and with travel to the core declining with distance. On this basis planners have continued to attempt to provide maximum accessibility to the core area from entire sprawling metropolitan areas. Some studies have indicated, however, the need to look at the changing nature of the core and the implications this has on its spatial relationships, as a prerequisite to transportation planning. Thus the changing employment pattern in the core and the sectoral market orientation of C.B.D. retailing has already been documented in the Vancouver case, and it has been shown that traditional notions of urban spatial structure do not provide a suitable description of the forces at work in structuring intra-urban travel patterns.
The core area of Greater Vancouver is the largest single focus of travel patterns within the metropolitan area as a result of its functional role as the location of increasingly concentrated growth of office activities and its continued role as the largest concentration of metropolitan retail activities. Explanation of travel patterns to the core are usually drawn from (a) traditional notions of urban structure which describe the core in terms of central place dominance (central place theory) or the point of maximum accessibility (ecological theory); and from (b) the basic principles of spatial interaction; distance decay, intervening opportunities and complementarity. Either approach suggests that travel to the core will decline in an orderly manner with distance from the core. However, case studies of the Vancouver area have provided indications that these generalizations of urban structure and spatial interaction do not consistently explain travel to the downtown core. Other forces have been shown to operate in structuring work and shopping travel patterns to the core in the local case. For example, the core area hinterland was found to be radially organized into homogeneous socio-economic sectors which are friction-free up to a distance of about five miles. Distance decay and intervening opportunity forces were found to operate beyond this distance resulting in a precipitous decline of trips to the downtown core. On closer examination of core-
hinterland relationships, specialized sub areas of the core were found to be oriented towards distinct sectors of the area within the "core zone of influence" termed the core-ring by Hardwick in a recent paper. (1)

Transportation planning is the focus of considerable attention in Greater Vancouver and has been for the past fifteen years, yet few of the plans have been implemented. Meanwhile the area has grown and its urban pattern has changed as have travel patterns, yet solutions to urban transportation problems appear to continue to view the entire metropolitan area as a core focussed system.

Although small in comparison to some North American metropolitan areas, Greater Vancouver (Figure 1) (with only 1,000,000 people) (2) is characteristic of many larger urban areas in terms of its transportation problems. With a growing high density, physically restricted core, extensive low density suburban expansion and a transportation system based primarily on automobile travel, Greater Vancouver is experiencing major transportation congestion in peak period travel to the core. Every day an estimated 200,000 to 300,000 automobile trips are made to, from and through the core. (3) By comparison, 60,000 to 65,000 people travel by transit to and from the core. (4)

So far only improvements in the road systems serving the core have been offered as solutions to ease congestion.
GREATER VANCOUVER

Figure 1
Yet these have been recognized as only partial solutions, and consultants' reports have stated that although improvements such as freeways and a new Burrard Inlet crossing are necessary, they too will become used beyond efficient capacity soon after completion. Transportation system improvements currently being studied for the Greater Vancouver area are focussed on public rapid transit. The findings of this report are not yet available, but judging from past reports, it may take a similar approach to previous road network studies which continually have resulted in recommendations to increase core area accessibility to distant peripheral suburbs.

2) Mass Transit Travel to the Core: A Case Study of Greater Vancouver

The purpose of this study is to identify and describe in an explanatory manner some of the functional relationships associated with the spatial patterns of transit travel to the core area of Greater Vancouver. Two facets of this problem are isolated for examination. The first is to define the role of the core as the focus of mass transit travel within the metropolitan area, and to indicate general factors inherent in the structure of the metropolitan area which appear to be functionally associated with local patterns of transit travel. This question is placed within the context
of existing case studies of Vancouver area travel patterns, which have already demonstrated that this area does not conform to some traditional notions of urban pattern. The second problem is to identify specific characteristics of the "zone of core area influence" which are functionally associated with the generation of transit trips to the core.

The approach used in this thesis is not oriented towards rigorous scientific analysis, since the research design for data collection was not developed to give conclusive answers to the questions posed in this thesis but rather to give general indications of transit travel pattern relationships in Vancouver. A rigorous scientific approach to the analysis is thus not justified nor possible. The approach taken is similar to that of a pilot study, where techniques are tested and expectations are examined. Hypothesis formulation is phrased in terms of expected relationships, and findings are interpreted in terms of "indications", rather than taken as conclusive support of expectations.

The derivation of these expectations is the purpose of Chapter II, a two part chapter. The first part draws inspiration from Appendix I, a review of urban transportation planning concepts and travel pattern prediction models. The second part summarizes, reviews and draws conclusions from the findings of some recent case studies of Vancouver's core
area and its relationships with the Greater Vancouver area. Chapters III and IV contain an empirical analysis of work trips and shopping trips by transit to the core of Vancouver. The level of analysis in Chapter III is descriptive, employing cartographic techniques to identify the spatial patterns of trip distribution and to 'test' notions about the influence of distance and trip demand (social area) characteristics on trip patterns to the core and its sub-areas. Chapter IV goes further and employs statistical techniques of analysis to test certain ideas about the relationships between trips generated to the core and the characteristics of residential areas. Correlation and backwards stepwise regression techniques and residuals from regression analysis are employed to isolate those characteristics of residential areas expected to give surrogate explanation of mass transit travel patterns. Finally, in Chapter V, conclusions are drawn, directions for further work are suggested, and some implications of the thesis findings to mass transit planning decisions in Greater Vancouver are advanced.

3) The Study Area
   a) Transit and Urban Form
      Greater Vancouver is characteristic of other North American cities, in that its present form was
structured by radial transit route patterns during its early development, which was followed by infilling and peripheral settlement expansion subsequent to the widespread use of the automobile.\(^{(7)}\) The period of influence of transit was from the inception of the first transit service in 1889, when Vancouver had little more than 10,000 people up to the Second World War. During this forty year period, the physical form of the City of Vancouver and adjacent areas, as well as North Vancouver City, was established. (Figure 2) (Today these areas form what Hardwick has called the 'core ring' with more spatial interaction focussed on the core than with other areas of the metropolitan area--in other words the 'core zone of influence'.\(^{(8)}\) It is noted here that this zone has historical origins structured by early transit route patterns. The implications of this zone or ring are discussed further in Chapter II, Part II.) Transit routes were located and developed to serve existing residential areas, and to encourage settlement along new routes. The objective of transit route planners was to provide service to all areas of the City (Vancouver) within a quarter of a mile, or five minutes' walking time. Strengthening of the commercial vitality of the core area (central business district) was the paramount
objective with all routes laid out to provide maximum direct service between developing residential areas and the central business district. (9)

Prior to the 2nd World War, and in anticipation of post-war years, Bartholomew and Associates, planning consultants to the City of Vancouver, accurately predicted the future of transit routing policies in the metropolitan area:

Prior to the advent of the automobile, transit facilities were the only means of mass transportation in urban areas. Consequently people lived close to transit routes and urban areas were compact. The automobile greatly increased the distance that people could travel between their homes and places of employment or other destinations, and urban residences immediately scattered over a wide area.

This change in population pattern had a profound influence upon the transit facilities. They were no longer the only source of riding and their revenue decreased. Furthermore the population became so widely scattered that it was no longer practical to extend lines—especially street car lines to keep pace with this new growth. The motor bus assisted in overcoming this difficulty, but in many instances the population was so thinly spread that the bus route was not economical because of long distance travelled to serve a small number of riders. (10)

The present major transit system is shown in Figure 3. This system is operated by the British Columbia Hydro and Power Authority, the predecessor of the British Columbia Electric Company. (Note that West Vancouver,
THE STRUCTURE OF DOWNTOWN

Figure 4

Source: City of Vancouver Planning Department

CORE TRAFFIC ZONES

Figure 5

Source: City of Vancouver Planning Department
Port Moody, Coquitlam and areas east are not served by this system and were not surveyed by the team who gathered the data on which this study is based. (See Appendix II) The routes surveyed are indicated in Figure 2. Routes in outlying areas not surveyed are connected with routes which serve the downtown core.) The present system follows a similar pattern to the 1928 system, the only major change being an infilling of routes as was projected in the policy statement discussed above. With the exception of two cross-town lines in Vancouver and suburban systems in other municipalities, the B.C.H. & P.A. Transit System remains a downtown core focussed transportation system.

b) Vancouver's Urban Core

The core area includes a variety of activities, and is internally differentiated into functionally distinct high density sub-areas. Activity groupings are shown in Figure 4, with the term CORE applied to that area of the Burrard Peninsula which is actually the Central Business District, containing the major retail store concentration of the entire metropolitan area, plus the Financial District. For analytical purposes, however, the core is defined in this thesis as the area enclosed by traffic zones 03, and '05 to 14. (Figure 5) This area includes not only C.B.D. type functions but activities, such as general business
and wholesaling, as well as port facilities and port oriented industries.

Over the past 15 years there has been rapid growth of administrative and service offices, and a decline and stabilization of retail activity in the core area of Vancouver. In 1953, five million square feet of office space were located in the core area. By 1963 this had increased by 1.8 million square feet, and between 1964 and 1968 building providing an additional 2.6 million square feet of office floor space was constructed in the core area. This office development boom raised the core area office space to 9.4 million square feet by 1968. (11) Retail floor space declined during the 1953 to 1965 period by about 150,000 square feet and has remained stable at about 3 million square feet since 1963. (12) These figures point out the changing role of the C.B.D. as a growing white collar employment centre, with the maintenance of its retail capacity. Construction now underway and potential large scale comprehensive developments planned for the future indicate that this retail picture will improve in the 1970's.
FOOTNOTES

(1) Hardwick, W.G., Vancouver: The Emergence of New Urban Patterns, unpublished draft, Department of Geography, University of British Columbia, Vancouver.

(2) Greater Vancouver Regional District, Planning Department.


(4) Department of Geography, University of British Columbia. Urban Core Project Transit Survey, 1965. For a discussion of this survey refer to Appendix II. This estimate also includes an estimate for bus passenger trip volumes from West Vancouver via the West Vancouver Municipal Transit Company which was not surveyed. Data was obtained for all routes indicated in Figure 3, (data for the most westerly north-south route in Vancouver (Dunbar) however was not as great as expected due to some discrepancy in the data collection or coding stage).


(6) See footnote 4, above.


(8) Hardwick, op. cit.


CHAPTER II

TRANSIT TRAVEL ANALYSIS:
DERIVATION OF PROBLEMS

The problems of this thesis are derived from three bodies of literature; urban transportation planning, geographical literature concerned with spatial interaction, and case studies of the urban structure of Greater Vancouver—particularly those local studies focussed on the role of the core in the metropolitan area as defined by its relations with the metro region. This chapter is actually divided into two parts, the first dealing with analytical concepts and tools used in both transportation studies and spatial interaction analysis; the second with empirical studies of urban travel patterns to the urban core of Vancouver. The conclusions drawn from this chapter provide the context for problem formulation and for the analysis of transit passenger travel patterns to the core of Vancouver in Chapters III and IV.

PART I

A GENERAL SYSTEMS APPROACH TO INTRA-URBAN TRAVEL PATTERN ANALYSIS

The general systems approach to functional relationships between the core and its hinterland conceptualizes
urban structure as "a set of objects, together with relationships between the objects and their attributes". (1) In other words, specialized areas within cities are related through circulating movements (spatial interaction) and the nature of these movements are a product of the attributes of interrelated activities and places. Taking this concept of movement further, by applying some principles of spatial interaction, a functional explanation of intra-urban travel patterns may be achieved.

The notion of complementarity or spatial interdependence suggests that movement is a result of a direct and reciprocal supply-demand relationship between or among places. The amount and range of movement is tempered by two restrictive forces, intervening opportunities and transferability. (2) The movement generated as a result of supply-demand linkages is inversely related to intervening sources of supply (or demand) and to the "friction" of distance (functionally measured in terms of cost, time, inconvenience, or some other measure). Other functionally relevant forces are identified and discussed as one approaches less general cases.

Mathematical formulations have been developed in geography and transportation planning fields to incorporate these notions and to explain or predict intra-urban travel patterns. The conceptual bases of three of these
formulations and their characteristics are discussed here, namely:

(1) Gravity models
(2) Intervening Opportunity models
(3) Multiple Regression models

A detailed review of the development, characteristics and use of these models is relegated to Appendix I. In this chapter a concise review of the aims and scope of these models is presented.

All three models have been used in comprehensive urban transportation studies in major metropolitan areas in North America. The gravity and opportunity model are trip distribution models, used for predicting inter-zonal movement. The multiple regression model is primarily a trip generation model which accounts for the volume of trips originating in a given area. It can also be used as a trip distribution model, by accounting for the number of trips originating in one area and destined to another area.

As urban transportation planning models, all the above have been developed primarily to predict intra-urban travel for some designated future period. These predictions are then used as the basis for decisions to allocate public funds to transportation facility improvements. The goal of these models is to achieve the most accurate prediction of trip generation and distribution with the least expenditure
of time and money as possible. Transportation planning models such as these do not generally concern themselves with rigorous scientific research design or testing for 'general explanation' of urban travel pattern phenomena, although this is changing. Nonetheless they have been developed from 'theoretical' notions of spatial interaction, and from demand studies of factors affecting mass travel behaviour.

1) Gravity Model

The gravity model is based on the hypothesis that the amount of interaction between two areas varies directly with the size of the mass of the areas and inversely with the distance which separates them. This hypothesis implicitly incorporates both the notions of complementarity and transferability. From the point of view of urban structure, the gravity model implies that as one moves away from the urban core, the amount of complementary interaction will decline as a function of declining population and increasing distance.

2) The Intervening Opportunity Model

The intervening opportunity model is based on the concept "that the number of people going a given distance is not a function of distance but rather a function of the spatial distribution of opportunities." The model thus
interprets spatial interaction as a complementary relationship between opportunities, the amount of interaction being directly proportional to the opportunities at a given distance and inversely proportional to the number of intervening opportunities. An example would be shopping trips to the core from suburban residential areas being attracted and absorbed by an intervening shopping complex. It has been found that an auxiliary relationship exists between the number of opportunities at a given distance and distance itself. Empirical studies of spatial interaction have found that intervening opportunities and distance vary together, and it has been argued that there is thus little difference between the opportunity model and the gravity model.\(^7\)

Mathematical formulations developed for both models rely heavily on iterative processes and the use of adjustment factors and exponents to obtain 'good fit' equations. Although effective procedures have been developed to fit empirical data to the models, neither model has been able to unambiguously differentiate between the influence of distance and intervening opportunity on travel patterns. This problem, however, has not concerned the practical users of these models. However, because of problems of application associated with the opportunity model, the gravity model has been more widely applied. It has also been developed to
incorporate surrogate complementarity measures, as well as weights for these measures which affect the propensity for interaction of the masses.

3) Multiple Regression Techniques and the Use of Travel Demand Variables

Functional explanations of spatial interaction require the identification and assessment of the importance of factors or forces inherent in, or causing movement. The notions underlying the gravity and opportunity models serve to isolate some of these forces and provide generalizations of mass behaviour. But both models rely on iterative equation fitting procedures and adjustment factors which are in effect error terms, to account for 'unexplained' variation outside of the conceptual parameters of the models. A similar breakdown of highly generalized urban spatial structure models is pointed out in the review of case studies of the Vancouver urban area in Part II.

The multiple regression technique need not be based on a priori theory, but can be a means of measuring association between a group of variables taken together, and some factor which is being explained in terms of its association with these variables. The identification of variables in urban transportation analysis is usually related to conceptual notions of both spatial interaction and demand
considerations. (For a description of the technique, refer to Appendix I).

Factors associated with urban travel patterns which could be quantified and incorporated in estimating equations using regression procedures were first systematically identified by Mitchell and Rapkin, who initiated the discussion of urban traffic as a function of land use activity systems. Several factors relating to the size and character of land use and of transportation systems were found to have constant and measurable relationships with urban travel patterns. Voorhees' early work with the gravity model followed similar procedures as Mitchell and Rapkin. For example, he introduced surrogate (or substitute) measures representative of land use activities into Reilly's law of retail gravitation for explaining and predicting travel patterns to commercial centres in cities. Essentially, the outcome of this approach to modeling intra-urban travel patterns was the development of better gravity models, by incorporating more representative measures of the complementarity of the interacting masses.

Oi and Shuldiner went one step further and isolated characteristics of residential areas which affected the propensity of an area to produce trips of given types. They categorized trips into production-oriented trips and consumption-oriented trips. While they recognized that work
trips (production) generated between two areas would be a function of the complementary relationship between origin zone labour force and destination zone employment opportunities, they also indicated that characteristics of the residential areas that affect travel demand also operated in determining the amount of trips between the two areas. Significant here was the availability of automobiles and socio-economic characteristics of the population. These surrogate demand factors were found to be even more important for consumption-oriented trips such as shopping or recreation trips. Multiple regression techniques have been used to account for these 'forces'. A typical example of such a model is the United States Bureau of Public Roads gravity model, which remains as a gravity model by the inclusion of a reciprocal distance factor. Other multiple regression models do not place distance in such an important position, but simply treat it as another variable.

The work of the above authors and many others in transportation studies throughout North America and Europe has resulted in the identification and use of a large number of variables found to be associated with trip generation for residential areas, non-residential areas and for modal split. Modal split is treated below as a special case of the discussion of factors affecting travel demand. In this part
of the discussion, we are only concerned with trip generation and not the distribution of trips.

Modal split refers to procedures used to allocate intra-urban travel to public mass transit and private automobile. As in other trip generation models, multiple regression procedures are often used. A detailed discussion of typical models and the variables incorporated is provided in Appendix I.

Modal split models focus on the concept of captive and choice riders in explaining the use of transit by urban travelers. Captive riders have no alternate means of transportation, which in effect means they do not have the use of an automobile. Area characteristics, such as automobile ownership or income, have been found to provide the best explanation of transit trips generated. Below a certain income, families do not own automobiles and trip makers must use public transit. People too old or too young to drive, and wives whose husbands use the family car, are also captive transit riders. Choice transit riders, those who have alternate means of travel but chose transit, are found to be affected by transportation system characteristics, particularly time and convenience (excess travel time).

Implications of Part I

Intra-urban travel patterns are usually looked at as the result of systematic functional relationships between
activities located in different parts of the urban area. Transportation planning models were discussed, and their role in explaining spatial interaction was indicated. The gravity and intervening opportunity model were found to be able to incorporate some of the essential basic forces operating in structuring urban travel patterns—complementarity, intervening opportunity and distance decay. However, both these models were conceptually limited in their original formulations, and the interpretive difficulty in breaking the auxiliary relationship between distance and intervening opportunity was made evident. A discussion of other factors associated with, and causally related to, travel demand pointed out that the three classical principles of spatial interaction did not in fact account for all forces structuring spatial interaction. Specific attributes of complementary masses were also found significant in explaining travel patterns. While these three principles serve to describe some important relationships underlying spatial interaction, they break down somewhat in application. This does not however destroy their value, but merely places some limitations on them as one approaches and tries to explain less general cases or problems.

On another level, the discussion in Part I has served to indicate several factors which will specifically affect bus passenger travel patterns. These include forces or
factors representing the now familiar notions of complementarity, intervening opportunity, transferability and demand functions. Specifically, we are concerned with the isolation of variables representative of interacting masses, intervening opportunities, distance measures and also surrogate measures of travel demand, notably income and automobile availability.

PART II
THE URBAN STRUCTURE OF GREATER VANCOUVER AND ITS IMPLICATIONS FOR TRANSIT TRAVEL PATTERNS TO THE CORE

The metropolitan area of Greater Vancouver has been the subject of several investigations designed to test notions of urban form and structure which have been advanced in geographical literature. Five of these case studies focus on the role of the urban core and aspects of its spatial relations with the metropolitan area. A recent paper by Walter Hardwick summarizes the findings of these studies in the form of a new model, which describes the urban pattern of Greater Vancouver. Case studies have shown that this area does not conform to traditional urban pattern models but rather to what Hardwick has called a 'core-ring' model.
The 'core-ring' model is composed of two concentric rings. The centre ring is a radially organized ring focussed on the traditional central business district; the second and outer ring is a circumferentially organized urbanized area composed of a series of interconnected communities and work places . . . by definition there is more interaction within each system than between them.(16)

The inner ring is comprised of the City of Vancouver, North Vancouver District and West Vancouver. The peripheral system includes New Westminster and the suburban municipalities of Burnaby, Richmond, Coquitlam, Port Coquitlam, Surrey and Delta. The transit system providing mass transit services in the Greater Vancouver area serves both the inner and peripheral systems.

These case studies and their findings are reviewed here to indicate relationships which may affect bus passenger travel patterns.

1) Journey to Work Studies in Vancouver

Two studies of journey to work in the Vancouver area have been done; Wolforth's Residential Location and Place of Work, and Hickman's Peripheral Journey to Work in Vancouver.

Wolforth found that the Vancouver area is radially segregated in terms of socio-economic patterns of residence, and journeys to work to the core area reflect this pattern, with the downtown labour catchment being biased towards the western sector of the metropolitan area. (West Vancouver and Point Grey). This pattern was considered as a reflection
of the higher income nature of most downtown office jobs and the housing characteristics of the western sector of the metropolitan area, where favourable site conditions have resulted in high income neighbourhoods. Low income downtown workers in the clerical and service groups were drawn from the eastern portion of the city (Main Street to Boundary Road) and from the high density residential (West End) area which is adjacent to the core. The former area had relatively small proportions of its total residential population working downtown, even in those parts which are immediately adjacent to the urban core. Differentiation of labour catchment areas occurred for areas within the core; for example the western part of the core had its labour catchment area oriented even more to the west, and eastern parts had a labour catchment area oriented to the east.

Wolforth was not concerned with modal split, but he suggested that low income areas would have a heavier reliance on public transit. Although much of the findings of his study were drawn from a study of automobile trips to downtown parking lots, it was assumed that the pattern of work-residence location held irrespective of the transit riding, in view of the high per capita car ownership throughout the metropolitan area.

The objective of Hickman's study of the peripheral journey to work was to determine the relative importance of
peripherally destined work journeys as compared to those destined to Vancouver's central core in the overall metropolitan traffic picture. The level of analysis and areas chosen to substantiate the hypothesis that peripheral work journeys are increasingly important in the travel patterns of metropolitan residents was quite limited.

Hickman's research indicated that the proportion of central area workers per residential area drops off with distance from the C.B.D., but not without considerable variation, which was considered suggestive of other structural factors. Work journey commuting in the Vancouver city and Burnaby areas was 60 per cent oriented towards the core area and its adjacent industrial employment areas, while the remaining 40 per cent was scattered to numerous peripheral work place concentrations. Other findings reflect and substantiate those of Wolforth.

2) C.B.D. Shopping Studies in Vancouver

Three studies of relevance to the analysis of shopping trips by bus transit trips to Vancouver's core area have been done. (17) Two of these indicate the range of retail shopping influence of the C.B.D. (as a whole and various sectors within it) over the metropolitan area.

Roger Leigh's Specialty Retailing--A Geographic Analysis uses the Vancouver area as a case study to demonstrate that traditional marketing geography interpretations of specialty
retail market areas and locations and does not explain the Vancouver area case. He tests and dismisses the generalization that high order retail stores have a 'C.B.D. location' and a 'city-wide market'. Of importance to this thesis are Leigh's concluding comments on the role of the C.B.D. as the specialty retailing centre within an urban area, in this case the Vancouver area.

Recency in decentralization of high order stores coincided with improvements in customer mobility in the City. This was interpreted to mean that in the contemporary city the C.B.D. market place has lost its accessibility monopoly. The clustering of high order businesses in the "inner city" (between the C.B.D. and south-western suburbs) tends to confirm the suggestion that this accessibility advantage is now shared by a territorially wider area of the city; in short, the C.B.D. market place is replaced by an inner city "market area" within which there are several locations equally accessible to customers in non-contiguous residential districts.

The significance of this study to the analysis of person trips to the Vancouver core by public transit for purposes of shopping is that the core area does not have a monopoly location for specialty retailing. Leigh's study did not separate transit from automobile users in reaching his conclusions, and his findings regarding the importance of the core may not hold for transit riders, especially since the transit system is a core oriented system.

This study leads into a subsequent paper produced by Hardwick and Leigh, which examined the market areas of the three major department stores located in downtown Vancouver.
While the earlier study pointed out the decline in relative importance of the C.B.D. as the only specialty retailing area in the Vancouver metropolitan area, the latter study indicated the strength of the C.B.D. as a metropolitan shopping centre and the nature of its retail influence.

The Geography of Central Retailing reviews theoretical constructs which have been used to interpret the role of the C.B.D. in the context of the spatial organization of intra-city retail trade—particularly in terms of ecological theory and central place theory:

1) Ecological theory, in brief, "stresses that the core is the centre of the city by virtue of its historical origins and position at the focus of major routeways . . . the point of minimum aggregate travel". (20) From such a central location stores command a city-wide market.

2) In terms of central place theory "based on the notion that demands for various goods occur with differing frequency among households" . . . leading to a . . . hierarchy of service centres . . . with frequently demanded services supplied by ubiquitous 'low order' centres serving local hinterlands . . . and . . . infrequently demand goods distributed through fewer high order centres, whose larger hinterlands embrace nests of lower order hinterlands", (21) the C.B.D. is the retail location for infrequently purchased goods. Both theories support the notion that the C.B.D.'s retail activities, typically department stores and specialty retails, serve a city-wide market.

3) Agglomeration economies are also indicated as being important to the dominant role of the C.B.D. (22) The clustering of retail activities combines their individual attractive forces by providing the opportunity for comparison
shopping, while the proximity of other core activities provides maximum convenience for consumers to realize several trip purposes while downtown. The large downtown labour force also supports C.B.D. retailing activities.

All these factors suggest the continuance of a strong retail function within the core area, while generalizations expressing C.B.D. dominance for specialized retail activities (specialty retailing and large department stores) suggest the C.B.D. draws customers from a city-wide market and is dominant within this market.

Hardwick and Leigh also point out the differentiated nature of core area land uses, particularly with reference to retail store type and quality. Areas within the C.B.D. demonstrate groupings of retail activities with different levels of quality which cater to different consumer groups who in turn are differentiated by their socio-economic characteristics. It has already been pointed out in the review of Wolforth's study that Vancouver is comprised of sectors of socio-economic residential groupings, and that certain parts of the core were oriented towards certain sectors--west to west, and east to east for work-journey purposes. Taking this further, Hardwick and Leigh proposed that certain areas of the C.B.D. cater to certain areas of the city in retail terms also. On this basis the relevance of notions of city-wide dominance by a homogeneous C.B.D. is questioned. A number of hypotheses were advanced for
testing--two of which are relevant to a study of transit travel patterns to the C.B.D.

"Hypothesis I. C.B.D. stores have morphologically sectoral, not city-wide hinterlands .... oriented towards socially distinctive and territorially localized groups within the city." (23)

"Hypothesis IV. Groups of stores (i.e. identifiable C.B.D. sub-areas) exhibit sectionally defined hinterlands since stores appealing to similar customer types tend to cluster together to facilitate competitive and comparative shopping by customers." (24)

Using five data source including store records, in-store surveys and a home interview survey, shopping trip patterns to the C.B.D. were investigated. The three major department stores in downtown Vancouver were chosen as the major representative shopping destinations. One store, the Hudson's Bay Company, was found to be oriented towards upper income groups, while another, Woodward's, was oriented towards lower income groups. The third, the T. Eaton Company, was discovered to be between the two extremes. This orientation can be expressed not only in terms of product and price marketing orientation, but in terms of location within the C.B.D. The Bay is located in the western portion of the C.B.D. at Georgia and Granville Streets—the latter being a major arterial from upper income suburbs. Woodward's is in the older eastern portion of the C.B.D. and is on Hastings Street, a direct link to lower income suburbs. Eaton's is located between the two and its location favours neither the lower income or upper income more than the other. (25)
Findings from the surveys indicated that the stores were not drawing customers evenly from across the metropolitan area, as the traditional notions of urban retail structure suggested. The Granville Street axis (including the Bay) showed definite orientation to the higher income western portion of the metropolitan area. The Hastings Street axis (Eaton's and Woodward's) drew customers more evenly from the City of Vancouver, suggesting this area's conformance to the ideal 'city serving' role of the C.B.D. Of greater importance for the Hastings axis was that its market area tended to be structured by distance rather than social class, yet there was a higher proportion of lower class customers to this area. By refining the analysis, Hardwick and Leigh indicated that the C.B.D. hinterland consisted of an inner and outer ring. The inner ring had a high proportion of customer origins per residence up to the limit of the five mile ring. Beyond five miles, the incidence of customer origins was seen to fall off precipitously. Finally "within the five mile zone, trip generation and residence does not fall off regularly with distance, but is apparently concentrated in different zones according to the social class appeal of stores and the territorial localization of involved social groups".

In a third study of shopping trips, R.A. Mackinnon examined 1962 shopping trips by private automobile to the
C.B.D. of Vancouver. Having similar objectives as the papers of Wolforth, Hardwick and Leigh, Mackinnon searched for factors related to the variation of trip origins to the C.B.D. and to different parts of the C.B.D. He attempted to describe the structure of patterns in terms of "suggestive causal relationships . . . by seeking causal factors, and thus 'explain' the observed patterns". (29) For all trip purposes (work 32%, business 32%, shopping 29%, and social-recreation and others 7%) trip frequencies rose to a peak at the five mile ring (from the core) then decline in the outer rings. (30) The shopping trip pattern started at a low level, increased at one mile distance, decreased in the two mile ring, then increased to the five mile ring and dropped off. Variation in the proportion of shopping trip patterns reflected variation in income levels, as indicated in Hardwick and Leigh's study. This was tested using regression techniques.

Stepwise regression was employed by Mackinnon to 'explain' the distribution of automobile shopping trip generation rates from origin zones to the C.B.D. Three variables were selected: per capita income of shopping zone population, log of distance to the Vancouver C.B.D., and distance to nearest competing centre. Sixty-three per cent of the variation in the shopping trips was associated with variation in these three independent variables, with per
capita income providing 39 per cent, distance to C.B.D. providing 14 per cent and distance to the nearest competing centres 10 per cent.\(^{(31)}\) Lack of available data limited further search for independent variables.

The second level of Mackinnon's examination of automobile shopping trip patterns dealt with variations in these trip patterns to various parts of the C.B.D. Again income and distance variation in origin zones was related to sub-areas of the C.B.D. He established that higher income areas are more important to the Bay and Eaton's areas, and less important to the Woodward's area within the C.B.D.

Mackinnon's study was done concurrently with Hardwick and Leigh's analysis of C.B.D. retailing. Using different data sources, similar findings resulted—suggesting that these findings describe the actual relationships of Vancouver's C.B.D., and its various sub-parts, with its hinterland or its various parts.

**Implications of Part II**

Travel patterns to the core area of Greater Vancouver seem to form a core-ring pattern, with an inner ring of spatial interaction focussed on the core. This ring includes the Cities of Vancouver and North Vancouver and the Municipality of West Vancouver. Within this ring, trips are radially organized from generally homogeneous residential neighbourhoods (homogeneous in terms of socio-economic
characteristics). Work trips to the core have a westward orientation, while shoppers are drawn more consistently throughout the Vancouver area, with some variation attributable to socio-economic and intervening opportunity factors. A breakdown of the core into retail activity sub-areas, however, indicated that the western retail nucleus within the core had a westward bias, and the eastern nucleus had an eastward bias reflecting socio-economic variation of the functions of the core area and in the patterning of its hinterland.

In Part I of this chapter, a review of concepts and models of spatial interaction indicated that spatial interaction could be modelled by the use of surrogate variables representing functional relationships between activities and locations. In Part II a review of case studies of the urban pattern of Greater Vancouver indicated some of these forces work in structuring travel patterns to the core area of this city. Both reviews demonstrated progress in the search for explanations of urban structure and the spatial relationships resulting from this structure. Both fields have moved away from simple generalizations based on distance decay and intervening opportunity concepts, to the inclusion of socio-economic characteristics of trip makers and their residential areas in functionally relevant model formulations.
FORMULATION OF PROBLEMS

From the discussion in this chapter, the problems of this thesis can be more specifically formulated. The problems are treated in Chapters III and IV. Chapter III deals with a general description of spatial characteristics of bus passenger travel patterns to the core, for the purposes of work and shopping. Chapter IV develops a multiple linear regression model to explain these patterns in terms of surrogate variables representative of functional relationships.

The review of case studies indicated that travel patterns to the core are structured primarily by distance and by directional orientation to radially organized residential areas of different social types. The question of whether these case study findings are tenable in also describing bus passenger travel patterns is the overriding programme of Chapter III. These expectations can be expressed as:

1) Bus passenger travel will be "core-oriented" within the inner core ring system comprised of North Vancouver and Vancouver (West Vancouver was not surveyed; it is served by a separate company).

2) Bus passenger travel to the core is expected to decline with distance from the core and especially to drop off very rapidly beyond the inner system (beyond five miles).
3) Transit work trip generation to the core will be subject to socio-economic variation within the inner core ring. An eastward orientation of the downtown core is expected. This is the reverse of orientation of the core for trips by all modes, but it is expected that lower income areas will generate more core destined trips per capita than higher income western areas.

4) Shopping trip patterns are expected to be more constant throughout the inner ring, indicating continued downtown business district (C.B.D.) dominance (as a retail complex) within this ring.

5) Sub-areas of the downtown core are expected to have sectoral orientation of trip patterns, with eastern areas of the core oriented to low income residential areas and western areas of the core oriented to high income residential areas. These patterns are expected for both work and shopping trips.

These expected relationships are identified in Chapter III and tested further in Chapter IV. A detailed discussion of variables used in model building and expected relationships will be presented in the introduction to this later chapter.
FOOTNOTES


(4) Refer to late 1960 publications of the Highway Research Board: Highway Research Record and National Co-operative Highway Research Program Reports.


(6) Ibid.


(17) Ibid., p. 111.

(18) Ibid., p. 112.

(19) Ibid., op. cit., p. 2.

(20) Ibid., pp. 3-4.


(22) Ibid., p. 14.
(25) Ibid., p. 28.
(26) Ibid., p. 33.
(27) Ibid., p. 41.
(28) Ibid., p. 42.
(29) Mackinnon, op. cit., p. 2.
(30) Ibid., p. 2.
(31) Ibid., p. 38.
CHAPTER III

BUS PASSENGER TRIPS TO THE CORE

The purpose of this chapter is to present cartographically and in tabular form the distribution patterns of work and shopping trips to the downtown core, and to interpret these patterns in terms of the expected relationships presented at the conclusion of Chapter II.

Data on origins and destinations of bus passenger trips was obtained from the University of British Columbia, Geography Department Urban Core Project Transit Survey carried out in conjunction with the British Columbia Hydro and Power Authority Transportation Division in May 1965. A discussion of this survey is provided in Appendix II. The research design and survey was conducted prior to the involvement of the author and therefore is not presented as a major part of this thesis.

All data is summarized to 65 traffic zones, 49 of which are served by the B.C.H. & P.A. Transit System and included in this study. (See Figures 3, 6 and 7). The construction of these traffic zones is discussed in Appendix III. The implications of the use of areal units such as traffic zones in urban transportation analysis is discussed in this Appendix and in Chapters IV and V.
Source: City of Vancouver Planning Department
Three aspects of both work and shopping trip patterns are analyzed in this Chapter:

1) Transit trip generation per capita destined to the core. (Figure 8)

2) Transit trips to the core as a percentage of all trips generated in each zone. (Figure 9)

3) Transit trip patterns to individual core zones. (Figures 10 and 11)

1) Per Capita Distribution of Transit Trips to the Core:

Bus passenger trips to the core for work and shopping purposes show a distinct pattern of distance and sector variation. (Figure 8)

a) Work Trips—Traffic zones within ten to twenty minutes travel time to the core have a relatively high per capita transit volume. (Table 1) These zones include the West End zones 02 and 04, with 02 having the highest transit generating rate of all zones. Zone 04, within walking distance of the core, has a lower rate. High rate zones include inner city districts of Kitsilano (30), Arbutus (34) and Fairview (23-29). The Hastings Street sector (38-39) also has a high transit riding ratio compared to western and southern areas of the city. These latter areas, which include Point Grey (31); Dunbar (33), Kerrisdale-Marpole (44), Fraser (43), and the South-east Sector (42) are low transit trip generators. Burnaby zones have a very low per capita
TABLE 1
BUS PASSENGER TRIPS PER 1,000 ORIGIN ZONE POPULATION TO CORE ZONES

<table>
<thead>
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<th>TRAFFIC ZONE</th>
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<th>SHOPPING</th>
<th>ZONE POPULATION</th>
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<td>Total</td>
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</table>
PER CAPITA TRANSIT TRIPS TO THE CORE

Figure 8

TRANSIT TRIPS TO THE CORE AS A PERCENT OF ALL TRANSIT TRIPS

Figure 9

Source: Vancouver Urban Core Transit Survey
transit passenger link with the core for work purposes. Areas further east and south have less than one person per 1,000 residents travelling by transit to Vancouver's core to work.

b) Shopping Trips—Variation in shopping trips per 1,000 residents to the core area is not as great as that for work trips. Only Zone 02 in the West End and Fairview Zones 23-29 and 21-25 have a high rate of bus passenger travel to the core for shopping. Per capita shopping trip generation for the remaining zones is constant and low over most of the entire transit service area beyond 15-20 minutes transit travel time from the core. This is reflected by the modal group for the shopping trip distribution which is less than ten trips per 1,000 residents.

2) Trips to the Core Compared With Total Trips Originating in Each Zone

The focus of the transit system on the core, indicating its role as a core-serving system is illustrated in Figure 9. Work trips by transit to the core comprise on the average (mean) 43 per cent of all work trips generated in each zone (modal class = 41-50). The pattern for shopping trips is quite different, with an average (mean) of 64 per cent of shopping trips originating in each zone destined to the core (modal class = 91-100). (Table 2)
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<th>ZONE</th>
<th>ALL WORK</th>
<th>WORK TO CORE</th>
<th>%</th>
<th>ALL SHOP</th>
<th>SHOP TO CORE</th>
<th>%</th>
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<td>-</td>
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<td>221</td>
<td>107 (48)</td>
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<td>48</td>
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<td></td>
<td>9</td>
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<td>37 (71)</td>
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<td>582</td>
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<td>119</td>
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</tr>
<tr>
<td>56</td>
<td>242</td>
<td>187 (77)</td>
<td></td>
<td>106</td>
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<tr>
<td>57</td>
<td>184</td>
<td>156 (85)</td>
<td></td>
<td>67</td>
<td>52 (72)</td>
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</tr>
<tr>
<td>58</td>
<td>134</td>
<td>110 (82)</td>
<td></td>
<td>56</td>
<td>55 (98)</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>43</td>
<td>13 (30)</td>
<td></td>
<td>6</td>
<td>6 (100)</td>
<td></td>
</tr>
</tbody>
</table>
a) Work Trips—The western zones, including the West End (02), Kitsilano (30), Arbutus (34) and Point Grey (31) have a relatively high percentage of total work trip transit volumes destined to the core. Eastern zones, including Victoria Drive (36) and East Hastings display a similar pattern. North and Central Burnaby (45, 46), the North Shore zones and West Richmond (50) forming a suburban ring also have a high per cent of total trips generated, destined to the core. Lower per cent ratios are found generally in south-west and central and south-eastern areas of the City of Vancouver.

b) Shopping Trips—Zones of high per cent shopping trip orientation to the core area are generally the same as those having high per cent work trip orientation. Greater relative shopping trip orientation to the core occurs in zones 02, 04, 15-18, 23-29, 32, 34, 35A, 38, 41, 42, 44, 45, 46, 52 and 68. In some of these zones 32, 35A, 50, 52 and 68 actual trip volumes are extremely low. Significantly greater orientation of shopping trips to the core occurs in the close-to-the-core West End and Fairview and inner East Hastings.

3) Distribution of Transit Trips to Specific Core Zones

The core area defined in Chapter I is comprised of eight traffic zones. (Figure 5) Employment in the core provides jobs for over 80,000 people, more than 60 per cent
of which are in white collar occupations. (Table 3) White collar employment is found primarily in the north-western areas of the downtown core, including zones 03, and 05-09. Blue collar employment is found in eastern and waterfront core zones including zones 10-14. Retail activity in the core is concentrated along the Granville and Hastings Street axes in zones 07, 05-06 and 13-14. These zones account for nearly three-quarters of core area retail employment, and form distinct shopping districts within the core.

TABLE 3

EMPLOYMENT IN THE URBAN CORE: 1965

<table>
<thead>
<tr>
<th>ZONE</th>
<th>BLUE COLLAR HORE.</th>
<th>WHITE COLLAR HORE.</th>
<th>TOTAL VERT. HORE.</th>
<th>RETAIL EMPLOYMENT VERT. HORE.</th>
</tr>
</thead>
<tbody>
<tr>
<td>03</td>
<td>1,550 (10)</td>
<td>13,950 (90)</td>
<td>15,500 (19)</td>
<td>360 (3)</td>
</tr>
<tr>
<td>05-06</td>
<td>5,080 (33)</td>
<td>10,520 (67)</td>
<td>15,600 (19)</td>
<td>2,030 (19)</td>
</tr>
<tr>
<td>07</td>
<td>5,010 (30)</td>
<td>11,690 (70)</td>
<td>16,700 (21)</td>
<td>2,920 (27)</td>
</tr>
<tr>
<td>08</td>
<td>1,230 (30)</td>
<td>2,870 (70)</td>
<td>4,100 (6)</td>
<td>950 (9)</td>
</tr>
<tr>
<td>09</td>
<td>1,620 (30)</td>
<td>3,780 (70)</td>
<td>5,400 (7)</td>
<td>470 (4)</td>
</tr>
<tr>
<td>10</td>
<td>2,380 (70)</td>
<td>1,020 (30)</td>
<td>3,400 (4)</td>
<td>390 (4)</td>
</tr>
<tr>
<td>11-12</td>
<td>5,480 (60)</td>
<td>3,720 (40)</td>
<td>9,200 (11)</td>
<td>490 (5)</td>
</tr>
<tr>
<td>13-14</td>
<td>8,130 (77)</td>
<td>2,470 (23)</td>
<td>10,600 (13)</td>
<td>3,010 (28)</td>
</tr>
<tr>
<td>Total</td>
<td>30,480 (38)</td>
<td>50,020 (62)</td>
<td>80,500</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: V.T.S., City of Vancouver Planning Department.

Work transit trips to all the core zones together and to each of these core zones are individually examined here to determine if different patterns of work trip orientation
towards separate areas of the urban hinterland are evident for each zone. Then, all core zones and three retail zones (07, including the Bay Department store; 05-06, including Eaton's; and 13-14, including Woodward's) are studied to determine if retail areas of the core have directional or socio-economic orientation, as indicated by shopping trip patterns. (See procedural note below)

a) Work Trips—Nearly twenty per cent of those working in the core travel by bus. Zones 05-06, 07, and 13-14 have a higher proportion of transit trip ends per employment opportunity than the other core zones as indicated in Table 4.

Procedural Note: For the purposes of this section, traffic zones in the transit service area have been combined into groups with relatively common socio-economic and directional and distance characteristics. These aggregations are admittedly crude, but do allow for visual comparison of the areas of influence of each core zone, relative to other core zones. This picture is presented in terms of the per cent of total trips to each core zone coming from each of the aggregated origin zones.
TABLE 4

BUS PASSENGER WORK TRIP ENDS AND EMPLOYMENT DISTRIBUTION IN CORE ZONES

<table>
<thead>
<tr>
<th>ZONE</th>
<th>EMPLOYMENT*</th>
<th>VERTICAL PER CENT</th>
<th>WORK TRIP ENDS</th>
<th>VERTICAL PER CENT</th>
</tr>
</thead>
<tbody>
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<td>03</td>
<td>15,500</td>
<td>(19)</td>
<td>1,406</td>
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</tr>
<tr>
<td>05-06</td>
<td>15,600</td>
<td>(19)</td>
<td>4,958</td>
<td>(33)</td>
</tr>
<tr>
<td>07</td>
<td>16,700</td>
<td>(21)</td>
<td>3,826</td>
<td>(26)</td>
</tr>
<tr>
<td>08</td>
<td>4,100</td>
<td>(6)</td>
<td>332</td>
<td>(2)</td>
</tr>
<tr>
<td>09</td>
<td>5,400</td>
<td>(7)</td>
<td>636</td>
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</tr>
<tr>
<td>10</td>
<td>3,400</td>
<td>(4)</td>
<td>216</td>
<td>(1)</td>
</tr>
<tr>
<td>11-12</td>
<td>9,200</td>
<td>(11)</td>
<td>707</td>
<td>(5)</td>
</tr>
<tr>
<td>13-14</td>
<td>10,600</td>
<td>(13)</td>
<td>2,849</td>
<td>(19)</td>
</tr>
<tr>
<td>Total</td>
<td>80,500</td>
<td></td>
<td>14,932</td>
<td></td>
</tr>
</tbody>
</table>

*SOURCE: V.T.S., City of Vancouver Planning Department

These zones also have a higher proportion of retail employment, (Table 3) and female rider work trip ends. (Table 5)

Other high proportion female rider trip ends occur in zone 03 and zone 10. Zone 11-12 and 08 have higher male rider trip end proportions.

Distribution of Work Trip Origins (Table 6, Figure 10)

(i) All Core Zones--The distribution of bus work trip origins for all core zones is evenly balanced over the study area, with some concentrations in Fairview-Kitsilano-Arbutus-Point Grey area, 22 per
TABLE 5

BUS PASSENGER WORK TRIPS TO CORE ZONES BY SEX OF RIDER

<table>
<thead>
<tr>
<th>ZONE</th>
<th>MALE TRIPS</th>
<th>HORIZONTAL PER CENT</th>
<th>FEMALE TRIPS</th>
<th>HORIZONTAL PER CENT</th>
<th>ROW TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>03</td>
<td>487</td>
<td>(35)</td>
<td>918</td>
<td>(65)</td>
<td>1,405</td>
</tr>
<tr>
<td>05-06</td>
<td>1,639</td>
<td>(33)</td>
<td>3,325</td>
<td>(67)</td>
<td>4,964</td>
</tr>
<tr>
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<td>1,179</td>
<td>(28)</td>
<td>2,643</td>
<td>(72)</td>
<td>3,822</td>
</tr>
<tr>
<td>08</td>
<td>165</td>
<td>(53)</td>
<td>148</td>
<td>(47)</td>
<td>313</td>
</tr>
<tr>
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<tr>
<td>11-12</td>
<td>415</td>
<td>(59)</td>
<td>289</td>
<td>(41)</td>
<td>704</td>
</tr>
<tr>
<td>13-14</td>
<td>1,254</td>
<td>(44)</td>
<td>1,610</td>
<td>(56)</td>
<td>2,864</td>
</tr>
<tr>
<td>Total</td>
<td>5,443</td>
<td>(37)</td>
<td>9,498</td>
<td>(63)</td>
<td>14,941*</td>
</tr>
</tbody>
</table>

*Difference in totals between Table 4 and Table 5 attributable to round-off errors.

cent; and the eastern south-east sectors of the City with 12 and 16 per cent respectively. North Vancouver and Burnaby origins account for 7 and 6 per cent, and Richmond for 1 per cent. This latter group reflects a decline with distance, but no sectoral emphasis.

(ii) Zone 03, the office bulge area, with almost 14,000 white collar employees at the time of the survey, has a high per cent of trip origins from the Fairview-Kitsilano-Arbutus-Point Grey area, 22 per cent; and the south-east sector, 18 per cent. North Vancouver and Burnaby are also well represented, with 10 and 8
### TABLE 6

DISTRIBUTION OF BUS PASSENGER WORK TRIPS TO CORE ZONES

PERCENT DISTRIBUTION OF WORK TRIP ORIGINS TO CORE ZONES

Source: Vancouver Urban Core Transit Survey
per cent. The West End is low with only 8 per cent. The orientation of this zone approximates that of the all zone pattern and supports the expected balance of westward orientation caused by lower income areas greater transit travel propensity.

(iii) Zones 05-06 have a central, 11 per cent; eastern, 14 per cent; and south-east sector, 19 per cent orientation. The West End accounts for 12 per cent of trips while the Kitsilano-Point Grey area accounts for 17 per cent, again supporting the expected balance orientation.

(iv) Zone 07, with two-thirds of the employment opportunities in white collar occupations, (as had zones 05-06) has a much greater orientation towards the western sectors of the city. Significant here is the 31 per cent from Fairview-Kitsilano-Arbutus-Point Grey area (23 per cent from Kitsilano-Fairview). North Vancouver is high with 14 per cent of trip origins from this area. As a western core zone with a western bias, this supports Wolforth's findings.

(v) Zone 08 has its highest recorded trip origins in Burnaby, particularly North Burnaby. Only the close-in areas of the West End, Kitsilano, Arbutus, Point Grey and Broadway-Mount Pleasant have a high
per cent of trip origins. The pattern within these areas is also different than for other core zones, with both Arbutus and Point Grey having greater representation than Kitsilano and Fairview. North Vancouver and the south-west, south central, south-east and eastern sectors of the city are few work trip origins with trip ends in this zone. No reasons for Burnaby's importance is suggested in the case study review or the data.

(vi) Zone 09 has its orientation towards eastern and southern zones primarily, although the western and south-western areas remain quite high. The West End is very low with only 5 per cent. Again no highly defined east-west bias is apparent.

(vii) Zone 10, an industrial-general business zone with two-thirds of its 3,400 workers in blue collar occupation, is oriented to the east and south-east, with a high representation from Burnaby. This supports both the expected east core to east hinterland relationship and income structure of these occupations and the eastern sector of the inner core ring.

(viii) Zones 11-12 are also blue collar zones with 60 per cent of employees in blue collar occupations. These zones have the opposite orientation to zone 10.
Where zones in the south-east and eastern sectors were highly represented for zone 10, these zones are low for zones 11-12. Origin zones in the western, inner central and south-western sectors, and North Vancouver have the highest orientation to these core zones. This is opposite to expected orientation.

(ix) Zones 13-14, with nearly 80 per cent of its 10,600 employment opportunities in blue collar occupations, has an eastward orientation as would be expected. Areas east of Oak Street account for 62 per cent of trip origins.

b) Shopping Trips—to the core are concentrated in those zones which have the highest portion of retail employment, zones 05, 06, 07 and 13-14. (Table 7)

Over 80 per cent of bus passengers travelling to the core to shop are female, particularly in zones 05, 06, 07 and 13-14. (Table 8)

**Distribution of Shopping Trip Origins** (Table 9, Figure 11)

(i) All Core Zones—7,659 shopping trips to the core were recorded during the Transit Survey. Ninety-six per cent of these trips were destined to zones 05-06 (22%), 07 (36%) and 13-14 (38%). Zone 07 comprises much of the Granville Street axis of the Central Business District; Zone 05-06 comprises the
### TABLE 7

**BUS PASSENGER SHOPPING TRIP ENDS AND RETAIL EMPLOYMENT DISTRIBUTION IN CORE ZONES**

<table>
<thead>
<tr>
<th>ZONE</th>
<th>RETAIL EMPLOYMENT</th>
<th>VERTICAL PER CENT</th>
<th>SHOPPING TRIP/ENDS</th>
<th>VERTICAL PER CENT</th>
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<td>03</td>
<td>360</td>
<td>(3)</td>
<td>154</td>
<td>(2)</td>
</tr>
<tr>
<td>05-06</td>
<td>2,030</td>
<td>(19)</td>
<td>1,723</td>
<td>(22)</td>
</tr>
<tr>
<td>07</td>
<td>2,920</td>
<td>(27)</td>
<td>2,775</td>
<td>(36)</td>
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<tr>
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<td>(1)</td>
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<tr>
<td>10</td>
<td>390</td>
<td>(4)</td>
<td>82</td>
<td>(1)</td>
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<tr>
<td>11-12</td>
<td>490</td>
<td>(5)</td>
<td>-</td>
<td>-</td>
</tr>
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<td>13-14</td>
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<td>(37)</td>
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<tr>
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<td>10,620</td>
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<td>7,659</td>
<td></td>
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</tbody>
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### TABLE 8

**BUS PASSENGER SHOPPING TRIPS TO CORE ZONES**

**BY SEX OF RIDER**

<table>
<thead>
<tr>
<th>ZONE</th>
<th>MALE TRIPS</th>
<th>HORIZONTAL PER CENT</th>
<th>FEMALE TRIPS</th>
<th>HORIZONTAL PER CENT</th>
<th>ROW TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>03</td>
<td>39</td>
<td>(22)</td>
<td>139</td>
<td>(78)</td>
<td>178</td>
</tr>
<tr>
<td>05-06</td>
<td>328</td>
<td>(18)</td>
<td>1,453</td>
<td>(82)</td>
<td>1,781</td>
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<tr>
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*Difference in totals between Table 7 and Table 8 attributable to response category variation and round-off errors.*
## TABLE 9

### DISTRIBUTION OF BUS PASSENGER SHOPPING TRIPS TO CORE ZONES

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**Column Totals**: 154, 1,723, 2,775, 26, 72, - 82, 2,827, 7,659
PERCENT DISTRIBUTION OF SHOPPING TRIP ORIGINS TO CORE ZONES

Source: Vancouver Urban Core Transit Survey

Figure 11
Eaton's Company area of the Hastings Street axis and zones 13-14 include the Woodward's area of the Hastings Street axis. The pattern of influence of all core zones in terms of the distribution of bus passenger origins for shopping trips is indicated in Figure 11. The West End accounts for 13 per cent of these trips; Kitsilano-Point Grey 16 per cent; and Dunbar-Kerrisdale-Marpole 6 per cent—a total of 35 per cent for the western sector of the city. The central areas account for 10 per cent as does the eastern sector, while the large south-eastern area accounts for 16 per cent. North Vancouver and Burnaby have 4 and 5 per cent of all core destined shopping trips respectively.

(ii) Zone 07--The Granville Street axis, with the Bay department store as its major focus, attracted almost 2,800 transit trips during the survey day. A definite western sector orientation of this zone is apparent, with 44 per cent of the trips coming from the area east of Oak Street (including the West End). The central and eastern areas including Burnaby were not as well represented as they were for the average picture given by the pattern for all core zones, and North Vancouver gained one
percentage point above this average. This supports Hardwick and Leigh's findings.

(iii) Zones 05-06--The Eaton's Company area, with less retail floor space than the other zones, and between these zones and thus subject to their intervening influence on customers coming from either the west or eastern sectors of the study area, had fewer trip destinations recorded than either the Bay (07) or Woodward's (13-14) areas. The western sector accounted for 42 per cent of shopping trip origins, slightly less than for 07, but displaying a different pattern, with the West End accounting for 19 per cent of shopping trips. The central area zones achieve their highest representation here with 18 per cent of all shopping trips to zones 05-06. The south-eastern area remained unchanged with 12 per cent, while the eastern sector gained four percentage points above showing for shopping trips to zone 07. The West End, Central and Eastern sector zones are indicated as the major areas of influence of zones 05-06. A somewhat central bias, as expected, is indicated.

(iv) Zones 13-14--The Woodward's Company area had slightly more trip ends than the Bay area,
with a total of 2,827 trips recorded. However, the orientation of this area is opposite to that of the Bay. The western zones account for only 22 per cent of trip origins to the Woodward's area. The central area maintains its average position, and the eastern and south-eastern sectors account for 39 per cent of trip origins to zones 05-06. This is double the influence of the Bay zone in this area. Zones 13-14 are much more highly oriented to Burnaby than to either of the other zones. Again earlier findings are supported.

(v) Internal Shopping Trips--Trips within the core area are examined together here as a special case. These trips may be indicative of second choice shopping destinations, and affect the interpretation of the above patterns.

--Destination 07--Of all trips destined to 07, 23 per cent originate from within the core. The largest portion of these, 17 per cent, come from zones 13-14, hinting at comparison shopping between the Woodward's and the Bay areas. Three per cent come from zone 03 which has a large residential population as well as employment concentration. Two per cent come from the nearby Eaton's area, hinting at comparison shopping.
—Destination 05-06—Fourteen per cent of all trips destined to 05-06 originate in the core. Six per cent of these come from the Woodward's area and two per cent come from the Bay area, hinting at comparison shopping among these areas. The remaining six per cent include four per cent from the mixed employment residential zone 03, and two per cent from other core zones.

—Destination 13-14—Twenty per cent of all trip ends in these zones originate in core zones. Zone 07 is highest with 10 per cent, and zones 05-06 represent 3 per cent. Again 4 per cent come from zone 03 and the remainder from other core zones.

If these core origins are interpreted as second choice trip ends, and assuming that the first choice trip end was made on the inbound trip to the core, the west, central and eastern orientation of shopping trips to the three retail core zones must be modified somewhat. Given this interpretation and assumption:

Where it was found that zone 07 had 44 per cent of its trips from west of Oak Street, it also had an additional 17 per cent of trips from the Woodward's area, where first stop trips primarily came from
the eastern and southern sectors of the study area. This suggests a balancing of the area of influence of the Bay across the study area. No comment can be made about the purchase of goods however. Where it was found that zones 05-06 had a central area orientation, 6 per cent of total trip ends also came from the Woodward's area, increasing the eastward orientation of this store cluster. Only 2 per cent of trip ends came from the Bay area, but it is noted here that although the Bay area is slightly closer than the Woodward's area, it is also downhill. Here again there is a balancing of influence to a limited extent, but a more eastward bias in orientation can be interpreted for this area. Where it was found that zones 13-14 were oriented very heavily towards the eastern and south-eastern sectors, the internal core movement patterns modifies this. Ten per cent of trips originating in zone 07 and ending in zones 13-14 suggest an increase in western sector influence, but not so large an influence as to balance the eastern and western portions of the study area. These zones (13-14) still appear to be oriented more towards the eastern sector.
4) Summary and Conclusions

1) **Per capita distribution of transit trips to the core:**
   
a) **Work Trips** to the core by transit do not follow the same pattern as automobile trips to the core found by Wolforth. Transit trips' patterns to the core as a whole are more oriented towards the eastern sector of Vancouver. The drop-off with distance in per capita transit trip generation is gradual within 3-4 miles of the core, then drops off rapidly in Burnaby and Richmond. The North Vancouver zones however have comparable per capita trip generation volumes as do Vancouver zones in the central and eastern areas. Within Vancouver, western zones, (with the exception of close-in Kitsilano and Fairview areas) have low per capita transit work trips to the core. These patterns suggest that transit as a transportation mode to the core has greatest attractiveness as a short distance mode, and as a means of travel for low income groups, or captive riders (those who have no alternative means of travel).

b) **Shopping Trips** to the core are relatively high (per capita) in zones located adjacent to the core, where shopping trips by transit from these zones are not restricted by distance or intervening
opportunities. Other Vancouver zones are relatively constant in their per capita trip production rates. Distance and intervening opportunity are perhaps significant factors here, but this is difficult to substantiate at the present level of aggregation. Both high income and low income residential areas have similar rates, indicating that in both types of areas the availability of autos for women in the household may be low. (Eighty per cent of transit shopping trips to the core were made by women). This relatively constant rate also suggests that core retail activities are continuing to maintain their shopping goods, attraction despite the presence of intervening opportunity convenience centres.

2) Transit trips to the core as a per cent of all transit trips:
The transit system was developed, and continues to function, as a downtown oriented transportation system within the Vancouver area, and has high frequency links to the core from suburban collector systems in North Vancouver, Burnaby and Richmond. The role of this system as a core-oriented system is measured here in terms of the per cent of total work and shopping
transit trip origins that are destined to the core.

a) Work Trips—Two bands of high per cent orientation towards the downtown core are apparent, an inner ring comprised mainly of those zones having high per capita transit generation rates; and an outer suburban ring of those zones with low per capita trip generation rates. The inner core ring ratio pattern gives an indication of the importance of the transit system to short distance riders who live near their work places. The pattern in the outer circumferentially organized ring gives an indication of the use of the transit system by captive riders who work in the core but chose their residential location for reasons other than proximity to work place. This pattern is consistent with Hardwick's inner core ring model or urban form; it indicates that the core has its greatest influence as a destination over a limited inner ring area.

b) Shopping Trips—Volumes are generally higher in orientation towards the core than are work trips, with greater orientation in adjacent-to-the-core zones. The transit system appears to function as a downtown core retail service system for this type of trip, and suggests a special relationship
of core retail activities and and transit system within the inner ring and for captive riders in the outer ring.

3) **Distribution of transit trips to core zones:**

In earlier studies of Vancouver's travel patterns, the orientation of travel patterns to individual core zones was eastward from eastern core zones, and westward from western core zones. This was generally found to be the case also with the transit travel patterns surveyed in the UBC-Transit Survey and described here.

a) Work Trips—The pattern for all core zones was evenly distributed throughout Vancouver with no apparent sectoral bias, but declining with distance. However, orientation of individual western core zones was generally westward, and eastern zones to the east with some exceptions. This pattern was associated with the portion of blue and white collar workers in each zone, with predominantly blue collar zones oriented east (working class areas). In exception to this were zones 11-12, a blue collar zone which was oriented west.

b) Shopping Trips—Three core zones were mapped. The patterns of trip origins for each were found to
parallel those found by Hardwick and Leigh with the Bay area oriented west, the Eaton's area oriented centrally and east and the Woodward's area oriented east. After an analysis of internal trips (between core zones) it was found that shopping trips between retail zones suggested comparison shopping, and thus a balancing of retail area orientation over the metropolitan area. These internal movements are also consistent with the generation of office worker trips from core area zones for shopping.

These discoveries about transit travel patterns to the core and individual core zones confirm earlier arguments that the core area is not a homogeneous unit but a collection of specialized functions with particular external connections. This realization has definite implications to downtown planning, particularly with regard to transportation system improvements, and these will be discussed in the final chapter.
CHAPTER IV

STEPWISE REGRESSION ANALYSIS OF BUS PASSENGER TRAVEL PATTERNS TO THE CORE

In the previous chapter travel patterns to the core by transit were seen to vary with distance and direction (socio-economic class). In Chapter II, Part II, it was pointed out that trip generation rates from residential areas could also be seen as a function of land use attributes which affect the demand for travel and the choice of travel mode. In this chapter, multiple regression techniques are used to identify and to provide statistical explanation for some of these relationships.

Twelve factors associated with urban travel patterns are chosen for the analysis of core destined transit trip volumes from the forty-one traffic zones served by the B.C.H. and P.A. transit system. Backwards stepwise regression procedures are employed to identify those variables significant in explaining core destined transit trip generation for work and shopping purposes.

Two cases are examined, all 41 zones and Vancouver zones only. The discussion in Chapter III indicated much higher per capita transit ridership in Vancouver City, and a consistently large percentage of trips generated in Vancouver than other municipalities, suggesting that the Vancouver area
has stronger relationships with the core than those areas beyond the almost friction free inner area of Vancouver. This suggests an inner core ring of even less area than that suggested by Hardwick is operating for the transit system.

The general characteristics of multiple regression analysis are discussed in Appendix I. In brief, one can say that stepwise regression, an improvement of multiple regression procedures, includes only those variables which provide a significant contribution to the equation (determined by a pre-selected percentage point of the appropriate F distribution.) At each step a variable is added to the equation. The first variable selected is that with the highest correlation with the dependent variable. Additional variables are added in order of their partial correlation with the dependent variable. F tests at each step determine if the variable to be added makes a significant contribution to the equation, otherwise it is not added. At each step, variables within the equation are re-examined to determine if they remain significant in combination with other variables, and if not the insignificant variable is deleted. A variable which may have been the best single variable to enter at an earlier stage may, at a later stage, be superfluous because of the relations between it and other variables now in the regression model. The process is continued until no more variables will be admitted to the
equation and no more are rejected. This technique is considered to be the strongest for identifying significant factors, and is valuable in its elimination of insignificant factors.\(^{(1)}\)

The procedures used in this thesis in the analysis of work and shopping trips by transit to the core are actually the reverse of those described above and are called "backward" stepwise regression. Instead of starting with the most highly correlated independent variable, the process produces a full multiple regression equation, including all nominated independent variables, then proceeds to eliminate the least partially correlated and insignificant variables.\(^{(2)}\) A 95 per cent confidence interval was selected for elimination. The backwards process enables one to follow the elimination of insignificant variables. It also produces a full equation regardless of significance of variables, which has greater predictive capability than the final stepwise equation, though this latter may have greater explanatory significance.

1) **The Identification of Independent Variables and Their Expected Relationships**

Survey data obtained from the Vancouver Transportation Study\(^{(3)}\) are used to test some of the notions advanced in geographical and planning literature and in earlier case studies, and to determine if these ideas apply to transit
travel patterns to the core of Vancouver. Independent variables used for analysis and their expected relationship with bus passenger travel patterns are listed here. All data used is for the year 1965 when the transit survey was also taken, except for median family income which is 1961 data. The code name used for each variable is in parentheses. Data used are listed in Computer Printouts 1-4, found in an appendix to this chapter. A code to related printout position to traffic zone is provided on the page preceding these printouts.

1) **Distance from the core (DISTAN)**

Five minute travel time intervals by transit from the core were used to code distance for each traffic zone. Transit trip origins are expected to decrease with distance from the C.B.D., demonstrating an inverse or negative relationship with distance from the C.B.D., (the distance decay notion). Traffic zones were assigned mean travel time values.

2) **Population (POPLTN)**

Trips generated are expected to be positively associated with the number of residents in an area, (a measure of complementarity). Population for each traffic zone is divided by ten for inclusion in input.

3) **Households (HSHLDS)**—similar to population in expected relationships. The number of households in each zone is used.
4) **Automobile availability (AUTOAV)**

More transit trips are expected to be generated in areas with fewer automobiles per household. This is a measure of captive transit ridership. Automobile availability is expressed as a ratio of the number of automobiles per household, and zonal values are used.

5) **Median Income (MEDINC)**

More transit trips are expected to be generated in zones with low income, another aggregate measure of transit ridership. Data on 1961 median family income for each traffic zone is used.

6) **Labour force (LABFOR)**

A surrogate complementarity variable is expected to have a high positive relationship with the amount of work trips generated in each traffic zone. The number of persons in the labour force for each zone are used.

7) **Blue collar labour force (BLULAB)**—is expected to have a high positive relationship with transit work trips generated to blue collar work areas, with more trips by transit expected from low income blue collar areas. However, since the core area is largely a white collar work place, this variable is not expected to be important in the generation of work trips to the core. The number of persons in the blue collar labour force living in each zone is used. (VTS uses DBS categories to differentiate between blue and white collar workers, with blue collar
occupations in manufacturing, mechanical, construction, transportation and labourers' categories.)

8) **White collar labour force (WHILAB)**

This variable is expected to have a high positive relationship with work trips to the core, given the nature of downtown jobs. This variable is a more specific measure of complementarity. The number of persons who work in white collar occupations who live in each zone is used. (Categories include proprietary and managemental, professional, clerical, commercial, financial, service and personal.)

9) **Employment (EMPLOY)**

An intervening opportunity function for work trips, this variable is expected to have an inverse relationship with residential zone transit generation, assuming that labour force seeks to minimize distance to employment. The number of employment opportunities in each zone is used.

10) **Blue collar employment (BLUEMP)**

Similar to employment, blue collar employment opportunities are expected to restrict the generation of trips to the core by the blue collar labour force. The number of blue collar employment opportunities in each zone is used.

11) **White collar employment (WHIEMP)**

The presence of white collar employment opportunities are expected to be inversely associated in a particularly influential way with work trips by the white collar labour
force to the core. The number of white collar employment opportunities in each zone is used.

12) Retail employment (RETEMP)—is expected to operate in the same manner for shopping trips as employment for work trips as an intervening opportunity. Used as a surrogate measure for retail activity attraction, it is expected to have a negative correlation with shopping trips generated to the core.

All twelve of these were included as independent variables in backwards stepwise regression analysis of work and shopping trip volumes. The association of these variables with transit trip generation for all zones and Vancouver zones only for work and shopping trips to the core is shown in the Computer Printouts 1-4, found at the end of this chapter.

The correlation coefficients are interpreted prior to the interpretation of regression equations and residuals.

2) Correlation Analysis of Transit Volumes and Variables Associated With Traffic Generation

Correlation procedures, which measure the degree of association between two variables, are used here to indicate those independent variables which have the highest degree of association with the dependent variables of work and shopping bus passenger trips to the core. Transit trip origins for 41 traffic zones, representing all non-core traffic zones served by the transit system, and also for the 26 non-core traffic zones in Vancouver, (in a separate analysis) are
related to the 12 independent variables listed above. Subsequently, intercorrelations or association among these independent variables will be examined.

Working trip origins destined to the core appear to have stronger relationships with the independent variables than shopping trip origins (Table 10). Higher correlation coefficients occur for both trip types when Vancouver zones only are included in the analysis. No strong correlation with a coefficient greater than +.50 with shopping trips to the core from all zones is found with any of the independent variables.

An examination of each case in Table 10 indicates that positive correlations occur between work trip volumes and the number of households, labour force and white collar labour force per traffic zone. These same variables have the highest correlation with shopping trips to the core but here all values are below +.50. For Vancouver zones only, work trips are found to be highly correlated with five variables. In rank order, these are population, households, labour force, blue collar labour force and white collar labour force. The same variables are associated with shopping trips, but to a lesser degree and not in the same order. The effect of distance in both the all-zones case, and the Vancouver-zones case is indicated as being low; however, it is interesting that distance has an inverse relationship when all zones are
TABLE 10

ASSOCIATION OF TRAFFIC GENERATION VARIABLES WITH BUS PASSENGER TRIP ORIGIN VOLUMES

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<th>VANCOUVER ZONES (n=26)</th>
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<tr>
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<td>.48</td>
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<tr>
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<td>-.13</td>
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<td>MEDINC</td>
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<td>.09</td>
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<td>RETEMP</td>
<td>.15</td>
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</tr>
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</table>

included, (as expected) but an unexpected positive relationship when Vancouver zones only are included in the analysis. This is actually consistent with Wolforth's discovery of a "friction free" zone in the inner city over which movement to the core does not vary with distance but rather with social class character of urban districts. It is also consistent with Hardwick's core ring model, since it implies a "distance threshold" beyond which connections to the core may be important.

From the correlation analyses, indications are given that some of the expected associations between independent
variables and trip volumes are tenable. Transit trip
generation characteristics representative of population are
found to be highly correlated (positively) with trip origins
to the core. Employment characteristics were not important.
Mode choice characteristics (AUTOAV and MEDINC) were not as
important to transit trip generation as expected, indicated
by low correlation coefficients. Distance from the core did
not demonstrate a strong relationship, and was found to be
negative only when the more distant peripheral ring zones
were included. As remarked, this suggests that the effect of
distance may be constant and negligible within the inner city
of Vancouver, and beyond Vancouver influential to a limited
extent.

Intercorrelations among the independent variables are
said to exist when correlation coefficients for each variable
with other independent variables are high. (Table 11) This
multicollinearity among independent variables, although not
critical to the predictive power of the regression model,
affects the interpretation of the additive values of
coefficients for each variable in the estimating equation.
This limits the explanatory power of the equation, for it is
difficult to discern which variable is critical to the
explanation. The high degree of association among the groups
of variables considered here suggests that they do in fact
vary together, and one of each group may be considered
TABLE 11
CORRELATION COEFFICIENTS FOR INDEPENDENT VARIABLES

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</table>
representative of the other. The selection of that which is most representative of its group would require factor analysis.

For the purposes of this thesis, we can simply recognize by visual inspection that among the 12 variables, it appears that six independent groups of variables are formed for "all zones":

1) distance and automobile availability;
2) population, households, labour force, blue collar, labour force and white collar labour force;
3) automobile availability and median family income;
4) employment and white collar employment;
5) blue collar employment;
6) retail employment;

and for Vancouver zones, five independent groups of variables are formed:

1) distance, population, automobile availability and median family income;
2) population, labour force, blue collar labour force, and white collar labour force;
3) automobile availability and median family income;
4) employment, blue collar employment and white collar employment;
5) retail employment.

These groups are expected to vary together, and to be represented by the most significant variable in each group in
equations solved by the backwards stepwise regression procedure.

3) Backwards Stepwise Regression Analysis of Bus Passenger Trip Origins to the Core

a) All Zones:

(i) Work Trips (Computer Printout #1)

Sixty-two per cent of transit work trips to the core were explained by population, labour force and white-collar employment, with a standard error of estimate of 249 trips. The estimating equation is: Work trips \( Y \) = 102.51 - 0.89 (POPLTN) + 2.83 (LABFOR) - 0.46 (WHIEMP) + or - residual

(ii) Shopping Trips (Computer Printout #2)

Fifty-five per cent of transit shopping trips to the core were explained by population, households, and white collar employment, with a standard error of estimate of 131 trips. The estimating equation is: Shopping trips \( Y \) = 73.08 - 0.20 (POPLTN) + 0.93 (HSHLDS) - 0.26 (WHIEMP) + or - residual

b) Vancouver Zones:

(i) Work Trips (Computer Printout #3)

Eighty-five per cent of transit work trips to the core were explained by population, automobile availability, median income, employment and white
collar employment, with a standard error of estimate of 188 trips. The estimating equation is:

\[
\text{Work trips (Y)} = 51.08 + 0.39 \times \text{(POPLTN)} - 9.94 \times \text{(AUTOAV)} + 0.14 \times \text{(MEDINC)} - 0.47 \times \text{(EMPLOY)} + 0.57 \times \text{(WHIEMP)} + \text{residual}
\]

(ii) Shopping Trips (Computer Printout #4)

Sixty-eight per cent of transit shopping trips to the core were explained by households, labour force, and blue collar labour force, with a standard error of estimate of 127 trips. The estimating equation is:

\[
\text{Shopping trips (Y)} = 8.46 + 1.82 \times \text{(HSHLDS)} - 1.47 \times \text{(LABFOR)} + 0.93 \times \text{(BLULAB)} + \text{residual}
\]

The interpretation of the relative contribution of each independent variable to the explanation cannot be determined from these equations because neither partial correlation coefficients nor standardized regression (beta) coefficients are provided by the computer programme. Standardization of the data for all variables would have allowed for the interpretation of the relative contribution of each variable.

High coefficients of determination (RSQ) were obtained in all cases, but large standard errors of estimate resulted, reducing the explanation. Some theoretically significant variables were included in the final equations for each case.
Work trips from Vancouver zones to the core had the highest explanation and retained the most variables in the equation. The influence on modal split characteristics of income and automobile availability were indicated by the inclusion of these variables in the equation. All equations included population and labour force variables, indicating that the relationship suggested by the notion of complementarity was tenable. The inclusion of white collar employment as a negative coefficient in work and shopping trips from all zones but as a positive coefficient for work trips from Vancouver zones cannot be interpreted from a priori notions, or from regression results.

The elimination of retail employment from the shopping trips equations suggests that the expected inverse relationship of retail employment opportunities to transit shopping trips to the core is not tenable for the case study data. The inclusion of modal split influences which favour transit ridership in only one equation suggests that either transit riding in the study area does not conform to conceptual notions of factors held to be significant in transit trip generation, or there are data collection unit problems. The elimination of distance in all cases indicates that distance decay is not significant in structuring trips within the transit system when this powerful statistical technique is used.
Before conclusions are drawn on these findings, an analysis of regression equation residuals will serve to indicate patterns of unexplained variation, which could lead to the identification of further independent variables, and provide further understanding of the regression results discussed above.

4) **Analysis of Residuals From Regression**

Residuals are the differences between the value of the dependent variables as calculated by the regression equation, and what is actually observed. They represent the amount of variation in the dependent variable which the equation has not been able to explain.

In the four cases examined above, it was shown that although there were high RSQ values for each equation, (particularly the Vancouver only cases) there were also high standard errors of estimate. These standard errors are calculated from the residuals, and measure the dispersion of unexplained variation about the regression equation. The wider the dispersion, the higher the standard error of estimate will be. An examination of residuals for individual traffic zones in each of the four cases indicates that transit volumes in some zones do not fit the pattern of explanation given by the independent variable included in the equation. An examination of residuals is thus important to the isolation of forces which could be associated with this unexplained
variation, as indicated by high residual values.

A mapping technique is employed to illustrate whether patterns indicative of spatial variation occur among the residuals. (4) Map values are derived by standardizing the residuals to allow for comparison of zones and cases. Six positive and six negative classes were derived for mapping residuals in each of the four cases (Table 12). The standardized values for each zone in each of the four cases are given in Table 13. Positive residuals represent calculated value less than observed, and negative residuals represent the calculated value greater than that observed.

**TABLE 12**

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<td>TRIPS</td>
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<td>(+or-)</td>
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<td>RESIDUAL CLASS</td>
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### TABLE 13

**STANDARDIZED RESIDUALS OF REGRESSION**

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a) All Zones

(i) Work Trips (variables in equation: POPLTN, LABFOR, WHIEMP).

Figure 12 indicates that the Vancouver area is generally under-predicted, while the peripheral areas are over-predicted. The pattern suggests that distance and socio-economic forces are operating. All zones outside of Vancouver are over-estimated, suggesting that while distance decay is effective in structuring work trips from these zones, because of the low trip volumes the distance variable was not included in the regression equation. Within Vancouver both under and over-estimation occurs. Highly under-estimated areas occur in both the eastern sectors of the city and Kitsilano. This could be attributable to higher ridership by lower income groups in these areas.

(ii) Shopping Trips (variables in equation: POPLTN, HSHLDS, WHIEMP)

A similar pattern for work trips exists, with the exception of North and Central Burnaby, which are under-predicted in this case, and some western Vancouver zones which become under-predicted with the use of these variables. More trips per capita, or per household, are generated in eastern zones than
RESIDUALS FROM REGRESSION

Figure 12
the equation accounts for. There are less trips in west central and most peripheral zones than are accounted for by these variables. Inconsistent socio-economic variation in zonal characteristics appears to be operating as does distance, but the latter to a lesser extent. No further variable can be identified.

b) Vancouver Zones Only

(i) Work Trips (variables in equation: POPLTN, AUTOAV, MEDINC, EMPLOY, WHIEMP)

Figure 12 also shows almost the same pattern as the "work trips from all zones" model, despite the inclusion of variables indicative of modal split, which are also surrogate for socio-economic class. However, both eastern and western sectors of the city are under-estimated, indicating that socio-economic variation and automobile ownership does not have a constant effect on transit trip generation to the core from over the City of Vancouver. The force of distance appears to be inconsistent as well, with both over and under-prediction occurring at different distances. Forces too fine to be isolated by aggregate data analysis appear to be in effect here.

(ii) Shopping Trips (variables in equation HSHLD, LABFOR, BLULAB)
Again a pattern similar to the "all-zones shopping trips model" occurs, with the exception of more over-prediction in the East Hastings sector and the Fraser area. The south-east sector, inner west and central areas were under-predicted. The pattern does not suggest a basic cause for over or under-prediction but indicates that variation occurs across socio-economic and distance parameters. Here again the level of data aggregation appears to be insufficient for the isolation of surrogate causal relationships between transit generation rates and particular forces. The residuals from all four equations indicate that unexplained variation in the pattern of transit trips to the core reflects factors to do with socio-economic character and urban areas and distance in some instances, but not in a constant manner. This suggests that other forces are at work in structuring transit travel patterns to the core which are not accounted for by the independent variables, or by the aggregation of these variables to the traffic zone level.

SUMMARY

Correlation, backwards stepwise regression and analysis of residuals from regression analysis were techniques used to test the association of twelve independent variables with transit trip generation for work and shopping to core zones of Vancouver. Work and shopping trip types were analyzed from
all zones served by the transit system, and a special case of Vancouver city zones only was selected. The Vancouver zones case was isolated as one way of determining if Vancouver itself (the inner city of the metro area) has a different relationship with the core than do more peripheral areas of the metropolitan system.

Of the twelve independent variables used, only households, labour force and white collar labour force were found to have correlation coefficients greater than .50 with work trip origins from all 41 zones. This was encouraging, since it indicated that the number of persons travelling to work by bus was associated with variables suggesting the supply side of the complementarity notion. No variables had a correlation greater than +.50 with shopping trips to the core from all zones. However, some indication of complementarity was shown, since households and white collar labour force had a correlation coefficient of +.48 for this case.

Isolating Vancouver zones only, work trip volumes to the core were found to be highly associated with a number of the independent variables including population, households, labour force, blue collar labour force and white collar labour force. For the shopping trip case the same five variables were found to have somewhat lower correlation coefficients, but these all remained above .50. Variables which were expected to have a relationship with transit trip
generation to the core such as distance, median family income, and automobile availability actually all had very low correlation coefficients. This indicated that the transit generation rates to the core in the inner area served by public transit appeared to be relatively insensitive to distance, or to socio-economic variations (measured by income and automobile ownership). This finding was strengthened by later analysis.

Prior to examining the regression equations, intercorrelations among the independent variables were pointed out. Several groups of variables were identified. Generally, residential zone measures of population and labour force were found to vary together (indicated by high correlation coefficients between variables in each group). Automobile availability and income were also correlated, as were employment variables, with the exception of retail employment. The significance of these intercorrelations to the interpretation of the regression equations was not great since the backwards stepwise elimination process selected only one or two variables from each group. Limitations in computer printout information did not allow for further consideration of intercorrelation problems, but these were not important to the level of interpretation sought in this thesis.

The regression equations solved by the backwards stepwise regression procedures gave explanations with high
RSQ values, but their power was limited by accompanying high standard errors of estimate. The notable absence of the automobile availability and income variables from the models (found important in other urban areas in affecting transit generation) also made acceptance of the explanation given by the regression equations open to question. Population, households and/or labour force per traffic zone, as well as white collar employment, provided the explanation of trip volumes in almost all cases. Trips per capita as a dependent variable may have provided better explanatory equations since the patterns for Figures 8 and 12 are comparable.

A comparison of the results for all zones and for the "Vancouver zones only" analysis, indicated that greater RSQ and lower standard errors of estimate could be obtained by modelling trips origins from Vancouver zones only. In the case of work trips from Vancouver zones, automobile availability and median family income were included in the estimating equation, indicating that social class was a factor influencing core trip generation at this scale.

Mapping of the standardized residuals failed to indicate any patterns of residual variation attributable to identifiable forces. In some cases distance and socio-economic forces appeared to be operating in structuring transit trip origins; however, patterns were rather inconsistent. Distance operated in some areas and not others,
as did social sectoral variation. The problem of using zonal averages for specific trip type, trip destination and modal type is indicated as the major cause for failure to successfully model transit trips to the core using the variables and techniques employed in this thesis. This problem will be the focus of a brief discussion of the direction for further work in Chapter 5.

FOOTNOTES


(3) City of Vancouver Planning Department, Metropolitan Vancouver: 1955, 1965 and 1985: Selected Data From the Vancouver Transportation Study, March, 1967. See also unpublished working papers prepared by the City of Vancouver Planning Department for the Vancouver Transportation Study.

## COMPUTER PRINTOUT #1  BUS PASSENGER WORK TRIPS TO THE CORE—ALL ZONES

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DEPENDENT VARIABLE IS BCODCW

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* END OF CONTROL SET *

STOP

EXECUTION TERMINATED

$SIG
## COMPUTER PRINTOUT #2  BUS PASSENGER SHOPPING TRIPS TO THE CORE—ALL ZONES

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**CONTROL CARD NO. 2**

* INVR *

**VARIABLE EXCLUDED WHILAB CORRESPONDING DIAGONAL ELEMENT L.T. .0001**

**CONTROL CARD NO. 3**

* STREG *

**PERCENTAGE LEVEL**

ACCEPT

REJECT

5

5

WARNING - VARIABLE WHILAB
THE AECVE VARIABLE IS A LINEAR COMBINATION OF VARIABLES INCLUDED IN THIS REGRESSION

DEPENDENT VARIABLE IS SHODCHW

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ENC CF CCM'OL SET

EXECUTIVE TERMINATED

$SIG
## COMPUTER PRINTOUT #3  BUS PASSENGER WORK TRIPS TO THE CORE--VANCOUVER ZONES

### DATA FORMAT

**CONTROL CARD NO. 1**

**DATA FORMAT** (13F5.0)

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**26 Observations**

**25 Degrees of Freedom**

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**26 Observations**

**25 Degrees of Freedom**
### CONTROL CARD NO. 2
- **INVR**

### VARIABLE EXCLUDED WHILE CORRESPONDING DIAGONAL ELEMENT L.T. .0001

### CONTROL CARD NO. 3
- **STPREG**

#### PERCENTAGE LEVEL
- **ACCEPT**
- **REJECT**

#### WARNING - VARIABLE WHILAB
THE ABOVE VARIABLE IS A LINEAR COMBINATION OF VARIABLES INCLUDED IN THIS REGRESSION

#### DEPENDENT VARIABLE IS WCROCN

### STEP NO. 1

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**Variables:**
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- FPPOB0
- STD ERR Y

**Coefficients:**
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**Additional Notes:**
- Step No. 3
- Step No. 4
- Step No. 5
- Step No. 6
- RSC
- FPROB.
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## COMPUTER PRINTOUT #4
### BUS PASSENGER SHOPPING TRIPS TO THE CORE—VANCOUVER ZONES

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**VARIABLE EXCLUDED WHILE (CORRESPONDING DIAGONAL ELEMENT L.T. .0001)**

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### CONTROL CARD NO. 3

**PERCENTAGE LEVEL ACCEPT REJECT**

- **WARNING**: VARIABLE #31213
- **The above variable is a linear combination of variables included in this regression.**

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**FPROM** = 0.6204  
**STD ERR Y = 139.1250**

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### STEP NO. 2

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**FPROM** = 0.6204  
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CHAPTER V

CONCLUSIONS

The purpose of this study was to identify the patterns of connection between the core area of Vancouver (and its sub parts), and the metropolitan region in terms of public transit travel for work and shopping trip purposes. It was also hoped to model functional relationships associated with core destined work and shopping trips by transit in the Greater Vancouver area. The analyses were placed in the context of literature concerned with intra-urban travel patterns as a problem in understanding and modelling spatial interaction and literature on urban form and the role of the core in the contemporary city.

From earlier geographic case studies of travel by automobile and all modes to the core of Vancouver, distance and alternate trip end opportunities were documented as major forces in structuring trips to the core, at a scale of investigation that included the whole metropolitan region. As a result of these studies, a "core ring" model was advanced to describe Greater Vancouver's urban spatial pattern by W. Hardwick. Beyond a certain distance, trips for work and shopping were said to be more oriented among peripheral activity concentrations and less oriented to the core. Within the inner ring, trips destined to the core were found to vary
with socio-economically differentiated residential sectors rather than distance, and the core (as a whole) was found to be oriented towards higher income western portions of the inner ring. Further study of shopping trips by Hardwick and Leigh indicated that sub-areas within the core also demonstrated socio-economic sectoral variation, and a directional orientation, with western core areas oriented west (to high income areas) and eastern core zones oriented east (to low income areas). It is within this context that expected transit travel patterns were first examined.

1) Summary of Findings of Descriptive Analyses

The travel patterns to the downtown core described above were seen as the context within which bus passenger trip patterns to the core were analyzed. Conclusions on the relevance of the "core ring" model, and on the selective orientation of individual downtown core zones are summarized here.

a) The core ring model defines the Greater Vancouver area as two concentric rings. The inner ring is focussed on the downtown core, and trips within this ring to downtown are structured by socio-economic variation in residential areas.

The cartographic analysis of the distribution of transit trips per capita indicated that the core ring model is tenable for describing transit travel patterns to the core, with Vancouver and North Vancouver City having relatively
high per capita transit trip links with the core compared to peripheral ring municipalities. An eastward orientation of work trips to the core by transit indicated the co-variation of trips with low income. But shopping trips per capita to the core did not appear to be sensitive to income variation in origin zones. These trips were low per capita, and constant throughout the study area, suggesting that the C.B.D. maintains its dominance over a metropolitan wide market; however, the low number of trips suggests that it serves a specialized role, i.e. the core caters to a certain type of shopping trip or consumer.

To give further indication of the relevance of the core ring model, the role of the transit system as core serving system was examined. Generally the core ring model appeared to apply, with the inner ring of the urban system having a greater percentage of total work trips generated destined to the core. However, an occurrence of a high proportion of work trips to the core was indicated in close-in areas of the peripheral ring also (Burnaby), which was suggestive of the importance of transit to captive peripheral area riders (low income or female) who worked in the core. The pattern for shopping trips indicated that as a means of travel for this purpose, the transit system was almost exclusively a core serving transportation system. Socio-economic variation did not appear to be important in
structuring the per cent of transit trips to the core of all trips generated for either work or shopping trip purposes.

From these descriptive analyses, the "core ring" hypothesis appears to be tenable but with a mixed influence of socio-economic sector variation for core transit connections, with connections in terms of shopping trips being least sensitive to this type of influence.

b) Orientation of sub-areas of the core was examined in terms of the per cent distribution of transit trip origins to all core zones and to individual core zones. For work trips to all core zones together no sectoral bias was evident, but at the disaggregated level, western core zones were generally oriented towards western residential areas and eastern core zones to eastern residential areas. For shopping trips the same appeared to be the case, but internal movement within the core suggested that many transit riding shoppers visited all core retail areas regardless of their zone of origin. This suggests a balance of trip origins to the entire central study area, qualifying the notion of sectoral variation of shopping trip patterns in terms of their orientation to retail sub-areas of the core.

2) Summary of Findings of Statistical Analysis

The second level of analysis involved the identification of measurable attributes of residential areas which were expected to be functionally associated with the propensity to
generate work and shopping trips to the core by transit. A number of surrogate variables were identified to account for expected functional relationships underlying this form of spatial interaction. These represented the notions of complementarity, intervening opportunity and transferability (distance decay); as well as demand variables important to transit use. Backwards stepwise regression procedures were employed to develop a model for work and shopping trips to the core from all zones in the study area and from Vancouver City zones only. Conclusions drawn from this analysis supported some of the expected relationships, but not consistently.

The backwards stepwise regression process selected zonal population, labour force and households as explanatory variables in all cases, while variables representative of travel demand (automobile availability and median family income) were selected in the work trips from Vancouver zones case. Distance from the downtown core was not selected in for any case. Only variables representative of zonal mass were thus found to be significant in explaining transit travel to the core. The expected role of travel demand and distance variables was not significant. This suggests that these variables are not significant in structuring transit travel patterns to the core, or that the scale of traffic zones used presented an aggregate data picture which was not
representative of core destined transit travellers' characteristics, or in any case not functionally relevant in terms of homogeneity of important characteristics. This problem is discussed at greater length in Appendix III.

The lack of importance of distance on the other hand leads one to suggest that transit ridership may be operating in a friction-free zone, at least within the City of Vancouver. This notion was supported somewhat in the mapping of residuals from regression where it was shown that work and shopping trips from all zones were generally over-estimated by the equations in areas outside of Vancouver. However, this conclusion was clouded by the occurrence of over-estimation in some Vancouver zones. For the Vancouver zones cases over-estimation and under-estimation was found to cut across both distance and sectoral (social status) variation, with forces of distance and social class appearing to operate in structuring transit travel in some areas, (South Vancouver), but not in others (Point Grey).

A much more detailed examination of transit travel patterns to the core is called for before conclusions may be drawn from the somewhat ambiguous findings of this statistical analysis.

3) Directions for Further Research
a) Research in Urban Structure--One of the major focii of this thesis has been the further testing of the findings of
other geographers in case studies of Vancouver's core area, and its relationships, which help define the urban structure of the Greater Vancouver Metropolitan area. A core ring model was advanced by Hardwick and this model was "tested" herein and it was found to be generally tenable in terms of transit travel patterns. However, public transit in the Vancouver metro area plays a small role in the overall pattern of spatial interaction in Greater Vancouver, and this thesis can be considered only as a preliminary pilot study of these patterns, and the urban structural relationships they imply. Definitive rigorously conceived research designs must be formulated to examine in even finer detail the relationships underlying spatial interaction for each aspect of movement in the metropolitan area. Hardwick and Leigh's study of C.B.D. retailing provides one link in the study of Vancouver's urban spatial structure as it applies to retail marketing. Another study of the same nature as Wolforth's but with identification of mode and individual traveller attributes must be done before one can accept Hardwick's notion of a core focussed inner ring. Similar studies of the peripheral ring must also be considered if a true understanding of Vancouver's urban structure is to be achieved. Only after aspects of Vancouver case have been thoroughly studied and documented can the findings be published for discussion and general theorizing about urban structure in general.
b) Research in Transportation Planning--This thesis has shown that in the search for explanation (and therefore more reliable prediction) of urban travel patterns, the study of aggregates or masses falls short of accurate identification of the forces at work in structuring travel patterns, and of the role and significance of these forces. It has been shown that generalized concepts of spatial interaction have evolved into comprehensive mathematical formulations to achieve the goal of accurately modelling as many forces as are accountable by these concepts at the aggregate scale; however, an understanding of travel behaviour at the disaggregate scale is now needed.

Future intra-urban travel research must move towards the study of finite behavioural units such as the household, or individual and general associations, implicit in the travel behaviour of these units. (See McCarthy, Appendix III) Once an understanding of individual travel behaviour is achieved, grouping of relevant characteristics into homogeneous areas will come closer to successfully modelling mass travel behaviour than do the present methods of arbitrarily selecting 'travel-sheds' regardless of internal homogeneity of characteristics.

4) Implications for Planning

The "core ring" model developed from findings of earlier case studies dealing with all modes and automobile
travel patterns, and supported by findings of this thesis, has extremely important planning implications for the Greater Vancouver urban area, and for other urban areas where a similar system of spatial interaction may be operating.

Generally the following urban pattern is evolving in the Greater Vancouver area. The core area is developing into an increasingly concentrated centre of high density, high income, white collar employment. The retail areas of the core serve a 'core ring' of less than 5 miles and demonstrate sectoral orientation, while the growth of the downtown daytime population in service, technical and administrative occupations will continue to play a major role in supply of customers to downtown retailing, but these activities will continue to serve a specialized retail shopping function within the core ring, especially for captive transit riders. As Wolforth pointed out, the core labour shed is oriented towards the higher income western sector of the city, although this thesis has suggested that this was not the case for transit riders who are captive riders for reasons of low income, age and automobile availability to women, and tend to originate primarily from areas within twenty to thirty minutes by bus from the core, and show no distinct direction orientation on the whole.

The implications of these findings to planning are that transit riding is not a popular means of long distance
travel to the core, offering no real comparative advantage to attract 'choice riders'—those who find transit more convenient. Downtown employment opportunities, while continuing to provide lower income jobs, will continue to increase in the higher income categories as the Provincial economy develops, and Vancouver's core continues to attract administrative activities. Housing for high income white collar managers and professionals has been traditionally in high amenity areas, located within the physically restricted western sector of the core ring. Suitable alternative areas for high income group housing have developed at the extreme periphery of the metropolitan area (i.e. Tsawwassen) forcing these people to travel to the core by car which is contributing to peak period congestion on travel routes to the core for long distances. Mass transit solutions to this problem must therefore recognize that service should be first directed to those areas which are traditionally strongly linked to the core, notably the North Shore and western areas of Greater Vancouver. At the same time, long range transit planning must lead to the service of more distant commuter hinterlands, up to twenty miles from the core—notably to South Surrey, Delta and White Rock.

These implications are advanced here for discussion. Perhaps subsequent study can more rigorously support or reject the findings of this thesis and earlier case studies. Further
study of these findings should be a prerequisite to long range transit planning in the Greater Vancouver area, lest travel routes be laid out which do not fit the present pattern of spatial relationships in Greater Vancouver, and thus do not meet present nor anticipated travel demand.


Hardwick, W.G. Vancouver The Emergence of New Urban Patterns, unpublished draft, Department of Geography, University of British Columbia, Vancouver, 1969.


Harland Bartholomew & Associates. A Plan for the City of Vancouver, British Columbia including Point Grey and South Vancouver and a General Plan of the Region, 1929, Vancouver, 1929.


Horton, Frank, ed. Geographic Studies of Urban Transportation and Network Analysis, Studies in Geography #16, Department of Geography, Northwestern University; Evanston, 1968.


Ollson, Gunnar. Distance and Human Interaction: A Review and Bibliography, Bibliography Series Number Two, Regional Science Research Institute, Philadelphia, 1965.


Sousslau, A.B., Heanue, K.E., and Balem, A.J. "Evaluation of a New Modal Split Procedure", HRR #88, pp. 44-68.


A REVIEW OF LITERATURE AND CONCEPTS ON SPATIAL INTERACTION

1. GRAVITY MODEL

The gravity model, an adaptation from Newtonian physics, is based on the interaction hypothesis; the amount of interaction or gravitational force between two groups varies directly with the size of the mass and inversely with the distance that separates them. The basic model takes the form:

\[ I_{ij} = k \frac{P_i P_j}{D^n} \]

where:
- \( I_{ij} \) = the amount of interaction between points i and j
- \( k \) = a constant (empirically derived)
- \( P_i, P_j \) = population or some other expression of mass at points i and j
- \( D \) = distance separating points i and j
- \( n \) = an exponent of distance (after MacKay 1968)

To obtain a 'better fit' to the amount of interaction \( I_{ij} \) the mass and distance factors are often manipulated until greater statistical 'explanation' is achieved between the model and the real world situation it attempts to represent. Sub-groups within the population mass, or characteristics of this mass which affect the linkage between groups, are sought by weighting the overall mass, while the functional effect of distance is obtained through an iterative process of
applying exponents \( n \) to the distance factor until a representative measure of the friction of distance is found.

A.M. Voorhees was the first to apply gravity model techniques to an urban transportation problem.\(^{(3)}\) He adapted Reilly's Law of Retail Gravitation to simulate the pull of shopping areas on a group of shoppers. For shopping trips for 'convenience goods', the floor area in food and drugs was used as the \( P_2 \) mass factor. For shopping goods, the floor area in apparel produced the best fit gravity model equation. Other trip purposes were represented by surrogate variables of trip end land use, such as for work trips--number of employees, and for social trips--number of dwelling units. He also recognized that for each trip purpose there was a different reaction to the friction of distance which could be accounted for by deriving different distance measure exponents for each trip purpose. Work trips tend to be less sensitive to distance than shopping trips so the corresponding values of the exponents are relatively small. Typical values for different trip purposes are: 0.5 for work trips, 2 to 3 for shopping trips and 3 for social-recreation trips.\(^{(4)}\) More recent models use travel time factors as the expression of the friction of distance for different trip purposes. These travel time factors are derived from observed data and are expressed in terms of numerical factors for different travel times.\(^{(5)}\)
Recent gravity model formulations bear little resemblance to the simple formula presented above. In recognition of the influence of social and economic forces affecting spatial interaction between traffic zones, parameters have been set up to incorporate variations in the effect of these and other forces. As an example, the Gravity Model of the Bureau of Public Roads takes the form:

\[ T_{i-j} = G_i \frac{A_j \cdot f(d_{ij}) \cdot K_{i-j}}{\sum_{x} A_x f(d_{i-x}) \cdot K_{i-x}} \]

- \(G_i\) = the total number of trips of the category in question generated at zone \(i\).
- \(A_j\) = the total number of trips of the category in question attracted to zone \(j\).
- \(f(d_{i-j})\) = travel time factor corresponding to travel time \(d_{i-j}\) from zone \(i\) to zone \(j\).
- \(K_{i-j}\) = an adjustment factor for trips from zone \(i\) to zone \(j\). (6)

The introduction of adjustment factors is necessary because travel time and land use were not found to be sufficient to 'explain' an observed travel pattern. Adjustment factors are chosen so that trip frequencies surveyed coincide with those found by applying the gravity model. By systematically stratifying trips by purpose, trip ends by land use characteristics, and transportation systems by factors of time, cost, inconvenience, etc., a balance is achieved between actual and modeled travel patterns.
In summary, several factors associated with trip interchange are more or less explicitly taken into account and 'plugged into' the gravity model to simulate travel patterns. In terms of urban spatial structure, the initial model was a distance minimization model based on the notion that people minimize distance in their travel patterns; however, the effect of other factors has been shown to take on more relevance in modeling travel patterns. Ollsen reports in his review of the gravity model that 'space preferences' resulting from socio-economic factors of origin zone populations affect distance traveled rather than distance, especially over short distances. The implications of these comments and the evolution of the gravity model which has been refined to account for empirical regularities in urban spatial structure and inter-area circulation patterns support the findings of investigations of intra-urban travel patterns in several Vancouver case studies.

With regard to the principles of spatial interaction, the gravity model incorporates the notions of complementarity and transferability. The notion of intervening opportunity is not accounted for directly in this model, although one could conclude that the distance factor and its exponent, or travel time factors, which were empirically derived, surreptitiously incorporate the effects of intervening
opportunities on spatial interaction. The difficulty of separating those two effects to determine their individual contribution to modelling travel patterns is difficult. This conceptual and technical difficulty will be discussed further in a later section of the review. One could also conclude that some of the adjustment factors of this model could incorporate the effects of intervening opportunity.

As the gravity model developed, it has moved away from the simple interactance hypothesis and taken on the form of a multiple regression model, and one of its key components, (distance) has less value at the intra-urban scale than have mass weighting factors. The notion of gravitational force, while valuable in initial conceptions of spatial interaction, has given way to more sophisticated explanatory models based on surrogate variables representing motivations that underly interaction, or at least affect motivation in a systematic way. The gravity model and its parallel in urban spatial structure, central place theory, are replaced by models based on structural relationships rather than physical laws or rational "economic man" generalizations.

2. INTERVENING OPPORTUNITY MODEL

First developed by Stouffer for migration studies in 1940, the intervening opportunity model is based on the concept that "the number of people going a given distance is not a function of the distance directly but rather a function
of the spatial distribution of opportunities.\(^{(10)}\) The intervening opportunity model simply states "the amount of interaction over a given geographical distance is directly proportional to the opportunities at that distance, but inversely proportional to the number of intervening opportunities".\(^{(11)}\) The equation for the intervening opportunity relationship takes the form:

\[
\frac{AY}{AS} = \frac{a}{x} \frac{x}{s}
\]

\(Y\) = the number of people moving from \(p\) to all places within a concentric zone of width \(s\).

\(x\) = the sum of opportunities at all points between \(p\) and \(s\), and finally

\(x\) = the number of opportunities within the band \(s\).\(^{(12)}\)

Compared to the gravity model, it has been argued that the intervening opportunity model is conceptually stronger in its capability for explaining spatial interaction. Stouffer stated "that the use of distance in any explanatory model is simply confusing the main relationship which is between movement and opportunities, with the auxiliary relationship between distance and opportunities which is almost certain to be present".\(^{(13)}\)

Starkie, in a comparative use of the opportunity model and the gravity model, observed that because of the auxiliary relationship between distance and opportunities,
the two models are virtually the same, and differ only in emphasis. (14) Both models use the same "mass" factors and the "friction" factors of distance in the gravity model, and intervening opportunities in the opportunity model vary together.

Zipf's principle of least effort accounts for the inter-correlated relationship between distance and opportunities. The declining number of opportunities as one moves outward from a centre of activity is based on the notion that activities, when locating in relation to one another, or people, when moving from activity to activity, endeavour to minimize intervening distance. It is difficult to separate the distance/opportunity relationship into the individual effects of distance and opportunities on movement. From a conceptual standpoint, Stouffer's argument gives the opportunity factor greater explanatory powers. But, as demonstrated below, the difficulties of calibrating the opportunity model have limited its use for modeling movement at the intra-urban scale.

An Intervening Opportunity, or simply Opportunity Model for predicting the distribution of intra-urban travel was first developed by Morton Schneider for the Chicago Area Transportation Study. (15) His formulation differs little from Stouffer's initial theory that the number of people moving a certain distance is directly proportional to the
number of opportunities at that distance and inversely proportional to the number of intervening opportunities. Schneider's model altered this concept by utilizing a probability function to account for intervening opportunities. The opportunity model he developed for the CATS states "that the probability that a trip will terminate within some volume of destination points is equal to the probability that this volume contains an acceptable destination, times the probability that an acceptable destination closer to the origin of the trip has not been found." \(^{(16)}\) Schneider's original model took the form:

\[
V_{ij} = V_i \times P(S_j)
\]

where \(V_{ij} = \) total trips from area \(i\) terminating in area \(j\); 
\(V_i = \) total trips from area \(i\); and 
\(P(S_j) = \) probability of any trip ending in area \(j\). \(^{(17)}\)

For computational purposes this model has undergone several alterations with the model now mathematically expressed as:

\[
T_{ij} = O_i \ e^{-LV_{j}} \ e^{LV_{j-1}}
\]

where \(T_{ij} = \) expected interchange from zone \(i\) to zone \(j\); 
\(O_i = \) volume of trip origins at zone \(i\); 
\(V_j = \) sum of possible destinations considered before reaching a given zone;

\(L = \) constant probability of a possible destination being accepted if considered. \(^{(18)}\)

The ability to accurately describe trips using the above Opportunity Model rests on the proper selection of the \(L\)
value. Considerable time and effort of transportation researchers has been applied to establishing consistent and reliable ways of calibrating the "L" factor in the opportunity model, and with somewhat confused success. (19)

Procedures for deriving L values range from direct fitting to the empirical data by grouping zones into long and short trips, and by trip end density classes, and inserting a number of L values into the equation until the O-D derived interaction is matched; or statistical derivation of L by means of a multiple regression procedure, or by an iterative procedure using numerical analysis to solve a non-linear equation. The latter was found to be most successful by Ruiter. (20) In all cases trips were stratified according to length and trip end density. Long trips were found to be destined in low trip end density zones and vice versa for short trips, (suggesting the relationship between length of trip and number of opportunities, or in other words the decline of opportunities with distance). Thus to a large extent the opportunity model is reliant on the auxiliary relationship between distance and opportunities, a relationship which the gravity model accounts for quite readily, and without the computational difficulties encountered with the opportunity model.

The opportunity model has not been developed to the same extent as the gravity model formulations to incorporate
other factors besides complementary and intervening opportunities to explain interaction. There is no evidence of the inclusion of factors other than distance and opportunities in relation to the L value, for instance socio-economic or behavioural forces, and transportation network characteristics. Undoubtedly these considerations would work towards achieving a more representative model—but at the same time would further complicate the derivation of L.

The intervening opportunity model has a more meaningful conceptual foundation if one accepts Stouffer's argument. But like the gravity model, the level of generalization used to develop it initially breaks down when a higher level of explanation is sought. Complicated and conceptually questionable procedures have been adopted to fit the model to empirical reality, making its interpretation difficult. If one does not accept the argument of Stouffer, and adopts Starkie's observation, then either model is applicable to explaining urban travel patterns since neither clearly separates the auxiliary relationship between distance and intervening opportunities in explaining spatial interaction. Recent formulations of the gravity model incorporates surrogate motivational factors, and in this sense do not differ greatly from multiple regression models developed for explaining spatial interaction. These models incorporate as
many conceptually relevant variables as are necessary to explain spatial interaction, and are not formulated from any one particular body of 'theory' of movement as have the intervening opportunity or gravity models.

3. MULTIPLE REGRESSION MODELS

The analysis and eventual explanations of spatial interaction requires the identification and assessment of the importance of factors or forces inherent in or causing movement. The notions underlying the gravity and opportunity models serve to isolate some of these forces and provide adequate generalizations of mass behaviour. As one seeks explanation from either of these models, a number of unaccounted factors appear, and both models rely on iterative equation fitting procedures to account for this variation outside of the model's conceptual parameters. A similar breakdown of highly generalized urban spatial structure models, such as central place theory, was recorded in case studies of the Vancouver urban area. (21)

a) The Technique

Before proceeding with a review of the development and use of multiple regression techniques for intra-urban travel pattern analysis, a brief description of the technique, its assumptions, and interpretations are provided.
Regression measures the relationship between a "dependent variable" (y) and an "independent variable" (x), or in multiple regression, a set of independent variables (X1 X2 X3). Relationships are actually summarized by an estimating equation that measures changes in y per unit change in x and by various associated statistics that indicate the reliability of the estimating equation (regression "model") and that provide further descriptions of the association between the dependent and independent variables. In short, the regression statistics relate variation in the dependent variable to measured variation in the independent variable(s) and to this extent explain changes in X1, X2, etc. (22)

Leigh points out that through regression analysis the transportation geographer is able to "assess the weight and importance of some potentially explanatory variables thought to represent forces or factors that could have brought about travel patterns". However, this technique has weaknesses, which affect its explanatory capabilities and these must be taken into consideration.

As an analytical tool for the exploration of causative or explanatory relationships, consideration must be given to assumptions made with regard to the selection of independent variables, and to the interpretation of the estimating equation and its associated statistics which determine the validity of the estimating equation. Independent variables must be normally distributed, independent and additive if they are to be considered as valid causative factors in explaining the variation in the dependent variable. However, since the multiple regression technique is considered quite powerful, the first
assumption can be relaxed if a high level of statistical significance is used in selecting independent variables (although this creates interpretive problems). When variables are not independent, inter-correlation exists (independent variables vary together) and the relative contribution of each variable cannot be accurately determined. This reduces the explanatory utility of the regression coefficients and as a result the multiple regression analysis has limited research value. (To remedy this situation principle components analysis may be used to identify inter-correlated groups of variables and select that variable which is most representative of the group for inclusion in the multiple regression model.)

The interpretation of the explanatory power of the equation involves consideration of the RSQ (coefficient of multiple determination), the F statistic (an expression of statistical significance), and the standard error of estimate (a measure similar to the standard deviation). The RSQ expresses the percentage of variation in the dependent variable accounted for by the independent variables on the right side of the equation. The F statistic determines if the relationship expressed by the equation is statistically significant. The standard error of estimate gives the range of values for the estimated dependent variable. The probability that the equation
will estimate the dependent variable within one, two, or three standard errors of estimate is taken from the normal curve distribution probability table (68.26%) within one s.e. of est., 95.44% within two and 99% within three). These statistics must be balanced if the estimating equation is to have any meaning as an analytical device; for instance an equation with a large RSQ which is not statistically significant, or which results in a very large standard error of estimate will not be as meaningful as an equation of a lower RSQ which is statistically significant, and does not vary as much in its chance of arriving at the correct values of the dependent variable.

The multiple regression technique is often not a model based on a priori theory but a means of measuring the level of association between a group of variables taken together and some factor which is being explained in terms of its association with these variables. The identification of variables in urban transportation analysis is based both on conceptual notions and on empirical findings.

b) Identification of Independent Variables for Multiple Regression Models of Intra-Urban Travel

Regression techniques have been used extensively in urban transportation planning to identify factors
associated with intra-urban travel patterns. The conceptual or theoretical bases for selecting and using these factors for prediction are drawn from systems ideas and from economic notions applied to spatial interaction or traffic generation.

Mitchell and Rapkin were the first to use the systems (functional) approach to urban transportation analysis. They considered traffic as a function of land use activity systems interacting through time and space. Trips were classified according to their purpose and took place between an origin and destination related to the fulfillment of this purpose. Characteristics of trip origin and trip end land use which affected the propensity to interact were then identified and quantified. Trips originating in (generated by) residential areas were found to be affected by the composition and character of the population. Trips attracted to commercial centres were found to be related to the size and character (order of convenience) of the centre. Transportation facilities were also found to have an effect on spatial interaction in this early study.

The findings of Mitchell and Rapkin were elaborated in subsequent work in the analysis of factors associated with intra-urban travel in urban transportation literature. These early findings also coincide with the notions of
spatial interaction put forward by Ullman\(^{(25)}\) in the geographical literature. These parallels of thought will be discussed later after a review of transportation planning literature.

Oi and Shuldiner's \textit{Analysis of Urban Travel Demands} provides a comprehensive study of the use of concepts from economics to identify forces affecting intra-urban travel.\(^{(26)}\) Taking a functional approach within the framework of economic theory, they examine urban travel demands as part of a larger demand for an economic good or service—"in other words as a derived demand or part of a joint demand. They divide trips into those which are consumption oriented and those which are production oriented. They then isolate factors which affect demand within these two trip categories. For instance, consumption oriented trip purposes to satisfy leisure demands will be a function of: (1) consumer space preference patterns, (2) his income or wealth, (3) price of joint commodities and (4) prices of complementary or competing goods (or services). Consumer space preferences, a behaviouristic variable, are measured in terms of surrogate or proxy variables such as age, sex, income, occupation, education and other measures of social characteristics. Production oriented trips are a result of functional relationships which can also be specified
by factors affecting the demand for travel. For instance, the journey to work will be a function of labour force and employment characteristics and their distribution in the urban area. Those factors listed above (1-4) will also affect demand for this kind of trip. In addition, transportation facility characteristics, such as the availability of automobiles, frequency of buses, and distance between activities are cited as affecting the demand for intra-urban travel.

Urban transportation studies in the United States have been identified and used for predictive purposes a wide range of variables found to be associated with intra-urban travel patterns. These variables have been selected as a result of studies of which Mitchell and Rapkin's and Oi and Shuldiner's are representative. Other studies of this type are found in numerous Highway Research Board publications. (27) A list of independent variables has been compiled from transportation studies in 78 United States urban areas between 1955 and 1967. (28)

(1) Residential Based Trips

- Population
- Persons over 5
- Persons over 5 making trips
- Population--Central City
- Resident Employment
- Labour Force
- School Attendance
- Median Income Per Household
- Average Family Income
4. MODAL SPLIT MODELS

Modal split is the general term given to procedures developed to estimate the proportion of intra-urban travel that is to be allocated to the two primary alternative modes of transportation, public mass transit and private automobiles. Three categories of factors found significant in determining modal split have been isolated: (1) characteristics of the trip, (2) characteristics of the trip maker and (3) characteristics of the transportation system.
Modal split models have been developed through the economic analysis of factors found to affect mode choice. This choice is considered a result of the wish on the part of the commuter to maximize satisfaction and minimize discomfort in making a trip. (29) His choice of mode is seen as a function of various economic, psychological and sociological factors which are relevant to him, and these in turn vary with the nature of the trip (for example, round trip, short distance) and the purpose of the trip. The trip maker's choice will thus depend on his consideration of money costs, time costs and inconvenience costs, the latter being a measure of the disutility the individual feels is involved in travelling by that mode.

Modal split models have been used since 1955 in major urban transportation studies in the United States and Canada. Most notable among the former are: Chicago, Pittsburgh, Erie, Seattle-Tacoma, (Puget Sound), Milwaukee-Racine-Kenosha, (Southwestern Wisconsin), Washington, Minneapolis-St. Paul, San Juan, Puerto Rico, and Buffalo. The Canadian example is the Metropolitan Toronto Area Transportation Study. All these studies have incorporated some of the following list of variables in multiple regression techniques to determine modal split: (30)

(1) Trip Characteristics

Trip purposes
Length of trip
Time of day
Orientation to CBD
(2) **Trip Maker Characteristics**

- Auto ownership
- Residential density
- Income
- Workers per household
- Distance to CBD
- Employment density

(3) **Transportation System Characteristics**

- Travel time
- Travel cost
- Parking cost
- Excess travel time*
- Accessibility**

Modal split models are classified as "trip end" models and "trip interchange" models. Trip end models use multiple regression to allocate a portion of total origins and destinations to alternative transportation modes before trip distribution by a gravity or opportunity model. Trip interchange models allocate portions of given person trip movements resulting from trip distribution to alternative transportation modes.

**Trip End Models**

Trip end Modal Split models take the volume of trips generated by or attracted to a given traffic zone and allocate this volume to alternative modes of urban transport. The forecast procedure involves the derivation of future zonal

*Travel time spent outside the vehicle during the trip; walk, wait and transfer times for transit trips and parking delay time for auto trips.

**A measure of the level of travel service provided by the transit or highway system to trip ends in the study area.
trip volumes by a multiple regression model which takes into account those land use and socio-economic variables discussed in the foregoing section. These volumes are then subjected to a "modal split model" which assigns trips to alternative modes. All modal split models incorporate multiple regression techniques to select statistically strong and conceptually viable independent variables. The five trip end models discussed in the above-mentioned report have found that the availability of an automobile; population density and income; the purpose, length and the orientation of the trip, and a ratio measure of accessibility of each zone to each other zone by alternative transportation systems have a measurable and constant effect on the propensity of a given zone to produce transit trips in a metropolitan area, as described below.

1. **Automobile Availability**—The greater the number of automobiles of the number of total trips fewer will be by transit. Also important here is the concept of 'choice' and 'captive' transit trips used in the Pittsburgh transportation study. Choice trip makers or trips refer to those persons or trips which have selected an alternative mode, whereas captive trip makers or trips are those where no alternative mode is available.

2. **Population Density**—Used in the Pittsburgh and Puget Sound models. In the Pittsburgh model it was found that CBD and other transit trip productions were
directly related to net residential density and that school transit trips were inversely related to it, a factor of the increased number of walk trips in denser areas. (32)

(3) Income--Used in the Puget Sound Study. Income is in effect a proxy variable for automobile ownership. Below a certain income, families did not own automobiles but above this an ascending proportion of automobiles per household is found. Income in itself has a relationship in the number of trips produced but it is difficult to separate this relationship from that of automobile availability.

(4) Orientation of the Trip--A factor considered in the Chicago and Pittsburgh models. Trips were divided into CBD and non-CBD or central and local trips for modal split. In Chicago trips to the CBD were found to be longer and were made by persons predominantly in working age groups whereas shorter, local trips were made by younger and older persons and were for non-work purposes. The importance of this orientation classification was further demonstrated in the Pittsburgh study. Of all trips made by transit, 85 per cent were by captive riders who, because of age or income, did not have access to an automobile and of the remaining 15 per cent 12 per cent of the choice trips were destined to the CBD.
Accessibility Ratios—Were derived for traffic in the Erie, Puget Sound and Southwestern Wisconsin modal split models. These ratios are measures of the relative accessibility each zone has to all other zones by alternative means of travel. The accessibility ratios in the Puget Sound and Wisconsin models are similar in that they both derive accessibility indices for the transit system and the highway system, using zonal trip production and attraction volumes and friction factors. The transit system index is then divided by the highway system index giving a ratio which demonstrates a direct curvilinear relationship to the per cent of a given transit use. This relationship however is also subject to the modifying influences of trip purpose and income. The above listed variables comprise the statistically and functionally relevant variables in trip end modal split models. It should be noted that only very general comment has been made on their use and implications in modal split analysis and projection.

Trip Interchange Models

For the sake of brevity only one of many "trip interchange modal split models" will be examined. The National Capital Transportation Study for Washington, D.C. interchange model will serve as an example of one of the more comprehensive approaches to mode selection models in
urban area transportation studies in North America. The Washington model is representative in that it incorporates almost all the variables used in other studies. More sophisticated models have also been developed, however, these are beyond the scope of this paper.

The Washington model is based on a market concept where all people moving between an origin and destination constitutes a travel market. Depending on their competitive position with respect to relative travel time, relative travel cost, the economic status of the trip maker and relative travel service, trips were allocated to each mode. Diversion curve and multiple regression analysis were used to select these variables for inclusion in the estimating equation, while the following factors demonstrated linear dependency with the above variables and were excluded from the model:

- Trip length, population density, employment density, transit seat capacity, and orientation to the CBD.

A description of the four independent variables used in the model is given here:

(1) Travel-Time Ratio:

$$TTR = \frac{X_1 + X_2 + X_3 + X_4 + X_5}{X_6 + X_7 + X_8}$$

where:  

- $X_1$ = time spent in transit vehicle  
- $X_2$ = transfer time between transit vehicles
\( X_3 = \text{time spent waiting for transit vehicles} \)
\( X_4 = \text{walking time to transit vehicle} \)
\( X_5 = \text{walking time from transit vehicle} \)
\( X_6 = \text{auto driving time} \)
\( X_7 = \text{parking delay at station} \)
\( X_8 = \text{walking time from parking place to destination} \).

(2) **Relative Travel Cost:**

\[
\text{Travel Cost Ratio} = \frac{X_9}{(X_{10} + X_{11} + 0.5X_{12})/X_{13}}
\]

where: \( X_9 = \text{transit fare} \)
\( X_{10} = \text{cost of gasoline} \)
\( X_{11} = \text{cost of oil change and lubrication} \)
\( X_{12} = \text{parking cost at destination} \)
\( X_{13} = \text{average car occupancy} \).

(3) **Economic Status of Trip Maker**—to take account of one's ability to purchase and maintain an automobile.

(4) **Relative Travel Service**—is a ratio of excess travel time, or time being spent outside the transit vehicle during the trip to time spent walking.

\[
\text{Travel Service Ratio} = \frac{X_2 + X_3 + X_4 + X_5}{X_7 + X_8}
\]

where: the X's have been previously described.
For each of these variables diversion curves showing the relationship between the transit share of trips and values of the independent variables (calculated for each traffic zone) demonstrate a declining propensity to use transit as above ratios increased, and as income increased. In all, 160 diversion curves were drawn for different stratifications of the cost ratio, economic status and the service ratio, and for different trip types. These curves enable the easy comparison of the propensity to travel under different combinations of these factors. For instance, transit usage is more sensitive to poor service when income is high than when income is low. The relationships visually apparent in the diversion curve analysis aided in the selection of the above independent variables, and they (diversion curves) serve to corroborate multiple regression equation estimation results. A similar analysis of Toronto and Philadelphia transit use and "factor" measures showed similar relationships, and this strengthened the reliability that could be placed on the Washington model.

Like the models discussed earlier, the modal split models are subject to considerable generalization through the use of surrogate independent variables and zonal averages. The multiple regression technique has served to select those variables which are statistically significant and show strong relationships to trip generation and to modal split at the level of generalization which is amenable to forecasting.
FOOTNOTES


(5) Overgaard, Ibid., p. 79.

(6) Overgaard, Ibid., p. 79.

(7) Ollson, Gunnar, Distance and Human Interaction: A Review and Bibliography, Bibliography Series Number Two, Regional Science Research Institute, Philadelphia, 1965.

(8) See Chapter II, Part II of this thesis.


(10) Lukermann, and Porter, op. cit.


(12) Ollson, op. cit., p. 64.


(17) Ibid.


(20) Ruiter, op. cit.

(21) Refer to Chapter II, Part II.


(25) Ullman, op. cit.


(30) Ibid., p. 3.


(33) Ibid.


APPENDIX II

THE VANCOUVER URBAN CORE PROJECT TRANSIT SURVEY

1) Survey Procedures:

An on-board origin destination survey of passengers was carried out during one week in May 1965 as part of the U.B.C. Geography-Urban Core Project under the direction of Dr. Walter Hardwick. The Urban Core Project was sponsored by the Canadian Council on Urban and Regional Research and the Transit Survey was done with the co-operation of the Transportation Division of B.C. Hydro and Power Authority.

Buses were boarded by survey personnel as they left outer terminals. A systematic sample of one bus each half hour was done. As passengers boarded the bus ridden by the surveyor, they were handed questionnaire cards. These cards were return addressed and postage paid, or they could be handed to the surveyor after completion. Approximately 6,000 cards were collected, some only partially completed. The data obtained on the returned cards was expanded by a factor representative of the total number of persons riding each bus passing a cordon point during each half hour survey period.

No control of the sample was made, and card returns vary considerably in terms of the percentage of bus passengers represented. It is possible, for instance, to have a
situation where only five per cent of the passengers responded for each half hour time period, and the answers they gave were expanded twenty times to represent all passengers. Within the research design there is no way of determining whether these responding passengers represented the non-responding passenger in terms of any of the answers to the questions.

The questionable representativeness of the sample limits its use in a discussion of indications of bus passenger travel patterns and associations as attempted in this thesis.

2) The Data:

The Urban Core Project Transit Survey obtained information on trip/origin, trip destination, time of trip, purpose of trip, sex of trip maker and bus route. Origins and destinations were coded to 95 Traffic Districts covering the metropolitan area used for the Metropolitan Highway Planning Study series in 1959. Sixty-five of these zones were in the City of Vancouver. In view of subsequent statistical analysis of the bus passenger data in Chapter IV, this data was aggregated to the 65 traffic zones used for the Vancouver Transportation Study. (2) (Figure 7) These arbitrarily defined data collection units place further limitation on the suitability of the data for travel pattern analysis. Small (1/4 mile) grid squares would have provided much greater flexibility by allowing for construction of functionally relevant data collection areas. Six trip
### TABLE 14

**BUS PASSENGER TRIP DISTRIBUTION TO CORE ZONES**

**FOR ALL TRIP PURPOSES AND BY SEX**

#### a) TRIP TYPES

<table>
<thead>
<tr>
<th>CORE ZONE</th>
<th>03</th>
<th>0506</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
<th>11-12</th>
<th>13-14</th>
<th>ROW TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home</td>
<td>272</td>
<td>325</td>
<td>304</td>
<td>77</td>
<td>224</td>
<td>-</td>
<td>54</td>
<td>276</td>
<td>1,532</td>
</tr>
<tr>
<td>Horizontal Percent</td>
<td>(18)</td>
<td>(21)</td>
<td>(20)</td>
<td>(5)</td>
<td>(15)</td>
<td>-</td>
<td>(4)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>1,406</td>
<td>4,958</td>
<td>3,826</td>
<td>332</td>
<td>636</td>
<td>216</td>
<td>707</td>
<td>2,849</td>
<td>14,932</td>
</tr>
<tr>
<td>Horizontal Percent</td>
<td>(9)</td>
<td>(33)</td>
<td>(26)</td>
<td>(2)</td>
<td>(4)</td>
<td>(1)</td>
<td>(5)</td>
<td>(19)</td>
<td></td>
</tr>
<tr>
<td>Business</td>
<td>435</td>
<td>878</td>
<td>946</td>
<td>107</td>
<td>175</td>
<td>-</td>
<td>97</td>
<td>448</td>
<td>3,086</td>
</tr>
<tr>
<td>Horizontal Percent</td>
<td>(14)</td>
<td>(28)</td>
<td>(31)</td>
<td>(3)</td>
<td>(6)</td>
<td>-</td>
<td>(3)</td>
<td>(15)</td>
<td></td>
</tr>
<tr>
<td>Shopping</td>
<td>154</td>
<td>1,723</td>
<td>2,775</td>
<td>26</td>
<td>72</td>
<td>-</td>
<td>82</td>
<td>2,827</td>
<td>7,659</td>
</tr>
<tr>
<td>Social Recreation</td>
<td>(2)</td>
<td>(22)</td>
<td>(36)</td>
<td>-</td>
<td>(1)</td>
<td>-</td>
<td>(1)</td>
<td>(37)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>154</td>
<td>311</td>
<td>656</td>
<td>23</td>
<td>28</td>
<td>-</td>
<td>134</td>
<td>144</td>
<td>1,450</td>
</tr>
<tr>
<td>Horizontal Percent</td>
<td>(11)</td>
<td>(21)</td>
<td>(45)</td>
<td>(2)</td>
<td>(2)</td>
<td>-</td>
<td>(9)</td>
<td>(10)</td>
<td></td>
</tr>
</tbody>
</table>

#### b) SEX

<table>
<thead>
<tr>
<th></th>
<th>ROW TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>9,562</td>
</tr>
<tr>
<td>Horizontal Percent</td>
<td>(8)</td>
</tr>
<tr>
<td>Female</td>
<td>4,552</td>
</tr>
<tr>
<td>Horizontal Percent</td>
<td>(9)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>29,123</td>
</tr>
<tr>
<td>ROW TOTALS</td>
<td>8</td>
</tr>
</tbody>
</table>
purposes were pre-coded for the survey: home, work, shopping, business, social-recreation, and other. Only shopping and work trips are examined in this thesis. A percentage breakdown of the data is provided in Table 14 to give an indication of general characteristics of transit travel to the urban core of Greater Vancouver.

FOOTNOTES


(2) City of Vancouver Planning Department, Metropolitan Vancouver 1955, 1965 and 1985: Selected Data From the Vancouver Transportation Study, Vancouver, 1967.
APPENDIX III

DATA COLLECTION UNITS IN URBAN TRANSPORTATION STUDIES--
SOME COMMENTS

The functional approach to urban transportation analysis has been developed in conjunction with use of regression and similar techniques. Independent variables have been used to predict trip generation and attraction rates of selected areas or traffic zones. These traffic zones have been used in all transportation studies regardless of which model is employed for forecasting urban travel patterns. But, given its focus on the functional description of urban travel patterns, the regression models require a more accurate delineation of functionally relevant areas than the less detailed gravity and opportunity models.

Traffic zones or traffic districts are the areas for which data on travel volumes and selected characteristics are summarized. Each of these zones are given a centroid number to which all data and information are assigned for computational purposes. The selection of criteria for these zones depends on many factors. The size of the zone is generally governed by density of population, with zones being progressively larger with increasing distance from the C.B.D. Traffic zone selection practices recommended by the Institute of Traffic Engineers suggest the division of a metropolitan
area into major sectors; "one sector includes the downtown area, and others are generally wedge-shaped with the point of the wedge touching or closely approaching sector zero".\(^{(1)}\)

Sectors are then subdivided into relatively square zones. Sector boundaries are determined by features which will prevent the flow of traffic, and more or less create traffic sheds. No other criteria are given for the selection of traffic zone boundaries by the Institute; however, from the observations of the author, it seems that consideration is also usually given to laying out zones which straddle major traffic routes.

By pre-selecting traffic zones on the less than exacting basis outlined above, there is considerable danger in clouding functional relationships, or even arriving at spurious correlations when using regression techniques. Traffic zone data on the independent variables and trip volumes may be subject to over-generalization. This of course will depend to a certain extent on the nature of the area with any given traffic zone, and on the level of stratification of either trip purposes or independent variable measures. A finer breakdown of trips and of activities would logically entail a similar focussing on point or cluster locations of specific activity groups, rather than arbitrarily defined traffic zone areas. However, even if the analysis does not involve an in-depth examination of activity interrelationships,
the process for selecting boundaries for traffic zones practised by traffic engineers is still open to question. If the intent is to arrive at functionally meaningful estimating equations, then it would be desirable that a total land use analysis of the urban area be done, and that all information be assigned to "objective" and spatially consistent data collection units. For example, the use of quarter mile square grid blocks, or quartiles, as found in the Chicago Area Transportation Study. All data can then be easily assigned to whichever functionally relevant areas are required for analysis and prediction.

An example of both the shortcomings of the use of large arbitrarily defined traffic zones as well as the problems associated with data aggregated to the level of traffic zones are the findings of McCarthy in a recent journal article. McCarthy pointed out that from a transportation planning point of view, the basic reason for aggregating origin-destination survey data in trip generation methodology is that '... enough behaviour must be aggregated to have statistically stable data and to discern consistent group travel behaviour patterns.' He questioned the validity of this procedure and hypothesized that "the use of zonally aggregated household data results in inaccurate predictive trip generation equations". It was found that zone sampling distributions were skewed rather than normal and
thus the use of zonal means were not representative of aggregate behaviour, and that in some instances zones considered to have homogeneous characteristics were heterogeneous with several model groups which could not be represented by mean or median values. Zonal aggregates therefore could not result in accurate representation of travel behaviour if relationships used for predictions were based on heterogeneous data. The author concluded that "multiple regression analysis should precede aggregation of individual household data rather than the aggregation of data preceding multiple regression analysis." (6)

FOOTNOTES


(4) Ibid., p. 35.

(5) Ibid., p. 42.

(6) Ibid., p. 42.