AN INVESTIGATION OF THE McMASTER COMMUTER DISTRIBUTION

by

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ABSTRACT: The purpose of this study is to investigate the McMaster commuter distribution. The total analysis is carried out in two sub-analyses. The first analysis examines the effect that different variables have on the mean trip length of various commuter groups. The variables examined in the first analysis are: residential tenure, occupation, duration of service or study, parking permit ownership and part-time versus full-time status of students. In general the first analysis is concerned with the mean trip length of on campus Faculty, Staff, and Students. the first analysis verified that residential tenure is an important variable in that students who commute from the homes of parents average a considerably greater mean trip length than students who commute from rented accommodation.

The second analysis employs a disaggregate singly-constrained spatial interaction model to distribute trips between McMaster and student residential locations. The second analysis shows that:

(i) the production-constrained model fits considerably better with observed data when the sample is partitioned into student renter and stay at home groups than when the sample is not partitioned. The attractiveness factors were varied between the two groups. Renters were considered to be attracted to renter occupied dwellings in a zone while students commuting from the homes of parents were considered to be attracted to the number of owner occupied dwellings in a zone.

(ii) straight line distance as a surrogate for travel cost yields a better fit for the renter group while automobile travel-time facilitates a better fit for the stay at home group. Auto travel time yields a better fit for peripheral trips because of the tendency for these trips to be made by car. Given the understanding that student renters are predominantly bus users who have chosen to locate close to the campus, euclidean distance is apparently more reflective of the travel impedance experienced by this group.

Future research should attempt to qualitatively link measures of travel cost with the client group they are attempting to model.

ACKNOWLEDGEMENTS

I should like to thank my supervisor, Dr. Fred Hall, for his patience and advice throughout the duration of this study. Certainly any failure to present the results coherently are through no fault of his. Mr. Howard Markle of the Parking Department cooperated wonderfully throughout the early stages of data collection, and the time he took to discuss parking problems is greatly appreciated. Miss Lynne Collingdon's cooperation in fine tuning the data is genuinely heartwarming. Once again the burdens of typing have fallen on my mother, Jean Neale. The job is not new to the lady who typed the doctoral thesis of Dr. L. G. Reeds!

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CHAPTER 1

INTRODUCTION

The purpose of this study is to investigate the McMaster commuting pattern. The paper is predominantly concerned with the distribution of McMaster commuters and the way the mean trip lengths of various groups of commuters differ.

The need for a study which explored the McMaster commuting pattern was cited by both the Hamilton-Wentworth Regional Planning Department and the McMaster University Parking Department. The former was interested in how trip production rates varied over space. The latter expressed an interest in the attitudes affecting the modal decision. These two interests fall under the respective topics of trip generation and modal split. While these two topic areas are not the focus of this paper, insights into specific aspects of these areas are possible.

The analysis is split into two phases. The first phase of the analysis explores the impact of five different variables on the distribution of McMaster commuters. The second phase uses the results of the first analysis to model the distribution of McMaster commuters.

Chapter 2 outlines the hypotheses and pursues the objectives of the first analysis. The objectives are to:

(i) discover how five cross sectional variables (residential tenure, occupation, duration of service or study, parking permit ownership, and part-time versus full-time status) affect the distribution of commuters;

(ii) verify whether "residential tenure" constitutes a viable variable for use in a disaggregate spatial interaction model.

These objectives are investigated predominantly through an analysis of mean trip length using analysis of variance in Chapter 5.

Chapter 3 is concerned with modelling spatial interaction. This chapter reviews some of the literature regarding trip distribution modelling and contrasts the modelling approach used by the Ontario Ministry of Transportation and Communications to the approach advanced by Wilson (1970, 1974).

The major objectives of the modelling analysis are to:

(i) establish whether a disaggregate approach which independently models two residential tenure groups is useful in improving overall "goodness of fit" in the model application;

(ii) explore and contrast the effectiveness of travel time and straight line distance as measures of travel cost.

It was hypothesized a-priori[1] that residential tenure would provide a useful and manageable basis for disaggregation or separation of McMaster commuters into two distinct groups for modelling purposes. Clearly if two groups of commuters illustrate large differences in their respective patterns of distribution, it is advantageous to model

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1. The limitations on time and data dictated the selection of a variable for use in disaggregation in advance of results from the first analysis. The choice of residential tenure is justified in Chapter 3.

these distributions using measures of zonal attractiveness which reflect the unique residential preferences of the two groups. These two groups can be equated to "owners" and "renters" but will be more specifically defined in Chapter 2. The analysis in Chapter 6 seeks to establish whether a separate consideration of these "owners" and "renters" enables a more successful model application.

The second objective is to compare travel time and straight line distance as measures of travel cost. This objective is also investigated in the first analysis where mean trip length is considered both in miles and in minutes for different groups of commuters. While it was predicted that automobile travel time would overestimate short trips and straight line distance would underestimate long trips, the greater implications of this prediction for both the first and second analyses remained obscure until the study was almost completed.

The combined thrust of the paper is therefore an attempt to better understand and model the distribution of commuters who share a common workplace. The wide range of lifestyles and occupations represented by the university situation is particularly conducive to an analysis of the factors affecting residential location on a fairly aggregate level.

CHAPTER 2

HYPOTHESES RELATED TO MEAN TRIP LENGTH

In this chapter, hypotheses are made regarding the relationship between the five study variables and mean trip length. To reiterate, the five variables being investigated are: occupation, duration of service or study, parking permit ownership, part-time versus full-time status, and residential tenure. It is recognized that relationships between variables must also be investigated where problems of colinearity exist. In addition, the chapter attempts to briefly introduce and describe the concepts associated with the analysis of mean trip length. The geographical literature will be drawn upon to substantiate and aid the discussion.

(i) Measuring Mean Trip Length

A common means of comparing the trip making characteristics of different groups is to measure mean trip length. (Examples can be found in Hathaway, 1974; Wooton and Pick, 1967; Hyman, 1970.) Group mean trip length is the average of all trip lengths between residences and the workplace for a specific group of people. Using analysis of variance, it is possible to determine whether differences in mean trip length are statistically significant for different groups of commuters.

(ii) Occupation and Mean Trip Length

The occupational groups being investigated in this study are all subsets of three large bodies present at any university: staff, faculty, and students. Table 2-1 shows the categories used as well as the more detailed information collected.

TABLE 2-1 OCCUPATIONAL GROUPS

FACULTY	STAFF
Professor	Administration
Associate Professor	General Staff
Assistant Professor	Hourly Staff
Lecturer	

STUDENTS

UNDERGRADUATES	MISCELLANEOUS	GRADUATES
Science	Adult Education Degree Studies	
Engineering	Certificate Extension	
Health Sciences	Employed Students	
Social Sciences		
Business		
Humanities		
Nursing		
Divinity		

There is at least some evidence in the literature that income classifications are fruitful for the analysis of trip making. The reader is referred to work by Hathaway, 1974; Hyman, 1970; Wooton and Pick, 1967; Lowry, 1963; Lansing, 1966. The confidentiality requirements of the McMaster University Personnel Department did not allow the collection of specific income information. However, the breakdown of occupation given in Table 2-1 is at least partially conducive to socio-economic ranking. Therefore the analysis may investigate hypotheses which attempt to relate occupational status to mean trip length.

The conventional hypothesis that mean trip length increases with occupational status makes little sense when the university is proximate to prestigious suburban areas. Research has indicated a positive relationship between trip length and occupational status when the workplace is located in the CBD (Lowry, 1963, p. 153; Duncan, 1956, pp. 48-56). However, Lansing (1966, p. 90) notes that while CBD based trips have mean trip lengths which are consistent with this hypothesis, peripheral or non-CBD based trips show an inverse relationship between trip length and occupational status. Since McMaster University occupies a peripheral urban location, mean trip length may well be inversely related to occupational status.

(iii) Parking Permit Ownership and Mean Trip Length

There is also the question of parking permit ownership. It is hypothesized that permit holders will average significantly higher mean trip lengths than non-permit holders. One might expect that the automobile will be employed by commuters living in isolated residential zones which are poorly serviced by public transit. However, the reader will recall that the university is already in a peripheral location. The tendency for public transit to be poorer in peripheral suburban areas may act to increase the numbers of short distance automobile commuters.

This hypothesis is further complicated by the colinearity which exists between parking permit ownership and occupational status. Figure 2-1 shows that, relatively speaking, faculty and staff have the highest "percentage of sector" ownership. However, in absolute terms Figure 2-2 shows that the staff and faculty are clearly dwarfed by undergraduate and graduate student parking-permit ownership.

FIGURE 2-1

Relative Sector Parking Permit Ownership

(March 1976)

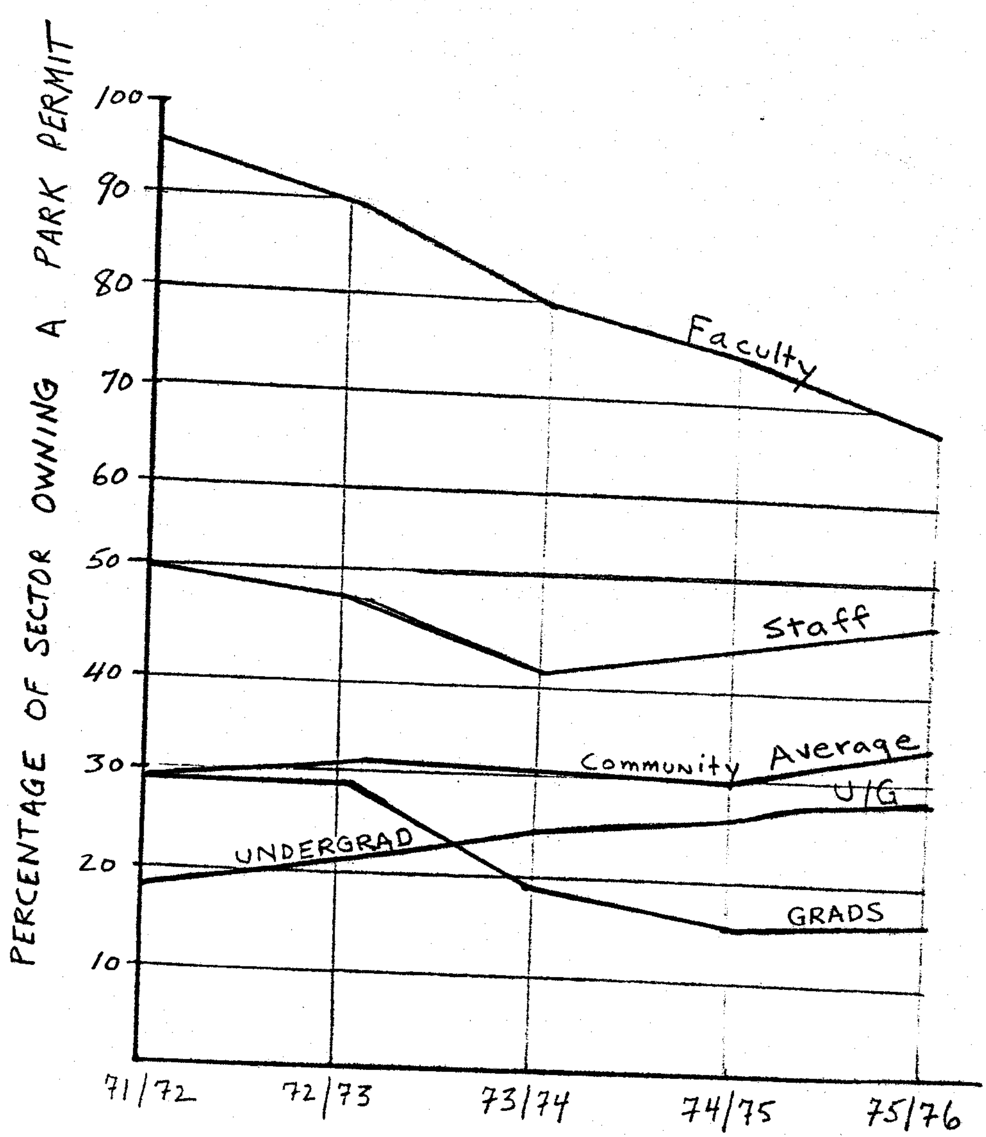
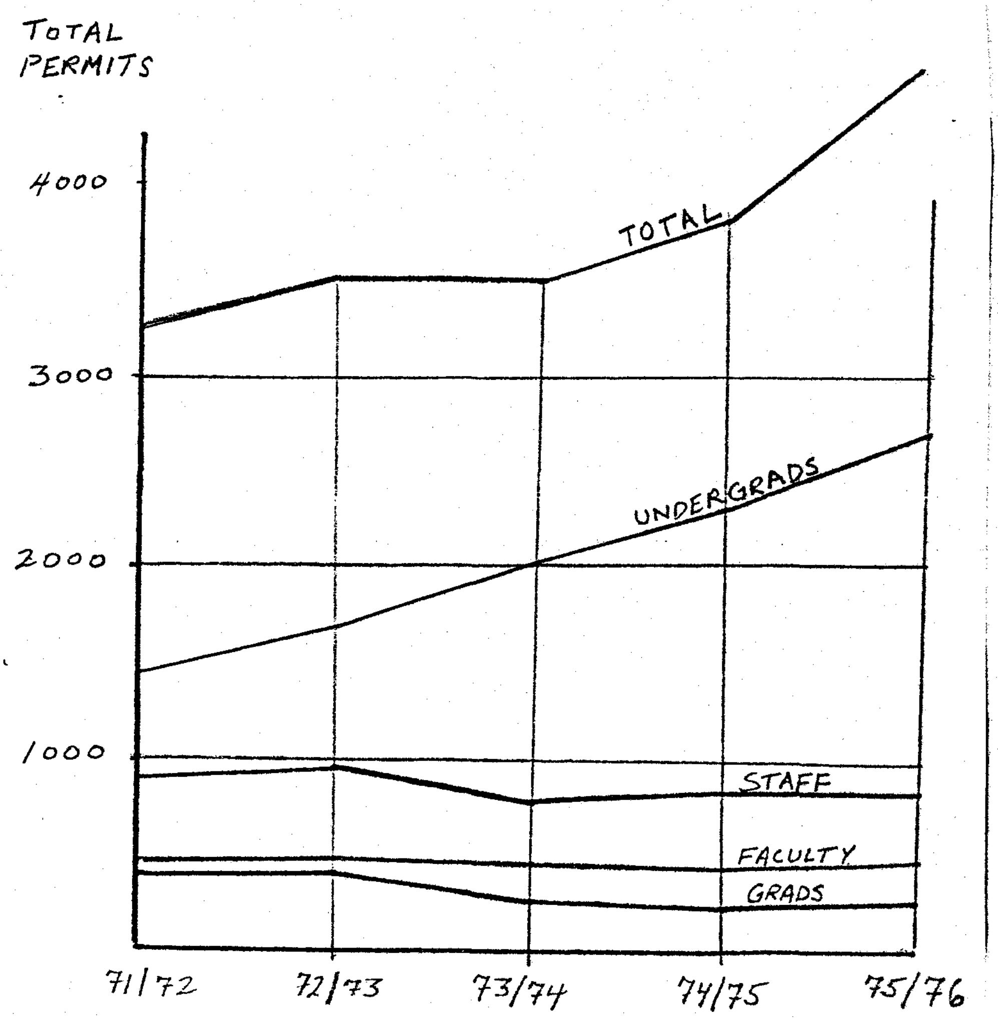


Figure 2-1 indicates that the percentage of sector parking permit ownership has declined dramatically for the faculty sector over the last five years. Increasing use of public transit and decreasing trip lengths may be at least partially responsible. However, with cross sectional data there is little chance of testing these predictions empirically.

FIGURE 2-2

Absolute
Sector
Parking Permit
Ownership

(March 1976)



Certainly this is an area worthy of further research.

(iv) Residential Tenure and Mean Trip Length

A significant difference in mean trip length is expected to exist between the group of students who rent their accommodation and those students who live at home. Because the rent group represents mainly students who originate from residential addresses which are too inaccessible for daily commuting, they will tend to locate in areas which are close to the university. Those students who live at home will be willing to pay more for transportation in order to save on the cost of accommodation and food. Therefore, the mean trip length of renters is hypothesized to be considerably less than that of students who live at home. Furthermore, students who live at home are expected to own a greater number of parking permits than students who rent. These hypotheses are expected to hold strongly even when on-campus residents are removed from the analysis.

(v) Part-Time versus Full-Time Status and Mean Trip Length

Another difference in trip making behaviour will probably exist between part-time and full-time students. Because full-time students come to the campus frequently, they will tend to locate in areas which are proximate to the university. The part-time student may only travel to the university once or twice each week and residential location is likely to be based on some more relevant set of accessibility needs. Therefore it is hypothesized that part-time students will average a significantly greater mean trip length than full-time students.

(vi) Duration of Service or Study and Mean Trip Length

Differences in distribution are expected to exist between paid staff (and faculty) and the 'client' group of students. It is hypothesized that staff will tend to locate closer to the university over time for reasons relating to accessibility. Students, however, will tend to locate closer to the university over time for reasons relating to privacy and housing supply. Therefore students, specifically renting students, will tend to locate further from the university over time. Unfortunately, cross sectional data may not be sufficient to substantiate trends which may be occurring "through" time rather than "in" time.

CHAPTER 3

MODELLING SPATIAL INTERACTION

In this chapter three topics will be discussed. Firstly, we will review some of the literature regarding spatial interaction modelling and compare the modelling approach of the Ministry of Transportation and Communications to that of Wilson (1970, 1974). Secondly, we will review Hathaway's disaggregate approach and introduce the concept of disaggregation of zonal attractiveness. At this time the hypothesis regarding residential tenure will be clarified. The chapter will close with a discussion of travel cost. The relative merits of travel time and straight-line mileage will be discussed.

(i) Spatial Modelling Review

Before describing the nature of the modelling investigation it is important to review some of the recent British contributions to spatial interaction modelling. In particular it is Wilson's (1970) concept of a "singly-constrained" spatial-interaction model which is relevant to this paper. The model proved particularly suited to consolidating both spatial-interaction and residential location into the same modelling framework.

In trip distribution, the gravity model has been the most enduring framework for examining spatial interaction. The simplest form of the model can be expressed:

$$Tij = KOiDj\ f(cij) \qquad (3\text{-}1)$$

In this model Tij represents the trips travelling from an origin zone i to a destination zone j. K is a scaling constant, Oi represents the numbers of trips leaving zone i (origins) and Dj represents the trips entering zone j (destinations). The amount of interaction between zonal pairs decreases with distance. Hence f(cij) represents some decreasing function of travel cost.

In the Ministry of Transportation and Communications User's Manual, Simplified Transportation Planning Computer Programs, the trip distribution function differs only slightly from the gravity model in equation (3-1). The relationship may be expressed as:

$$Tij = Kij\ Pi\ Aj\ F(cij) \qquad (3\text{-}2)$$

Pi and Aj represent the magnitude of production and attraction forces in individual origin and destination zones respectively. These parameters are based on some characteristic of the land use such as the number of dwelling units.

Kij is a "socio-economic adjustment factor". However, the MTC doesn't include the Kij because "very few cities have found it necessary to use them". (MTC, 3-TR 3304-04). Without the socio-economic adjustment factor, the relationship can be rewritten:

$$Tij = Ci\ \ Pi\ \ Aj\ \ F(cij) \qquad (3\text{-}3)$$

In this equation, Ci is a scaling constant for the origin zone i. It ensures that the total number of trip productions is equal to the total number of trips (Tij) in the system. However, the model does not ensure that total trips are equal to total attractions. For this, an iterative solution is used (Ibid.).

The concept of a spatial-interaction "family" of models was first introduced by Wilson (1970, pp. 37-63). The MTC distribution model just introduced is not directly represented in this family of four spatial interaction models. The MTC is a hybrid of what Wilson calls the unconstrained, singly constrained and doubly constrained spatial interaction models.

The unconstrained model is equation (3-1) which is restated below:

$$T_{ij} = K\, O_i\, D_j\, f(c_{ij}) \qquad (3\text{-}1)$$

The number of trips entering and leaving each origin and destination are known. The trip interchange is allocated to reflect spatial accessibility.

K is calculated as a single scale factor. K ensures that the total number of origins equals the total trip interchanges. Alternatively K could also be used to ensure that the total number of destinations equals the total trip interchanges. It makes no difference which form of K is used because total number of destinations should be made equal to total number of origins; the number of people leaving for work (presumably) equals the number of people arriving at work.

Wilson also defines a singly-constrained case. Both the "production-constrained" and the "attraction-constrained" cases are singly-constrained interaction models (Wilson, 1974, pp. 65-66). In the production-constrained case, the origins are known but the destinations are not. Hence O_i may enter the equation but D_j will be replaced by W_j. The model can be stated:

$$T_{ij} = A_i O_i W_j f(c_{ij}) \tag{3-5}$$

where

$$A_i = 1 \Big/ \sum_{j=1}^{N} W_j f(c_{ij}) \tag{3-6}$$

In the attraction-constrained case, D_j is known while O_i is not. Hence D_j enters the equation directly while O_i is replaced with the production term W_i. The model can be stated:

$$T_{ij} = B_j W_i D_j f(c_{ij}) \tag{3-7}$$

where

$$B_j = 1 \Big/ \sum_{i=1}^{N} W_i f(c_{ij}) \tag{3-8}$$

Wilson argues that the singly-constrained model incorporates a residential location model and spatial interaction. If, for instance, we can accurately obtain information defining zonal destinations (D_j), the singly-constrained distribution model is capable of predicting the residential location of trip makers based on some measure of land-use intensity (Wilson, 1970, pp. 63-88).

Wilson makes the point that "concepts of economics do not lend themselves to theory building in spatially disaggregated systems" (Wilson, 1970, p. 65). Any location model must attempt to replicate the existing housing market. Economic concepts imply a need to incorporate both demand and supply forces into models of residential location. When speaking about the location of people, Wilson argues that it is conceivable to treat the home end as a zonal variable describing the number of households in a zone (Wilson, 1974, p. 180).

The fourth spatial interaction model introduced by Wilson is the case where all origin and destination zonal totals are known. The model's only function is to "distribute" the trips among these competing zones. Only the effect of accessibility is allowed to enter the model's allocative mechanism. Wilson calls this the "doubly-constrained" case where:

$$Tij = Ai\ Bj\ Oi\ Dj\ f(cij) \qquad (3\text{-}9)$$

In this equation Ai and Bj are both scaling constants needed to ensure that:

$$\sum_{j=1}^{N} Tij = Oi \qquad (3\text{-}10)$$

$$\sum_{i=1}^{N} Tij = Dj \qquad (3\text{-}11)$$

Since Ai is dependent on Bj and vice versa, the two must be solved using an iterative solution.

The MTC model is most closely related to Wilson's doubly-constrained model. Instead of calculating both Ai and Bj iteratively, the MTC model chooses to define one normalizing factor precisely and the other iteratively. This difference is unimportant. Wilson's framework does, however, introduce model consistency and the concept of the singly-constrained solution to North American planners.

(ii) Disaggregation and the Model Hypothesis

The production constrained version of the trip distribution model has been adopted by this study in modelling the McMaster commuting distribution. Increased calibration accuracy should be achieved if disaggregate measures for zonal attractiveness are used.

Hathaway (1974) disaggregated the doubly-constrained model. He tried disaggregating in age-sex groups, in socio-economic groups, in occupational groups, and in industrial classification groups. The form of Hathaway's model can be stated:

$$Tij^{k} = Ai^{k}\ Bj^{k}\ Oi^{k}\ Dj^{k}\ \exp\ (- \lambda^{k}\ cij) \qquad (3\text{-}12)$$

Aside from the superscript k, equation (3-12) is identical to the distribution equation (3-9). Hathaway used equation (3-12) to separate trip distribution into k different group distributions. Hathaway was forced to conclude that separate distribution models for each group of trip maker provided only marginal improvements in goodness of fit. In concluding, Hathaway suggests that different travel cost functions (cij) for different sub-areas would improve the accuracy of calibration more significantly (Hathaway, 1974).

Hathaway's treatment of disaggregation ignores any attempt to link locational forces to disaggregate measures of either zonal attractiveness or travel cost. Essentially Hathaway's paper illustrates the failure of income groups and occupational groups to improve model fit. Hathaway disaggregated zonal attractiveness only in a quantitative sense. The measure of attractiveness used remained the same for all occupational groups. In order to disaggregate attractiveness for these various occupational groups, it is necessary to define the housing preferences of these groups.

Increased calibration accuracy should be achieved if disaggregate measures for zonal attraction (Wj^k) or production (Wi^k) are used in the singly-constrained trip distribution model. The mathematical expression of this disaggregate attraction-constrained model could be written:

$$Tij^k = Ai^k \; Wj^k \; Oi^k \; (e^{-\beta^k} cij) \qquad (3\text{-}13)$$

In this model Tij^k represents trip interchange in the k^{th} (occupational) group. Wj^k represents the measure of attractiveness which is to be associated with the k^{th} group. Only cij remains qualitatively unaffected by disaggregation.

Residential attractiveness has considerable reason to vary among different groups. If a single attractiveness measure, such as the number of households, is used for all groups, a large part of misestimation will be due to the conflicting housing preferences of different lifestage groups. A zone which possesses detached unit dwelling stock is indicative of a middle class family life style. In reality, such a zone would have a much stronger pull for persons who find this landuse to be compatible with their particular stage in lifecycle needs. Since a student has specific short term goals and financial limitations, he is much more likely to be attracted to rentable dwellings which can be shared with other peers at reasonably low costs. For example, in Ancaster, housing stock is expensive and predominantly single family units. Rentable housing is in short supply and claimed largely by the local young. Consequently, the aggregate model will overestimate the number of students living in Ancaster if zonal population or aggregate number of households is used as a pull factor. It is hypothesized that disaggregation of attractiveness by "owner-occupied" versus "renter-occupied" households will bring increased accuracy to the calibration of this singly-constrained model.

However, it should be added that the groups being modelled must correspond as closely as possible to the measures of attractiveness used in the distribution of trips. Clearly if "student" versus "non-student" groupings are associated with "rentable units" versus "owner occupied" units respectively, a one to one correspondance is being assumed. Certainly it is not the case that 100 per cent of students prefer rentable dwellings. Many students will be living with parents in single-family owner-occupied dwellings.

Consequently the groups should not be occupational groupings. In order to ensure a one to one correspondance between the group and the attractiveness measure, "stay at home" and "renter" were chosen to correspond to owner-occupied and tenant-occupied housing respectively. The modelling effort was restricted to students.

(iii) Investigating Travel Cost

In theory, there are an infinite variety of ways to measure travel cost (cij). The most common methods are network travel time, euclidean (straight-line) distance, and rectangular grid distance. Work by Haines and Hall (McMaster Geography Department, 1976) illustrated that, for a typical trip distribution model, it made little difference to goodness of fit whether euclidean or rectangular grid distance was used. In this study we will be using both straight line distance and network travel time as measures of travel cost.

In this study, travel time was measured in terms of automobile travel time. Generally, car owners have the ability to travel further in the same length of time than persons using the bus system. This is likely to be an important discrepancy where we have university groups heavily dependent on public transit. Whereas a measure of travel cost based on automobile travel times will tend to overestimate nearby trips, a measure based on euclidean distance will likely underestimate the frequency of more distant trips due to the time savings of automobile freeway travel. Therefore the study will attempt to determine the usefulness of these two travel cost measures and discover whether one measure is better than the other for the university situation. This investigation will be conducted both in the first analysis of mean trip length and in the modelling analysis.

In this paper f(cij) is defined:

$$f\,(cij) = e^{-\beta\, cij} \tag{3-14}$$

This function is computationally congenial to maximum likelihood calibration procedures (Wilson, 1974, p. 70).

CHAPTER 4

SAMPLE AND METHODOLOGY

In this chapter, the sampling and variable methodology are presented. The zonal system is discussed to present its limitations and strengths. The choice of variables is explained and surrogate values for variables are discussed. The chapter begins with a discussion of the sample.

(i) The Sample

The sample consisted of 754 observations. A general breakdown of the sample is shown in Table 1. The overall sampling fraction was approximately 4.5%. However, as stated before, part-time staff and faculty were not included in the sample.

TABLE 4-1 OCCUPATION BREAKDOWN (1)

OCCUPATION	April 1976 SAMPLE Number	SAMPLE FRACTION % of Actual	May 1976 ACTUAL Number
FULL-TIME STAFF	93	5.7%	1,620
FULL-TIME FACULTY	52	6.4%	813
GRADUATE STUDENTS	74	3.6%	2,049
UNDERGRADUATES, ADULT EDUCATION, AND CERTIFICATE EXTENSION	535	4.4%	12,214
	754	4.5%	16,696

The sampling method had elements of both randomness and uniformity. Since data were extracted from printouts, no more than one case per page was chosen; hence the element of uniformity. An individual was chosen from any given page in a random fashion. Pages were chosen to ensure a wide cross section of the alphabet. Originally, it was felt that a 5 per cent total population sample would facilitate a representative sample in which all sub-groups were adequately represented. In retrospect, a representative sample was not a paramount requirement. Many sub-groups were insufficiently represented in the analysis. Consequently analysis often had to be restricted to the more aggregate occupational classifications of Staff, Faculty, Graduates, and Undergraduates. For the purpose of comparing group travel behaviour, a stratified sample might have been more appropriate. The redeeming advantage of a representative sample is that the relationships between variables and among occupational groups retain a sense of "relativeness". Clearly a significant difference between two groups is of little import if the groups represent only a small proportion of the overall commuter distribution.

(ii) The Zonal System

The commuter hinterland investigated in this study extended seventy miles from the workplace. For spatial modelling purposes, a smaller sub-system was used extending less than twenty miles from the campus. Figure 4-1 shows the 33 zone system used in the modelling effort along with the distribution of faculty, staff, and students described by the data. Figure 4-2 describes the perimeter of the

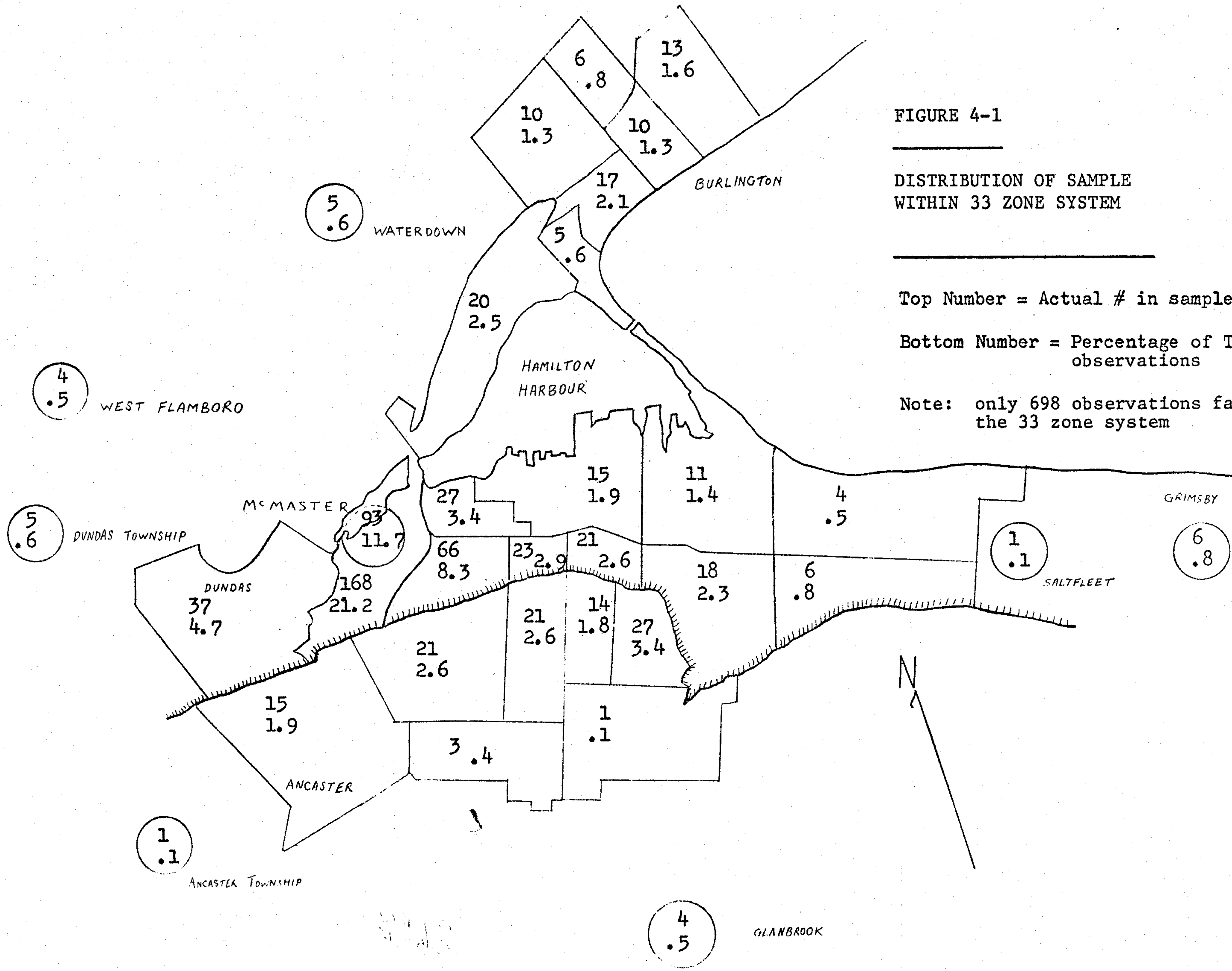
FIGURE 4-1

DISTRIBUTION OF SAMPLE
WITHIN 33 ZONE SYSTEM

Top Number = Actual # in sample

Bottom Number = Percentage of Total (789 observations

Note: only 698 observations fall within the 33 zone system



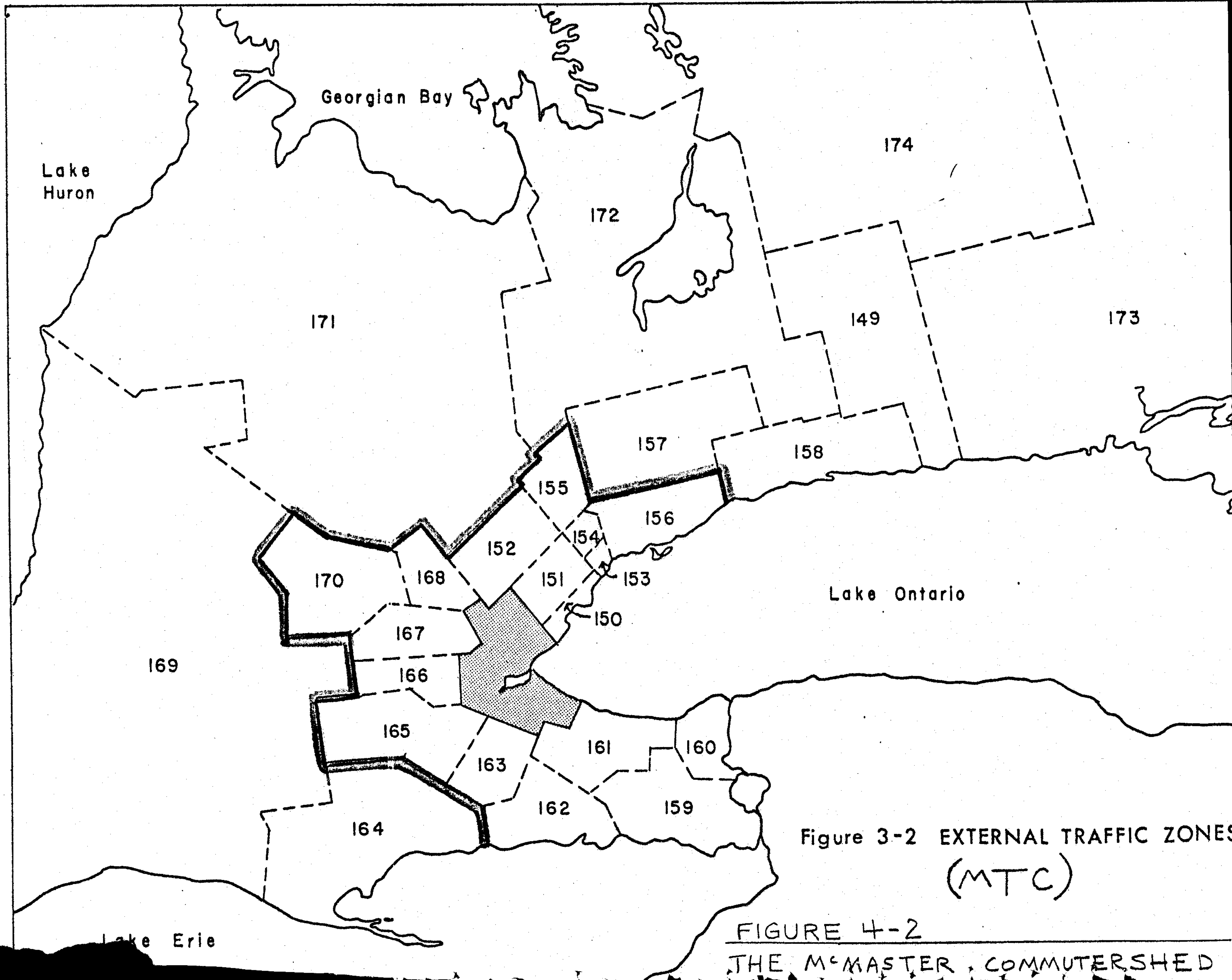


Figure 3-2 EXTERNAL TRAFFIC ZONES
(MTC)

FIGURE 4-2
THE McMASTER COMMUTERSHED

area considered in the calculation of mean trip length used in the first analysis.

The boundaries of the zones in Figure 4-1 were adopted from the postal code system. Originally, it was felt that the first four digits of the postal code could provide a highly detailed zonal system. However, the four digit level represented an overlapping zonal system not conducive to spatial modelling. Such a zonal system would have proved unmanageable, in its treatment of trip length and spatial interaction.

The three digit level of aggregation represented a contiguous zone for which some housing data was available. In addition, census tracts could be aggregated to match the three digit postal code zone fairly accurately. Convenience was a large part of the reason for choosing postal codes. Data was provided from a University printout and addresses were always stated. In forty per cent of the cases the postal code was listed. The other sixty per cent of the addresses were obtained using the Postal Code Directory for South Western Ontario.

Both travel time and miles were used as measures of travel cost. Network times were provided by the Hamilton-Wentworth Regional Planning Department. The Regional Planning Zone and MTC traffic zone systems facilitated an accurate conversion of travel times for the zones used in this study. Network times were based on peak hour automobile travel times. Euclidean distance can be defined as the straightest path between two points. This definition was modified slightly to read the straightest 'passable' path between two points. Distances were never measured over water, or escarpments, and the "opposometer"[2] was traced down the nearest roadway access before proceeding, as the crow flies, to the university.

As previously mentioned, a large zonal system of 51 zones was used in the first analysis, and a smaller sub-system of 33 zones was used to model spatial interaction. The smaller zonal system was used to model residential location for two reasons. The first reason is the difficulty of collecting zonal attractiveness data for zones which become exceptionally large as distance from the university increases. The second, more fundamental reason, is the inability of the study model to account for "intervening opportunities". In peripheral areas, the 'pull' forces of other universities will cause the actual interaction to fall off at a greater rate than the estimated interaction. In order to consider this effect, the study would be forced to consider a multiple university setting. A thorough consideration of intervening opportunities is beyond the scope of this study. Therefore a more proximate sub-set of the original zones was selected.

(iii) Variable Measurement

Six items of information were coded for each of the 754 observations. They included the individual's zone, occupation, start date, and indicated whether the individual was a permit holder, student renter, or part-time student. The data were provided from two print-

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2. An opposometer is an instrument used in cartography to measure map distances.

outs. Since data were not readily accessible, the choice of variables was largely a function of their availability.

Part-time staff who were currently employed could not be distinguished from part-time staff who were no longer employed. Therefore only full-time staff and faculty could be reliably represented.

Knowledge of residential tenure was essential to the investigation. Since this information was not directly available, a surrogate measure was used. In the 1976 student directory, students having one address were treated as students who lived at home. Students having two addresses were thought to be living away from home and commuting from a rented dwelling.

Since the above variable (rent vs. stay at home) was used in modelling zonal attractiveness, it was important to ensure that this variable did not lead to "bogus calibration". Batty (1976, p. 138) states that, "a perfect distribution of activity will occur if that activity is allocated in proportion to a measure of attraction based on the same variable which is being allocated".

For example, it would be incorrect to distribute students to a zone if zonal attractiveness was based on the number of students living in that zone. The function of the attractiveness factor is to incorporate a spatial variable which is not influenced by the spatial distribution of people or goods being distributed. Such a factor should account for the differing ability of residential zones to attract trips. While the variable used in this study has definite spatial trends, positive relationships between zonal attractiveness and zonal proximity are coincidental rather than consistent.

Zonal attractiveness data were available from two sources. The post office provided information for three digit zones which separated numbers of "households" from numbers of "apartments". (Direct Mail Household Directory, 1975). A more pertinent source of information was available from the census. Census information allowed a zonal breakdown of tenant occupied and owner occupied households. (Census 95-709). The latter information was collected and coded. When extreme problems of boundary interpretation arose the post office information was used as a surrogate. Problems in this respect arose in Dundas, Dundas Township, and Ancaster Township.

CHAPTER 5

THE ANALYSIS OF MEAN TRIP LENGTH

In this chapter the hypotheses of Chapter 2 are investigated. Each of the five variables is discussed in turn. The trip length hypotheses investigated in this chapter are:

(i) The higher one's occupational rank, the closer one's location with respect to the university.

(ii) Parking permit holders will average a greater trip length than non-permit holders.

(iii) Full-time students who rent their accommodation will average considerably lower trip lengths than students who stay at home with parents.

(iv) Part-time students will average higher trip lengths than full-time students.

(v) The longer a staff or faculty member has worked for the university, the closer he will locate to the university.

(vi) The longer a renting student has attended McMaster, the futher he will locate from the university.

In addition, frequency distributions and cross-tabulations are occasionally used to describe the data more fully. The first section, occupation, includes a discussion of analysis of variance and explains the F-statistic used to determine significance levels for more of the hypotheses.

(i) Occupation

Table 5-1 outlines the sample distribution of the eleven occupational groups included in the sample. The table shows that the sample corresponds fairly well to the actual distribution.

TABLE 5-1 OCCUPATION BREAKDOWN (2)

Occupation Group	SAMPLE		ACTUAL	
	ABSOL.	REL.%	ABSOL.	REL.%
FACULTY	52	6.9	813	4.9
Professors	18	2.4		
Associate Professors	14	1.9		
Assistant Professors	20	2.7		
STAFF	93	12.3	1,620	9.7
Administration	11	1.5		
General Staff	59	7.8		
Hourly	23	3.1		
ALL STUDENTS	609	80.7	14,263	85.4
Undergraduate	420	55.7	8,610	52.0
Graduate	74	9.8	4,116	24.7
Adult Degree Studies	84	11.1		
Certificate Extension	31	4.1		
Total	754		16,696	

Average trip length varied significantly among different occupational groups. Table 5-2 shows the average trip length in both straight line distance and network travel time. The overall significance of the relationship between mean trip length and occupation is acceptable by conventional standards. However, whereas the 'whole' is significant it was not always possible to prove that the mean trip length of an individual occupation was significantly greater than that of another.

TABLE 5-2 OCCUPATION : MEAN TRIP LENGTH (1)

*Standard Deviation

GROUP	COUNT	STRAIGHT LINE DISTANCE MEAN (miles)	* σ	TRAVEL TIME MEAN (minutes)	* σ
Administration	11	4.85	8.9	12.68	13.4
Clerical	59	4.44	6.1	12.12	9.4
Hourly	23	3.02	1.8	11.17	5.6
Professor	18	4.60	6.1	12.68	13.4
Associate Professor	14	6.65	12.0	12.81	8.5
Assistant Professor	20	8.98	13.9	17.64	17.6
Undergraduates	420	6.02	10.7	14.11	13.6
Graduates	74	9.26	13.8	17.63	17.0
Adult Degree Studies	84	9.81	9.4	22.10	13.1
Certificate Extension	31	11.83	13.2	23.66	17.0
Student Employees	59	8.45	13.7	15.68	16.7
TOTAL	813	6.94	-	15.51	-

OVERALL STRAIGHT LINE MEAN TRIP LENGTH SIGNIFICANCE = .004
OVERALL TRAVEL TIME MEAN TRIP LENGTH SIGNIFICANCE = .000

Overall significance compares the ratio of "between" group sum of squares to "within" group sum of squares for all groups. Mathematically, the overall significance estimate can be expressed:

$$F = \frac{N \sum_{i=1}^{k} (\bar{x}_{i.} - \bar{x}_{..})^2 \Big/ (k-1)}{\sum_{i=1}^{k} \sum_{j=1}^{n} (x_{ij} - \bar{x}_{i.})^2 \Big/ k\ (N-1)} \qquad (5\text{-}1)$$

The numerator represents the "between" group's sum of squares (divided by degrees of freedom) while the denominator represents the "within" group's sum of squares (divided by degrees of freedom). The between group sum of squares represents the variability of group means from the grand mean. Within group sum of squares measures the variance of the elements of a group from their group mean in each group. The resulting F statistic can be used to find the probability of making a type one error. A type one error is the error committed by rejecting the null hypothesis when it is correct. In this example, the null hypothesis states that the mean trip lengths of all occupational groups are equal. The overall significance of .000 indicates that we can reject this hypothesis with minimal uncertainty. In this study it was possible to say that in general, mean trip length varies significantly among different occupations.

However it is a completely different question to ask whether the mean trip length of one particular occupation is significantly greater than the mean trip length of another occupation. To test the strength of individual comparisons analysis of variance was used to compare selected occupations. F - Tests for hypothesized relationships revealed that on an aggregated level, the occupational classes showed significant differences in mean trip length. Table 5-3 shows the mean trip lengths for aggregated occupational groupings.

TABLE 5-3 OCCUPATION : MEAN TRIP LENGTH (2)

Table's overall F Probability .023

	NUMBER	MILES	MINUTES
STAFF	89	4.32	12.49
FACULTY	46	6.99	16.22
UNDERGRADUATES	411	6.14	14.42
GRADUATES	73	9.38	17.87

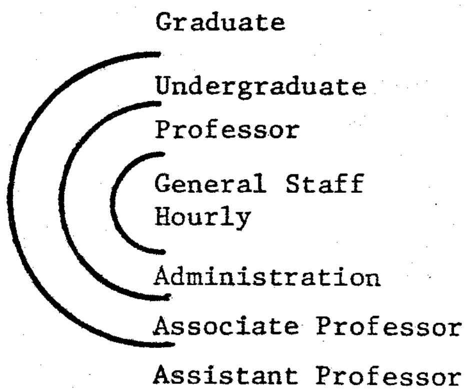
Selective analysis revealed that Graduates had a significantly greater trip length than either Staff or Undergraduates. Undergraduates had significantly greater trip length than Staff. Selective testing could not establish a significant rank for Faculty.

In Chapter 2 it was suggested that mean trip length might exhibit an inverse relation to occupational status. McMaster occupies a peripheral urban location nearby to a wide variety of land use. Within three miles of the university one finds both upper middle class housing and higher density low rent housing.

The general distribution of occupational groups does not illustrate any clear relationship to distance. Figure 5-1 illustrates the mean trip length of various groups through a series of concentric rings.

FIGURE 5-1

Concentric Ring Distribution of Occupations



Associate and assistant professors tend to reside in Burlington.

(ii) Parking Permit Ownership

Table 5-4 shows the difference between percentage of sector owning permits as determined in the sample and compares this to the parking department estimates. According to the Table, the sample overestimated the proportion of graduates holding permits but underestimated every other group.

TABLE 5-4 OCCUPATION : SAMPLE COMPARISON TO ACTUAL PARKING PERMIT OWNERSHIP

OCCUPATION	Percentage of Sector Holding Permits	
	SAMPLE	ACTUAL
Staff	37%	46%
Faculty	35%	66%
Graduates	25.7%	16%
Undergraduates	24.5%	28%

While the sample is bound to exhibit some inaccuracy, part of the error may stem from the use of only full-time faculty and staff in the sample. It is not of paramount importance that the sample percentages be proportional to actual sector percentages. As long as each group is adequately represented, hypotheses regarding mean trip length, group status, and parking permit ownership will remain testable.

In Chapter 2 we hypothesized that parking permit holders would average a significantly higher mean trip length than non-permit holders. Rather surprisingly, the trip lengths of these two groups were almost exactly the same: approximately 7 miles or 16 minutes. The difference in mean trip length between permit holders and non-permit holders was not significant. However, since part-timers will tend to pull up the mean trip length for the non-permit holder group, the analysis was carried out again after this group had been omitted. The results of this measure proved slightly more successful. It is possible to say with reasonable certainty ($\alpha = 0.05$) that permit holders average a greater mean trip length than non-permit holders. Only full-time students and staff were considered. Full-time staff, faculty and students holding permits averaged a mean trip length of 6.7 miles or 16.7 minutes. The non-permit holders of this full-time group averaged 5.4 miles or 12.6 minutes. The F - level significance was .001 for travel time but only 0.182 for straight line distance.

Travel time is more significant than straight line distance because the predominant stay at home group is better represented by travel time. The relationship between travel cost function and residential tenure becomes clearer in Chapter 6.

Earlier in the paper Figure 2-1 illustrated colinearity between occupational status and parking permit ownership. In order to determine how strongly occupation and parking permit status were correlated, the Chi-square statistic was calculated. Table 5-5 shows the breakdown by occupation and parking permit ownership. The chi-square significance indicated that parking permits are not distributed equally among all occupational groups.

TABLE 5-5 PARKING PERMIT OWNERSHIP BY OCCUPATION

OCCUPATION	NO PERMIT	PERMIT	TOTAL
Administration	5 (45.5%)	6 (54.5)	11
Salaried Staff	38 (64.4%)	21 (35.6)	59
Hourly Staff	16 (69.6)	7 (30.4)	23
ALL STAFF	59 (63%)	34 (37%)	93
Professor	12 (66.7)	6 (33.3)	18
Associate Prof.	9 (64.3)	5 (35.7)	14
Assistant Prof.	13 (65.0)	7 (35.0)	20
ALL FACULTY	34 (65%)	18 (35%)	52
Graduates	55 (74.3)	19 (25.7)	74
Undergraduates	317 (75.5)	103 (24.5)	420

Chi-Square significance = .0001

Since the chi-square statistic supported the observed colinearity between permit ownership and occupation, it is important to control occupation by parking permit status and determine whether occupational groupings have the same mean trip length ordering, regardless of permit ownership.

Table 5-6 shows the relationship between occupation and permit ownership when only permit holders are considered. Table 5-7 shows the relationship when only non-permit holders are selected.

In general, occupational groupings do have the same mean trip length ordering regardless of permit ownership. Staff live closer to campus than any other group. Faculty do not exhibit a significant rank in either Table 5-6 or Table 5-7. However, as illustrated before,

TABLE 5-6 PERMIT HOLDERS

Occupation	Number of Respondents	Average Travel Time (Minutes)	Average Distance (Miles)
10 Staff	32	13.0	4.1
11 Faculty	18	17.0	8.1
12 Undergraduates	102	17.6	7.0
13 Graduates	19	18.8	9.6
TOTAL	171	16.8	6.9

TABLE 5-7 NON - PERMIT HOLDERS

Occupation	Number of Respondents	Average Travel Time (Minutes)	Average Distance (Miles)
10 Staff	57	12.2	4.5
11 Faculty	28	15.7	6.3
12 Undergraduates	309	13.4	5.9
13 Graduates	54	17.5	9.3
TOTAL	448	13.9	6.1

the professor sub-group has a small mean trip length which is similar to staff while associate and assistant professors exhibit a longer trip length similar to those of students.

(iii) Residential Tenure

In Chapter 2 we hypothesized that renters would locate much closer to the campus than stay at home students. In fact the difference was very pronounced and highly significant. The significance level was greater than 0.001. The renter group possessed a mean trip length of 1.73 miles or 6.21 minutes. The stay at home group averaged a trip length of 9.41 miles or 19.88 minutes.

Even when the ninety on-campus residents were omitted from the analysis, the results revealed highly significant differences in mean trip length for the two groups. In the analysis excluding campus residents, the renter group averaged 3.80 miles or 10.48 minutes. The stay at home group remained the same at 9.41 or 19.88 minutes. These results were significantly different with only a .001 chance of making a type one error.

It is of interest to compare these findings to Table 5-8 which breaks down permit ownership according to rent/stay at home status. The table indicates that student renters are not the predominant permit holders in the student group.

TABLE 5-8

Status	Rent		Stay at Home	
Permit holder	28	16%	93	30%
No permit	147	84%	216	70%

X^2 = .0009 = Chi-Square Significance

(iv) Part-Time vs. Full-Time Student Status

It was also hypothesized that part-time students would average higher mean trip lengths than full-time students, staff, and faculty. Through analysis of variance, this hypothesis was confirmed. The probability of making type one error was less than .001. The mean trip length of part-time students was 10.76 miles or 22.16 minutes. The mean trip length of full-time students and staff was much lower at 5.85 miles or 13.74 minutes.

(v) Duration of Service

It was hypothesized that staff and faculty would tend to locate closer to the university as duration of service increased. The Pearson's R (correlation coefficient) was low at .0853. The significance was also low at .163. Therefore, with cross sectional data, there does not appear to be any tendency for staff and faculty to locate closer to the campus as duration of service increases.

It was also hypothesized that students would show a tendency to move away from campus or decentralize with increasing duration of study. This hypothesis was first tested using the whole sample. Using the Pearson correlation coefficient, the statistic remained low at -.1019 with a significance level of .013. For the sample as a whole, there is a slight tendency for students to move further from the university as duration of study increases. As mentioned in Chapter 2, one might expect the trend towards student decentralization to be much stronger with the "renter" group than with the "stay at home" group. When the test was controlled for renters only, the correlation coefficient remained poor at -.0916 with a significance of .022.

Table 5-9 shows the results of controlling for the renter group.

TABLE 5-9 MEAN TRIP LENGTH VS. DURATION OF STUDY FOR STUDENTS WHO RENT

Duration of Study	Number	Average Straight-Line Distance (miles)	Standard Deviation
1 year	51	.9468	1.2582
2 years	46	1.8721	5.9673
3 years	33	1.8243	6.9730
4 years	29	2.2572	7.3963
5 years	5	3.0840	2.4680
6 years	8	2.3307	2.3862
8 years	2	2.5360	3.3036
12 years - 14 years	1	4.1260	-
Total	172	1.73	

There is a slight tendency for renters to decentralize over time. However, the trend is certainly weak and cannot be regarded as in important characteristic of the McMaster commuting distribution.

CHAPTER 6

MODELLING AND CALIBRATION ANALYSIS

In this chapter, the spatial-interaction modelling framework is used to investigate the hypothesis that separation of the respondents into two commuter groups would improve the model fit. The two commuter groups are students who commute from rented accommodation and students who commute from the home of parents. The only qualitative difference between the aggregate and disaggregate approaches is the attractiveness term. In the aggregate model, the number of households is used to model zonal attractiveness. In the disaggregate procedure, attractiveness is equated to the number of rentable households for the renter group while owner occupied dwellings are associated with the stay at home group.

The model which we are using is the production-constrained model. In this example, we have only one destination: McMaster University. The disaggregate production-constrained model can be written:

$$Tij^{k} = Bj^{k}\ Wi^{k}\ Dj^{k}\ (e^{-\beta\, cij^{k}}) \qquad (6\text{-}1)$$

In this model k is specific to either renter or stay at home population.

The object of model calibration is to arrive at a value of beta (β) which most accurately facilitates a reproduction of the actual distribution of trips. With the exception of beta, all of the parameters in (6-1) are either given or directly calculable from the data.

Beta is the only parameter which is not known. The Newton-Raphson method is a procedure for non-linear optimization and is therefore suited for calibration where the unknown is an exponent. In this method a new value for beta is calculated on the basis of mean trip length statistics. The Newton-Raphson method calculates a new value for beta where:

$$\beta_2 = \beta_1 - \frac{F(\beta_1)}{F^1(\beta_1)} \qquad (6\text{-}2)$$

In equation (6-2), $F(\beta_1)$ is a function which measures the difference between two contiguous[1] estimates of mean trip length and divides this difference by an arbitrarily small increment.

$$F(\beta_1) = \frac{(\text{Predicted Mean Trip Length})_n - (\text{Pred. Mean Trip Length})_{n+1}}{(1.0 / e^{30})} \qquad (6\text{-}3)$$

$F^1(\beta_1)$ is a derivative approximation which measures the difference between actual mean trip length and calculated mean trip length in the current iteration.

$$F^1(\beta_1) = \mu\,\text{act.} - \mu\,\text{est.}\,(\beta_1) \qquad (6\text{-}4)$$

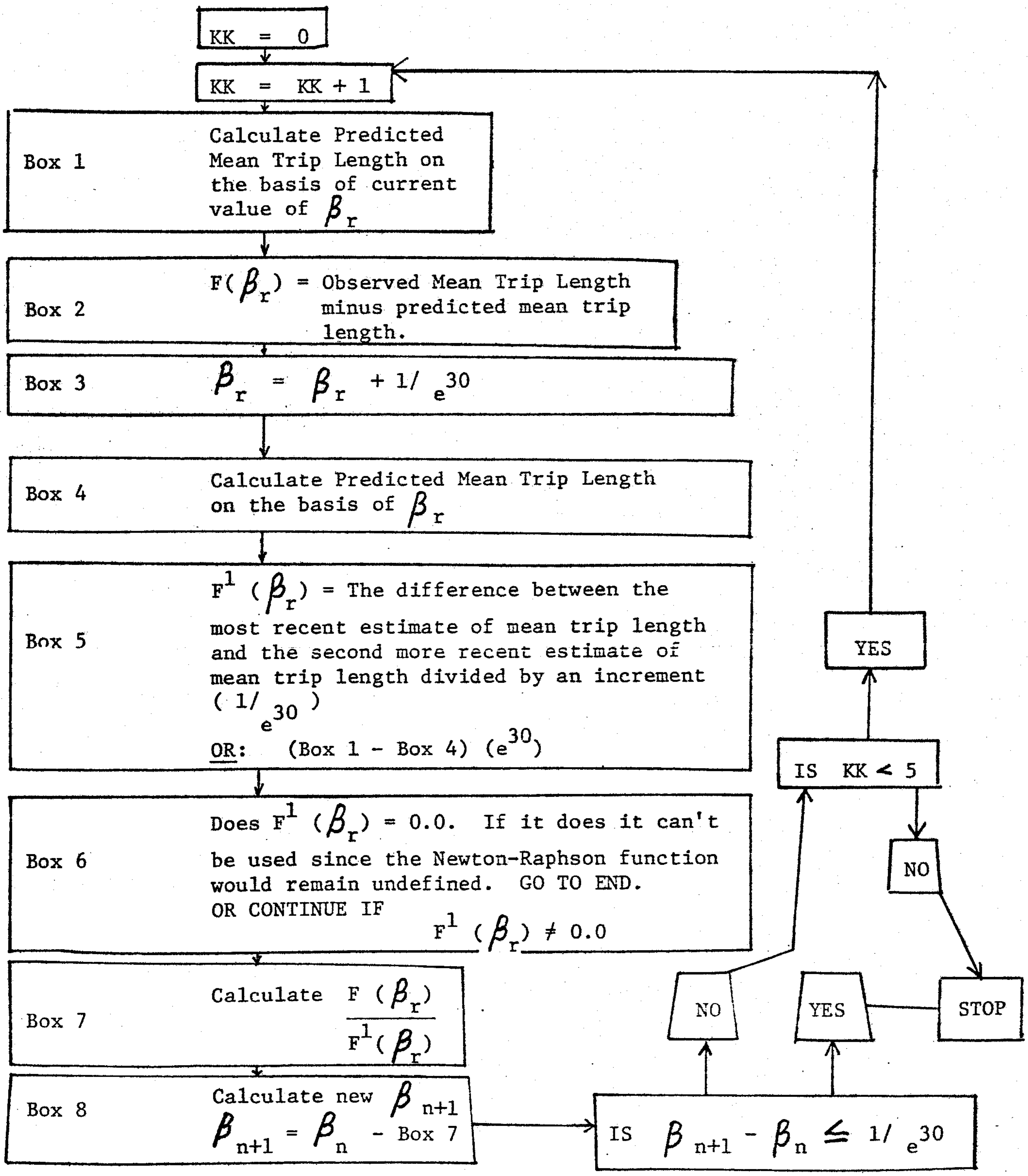
The following alogorithm proceeds to outline the process of cali-

---

1. "Contiguous estimates" from neighbouring iterations, n and (n+1).

bration adopted in this study. The model was modified from Batty's work in Waterloo (1975) for the singly constrained problem with one destination.

FIGURE 6 ALGORITHM OF NEWTON-RAPHSON METHOD



(i) Goodness of Fit

There are some additional summary statistics whose purpose it is to determine the variance between observed and predicted trip distributions. In the Fortran programs adopted, this study uses a modified version of TNET 21 (Homburger, 1974). The program reads actual zonal trip interchange figures and translates them into 120 trip length categories. The same is done to the array of predicted trip interchanges. Comparison between actual and estimated trip length frequency distributions is shown in Figures 6-1 through 6-4.

Another important summary statistic is the coefficient of determination. This goodness of fit statistic measures the variation between predicted and actual trip interchange vectors. The coefficient of determination is found using the relation:

$$R^2 = 1 - \frac{\sum_i^N (\hat{t}_{ij} - t_{ij})^2}{\sum_i^N (t_{ij} - 1/N \sum_{ij} t_{ij})^2} \qquad (6\text{-}5)$$

where: R^2 = coefficient of determination
$\hat{t}_{ij}$ = estimated interchange
t_{ij} = actual interchange
N = number of zones

The statistic measures the accuracy of the model by comparing all pairs of actual and estimated interaction for each zone. The value of R^2 ranges from zero to one. The closer the value of R^2 to one, the better the goodness of fit of the model.

(ii) Results

The hypothesis that separation of commuter groups will improve model goodness of fit is substantiated. The goodness of fit is notably improved if the renter group and stay at home group are modelled separately. The coefficient of determination for the aggregate model was 0.59722053. The disaggregate model's combined coefficient of determination was 0.8937. Therefore the separation of the two groups provides a rather striking improvement.

On the disaggregate level the rent group had a coefficient of determination of .95693305. The stay at home group had a coefficient of determination 0.66061991. These statistics are based upon zonal comparison rather than trip length category comparison. Due to the small number of zones, such an approach is more rigorous. These results are summarized in Table 6-1.

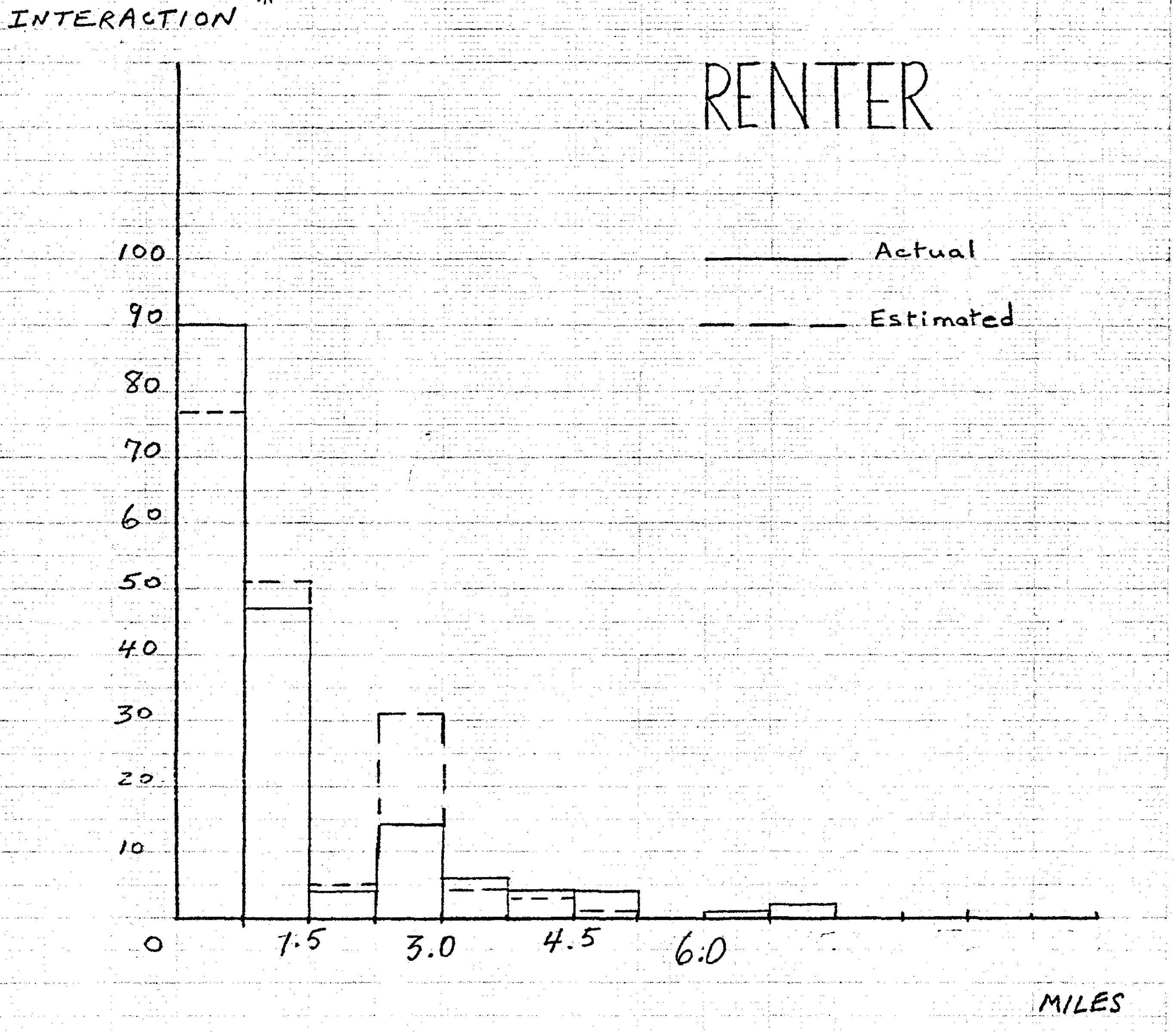
It is useful to represent trip interchange in terms of trip length categories for visual impact. Figures 6-1, 6-2, 6-3, and 6-4 represent the comparisons between actual and calculated distributions for the Renter, Stay at Home, and Whole Sample groups.

Figure 6-1 illustrates the distribution for the renter group. While interaction shows a pronounced distance decay, the irregularity of rental supply over space is also having a marked affect on the distribution.

Likewise, Figure 6-2 shows the distribution of the stay at home group. The distribution has a pronounced lack of distance decay within the study area. This is explained by the tendency for owner

SAMPLE TRIP LENGTH DISTRIBUTION
VS.
ESTIMATED TRIP LENGTH DISTRIBUTION

FIGURE 6-1



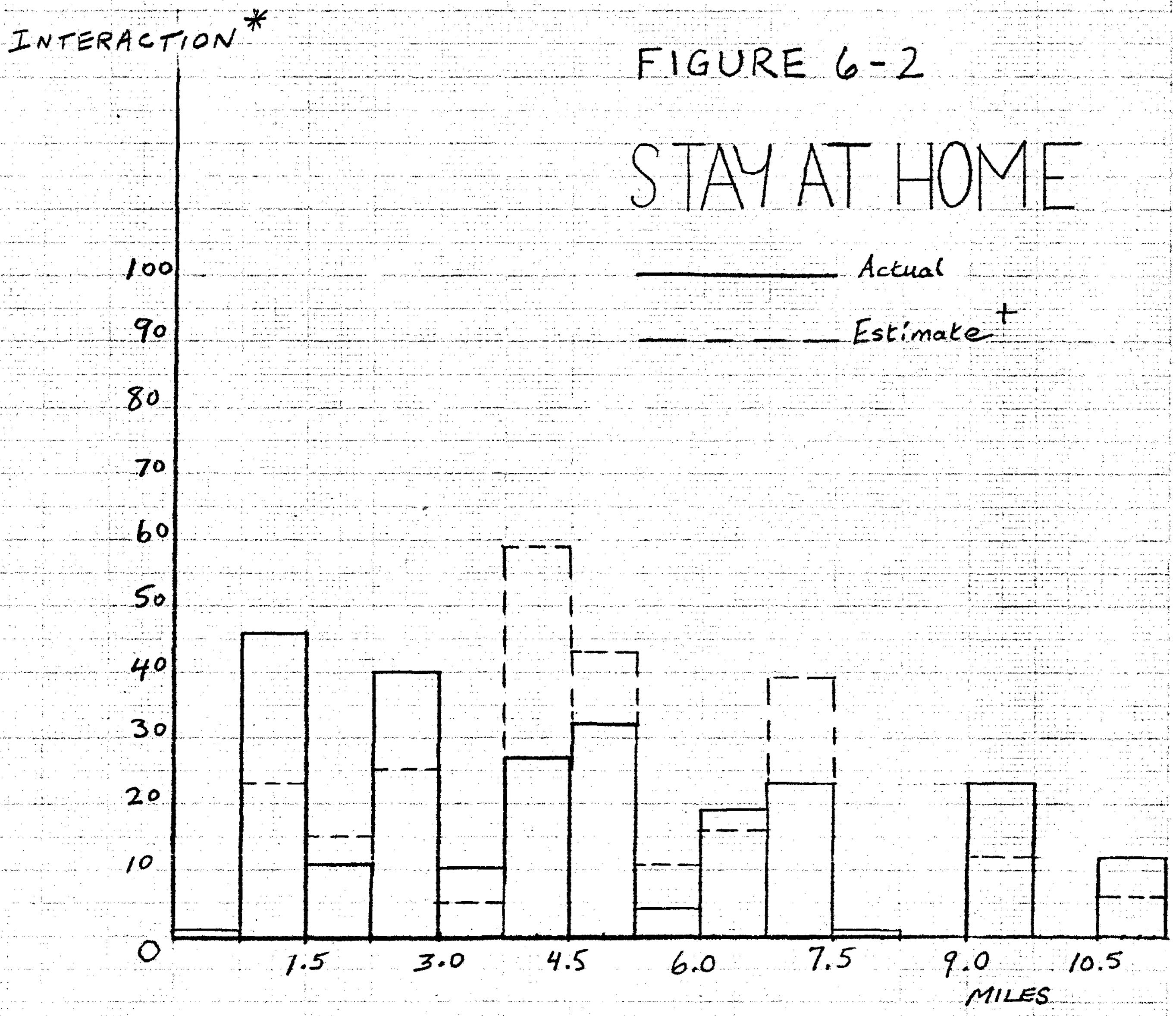
INTERVAL = 0.75 MILES

* IN ORDER TO CONVERT THESE FIGURES TO "TRIPS PER PEAK PERIOD" ONE MUST BE PREPARED TO ASSUME THAT COMMUTERS ARE COMING IN THE PEAK PERIOD. (NIGHT STUDENTS HAVE NOT BEEN INCLUDED). INTERACTION DOES NOT INCLUDE MEDICAL CENTRE EMPLOYEES.

SAMPLE TRIP-LENGTH DISTRIBUTION
VS
ESTIMATED TRIP-LENGTH DIST.

FIGURE 6-2

STAY AT HOME



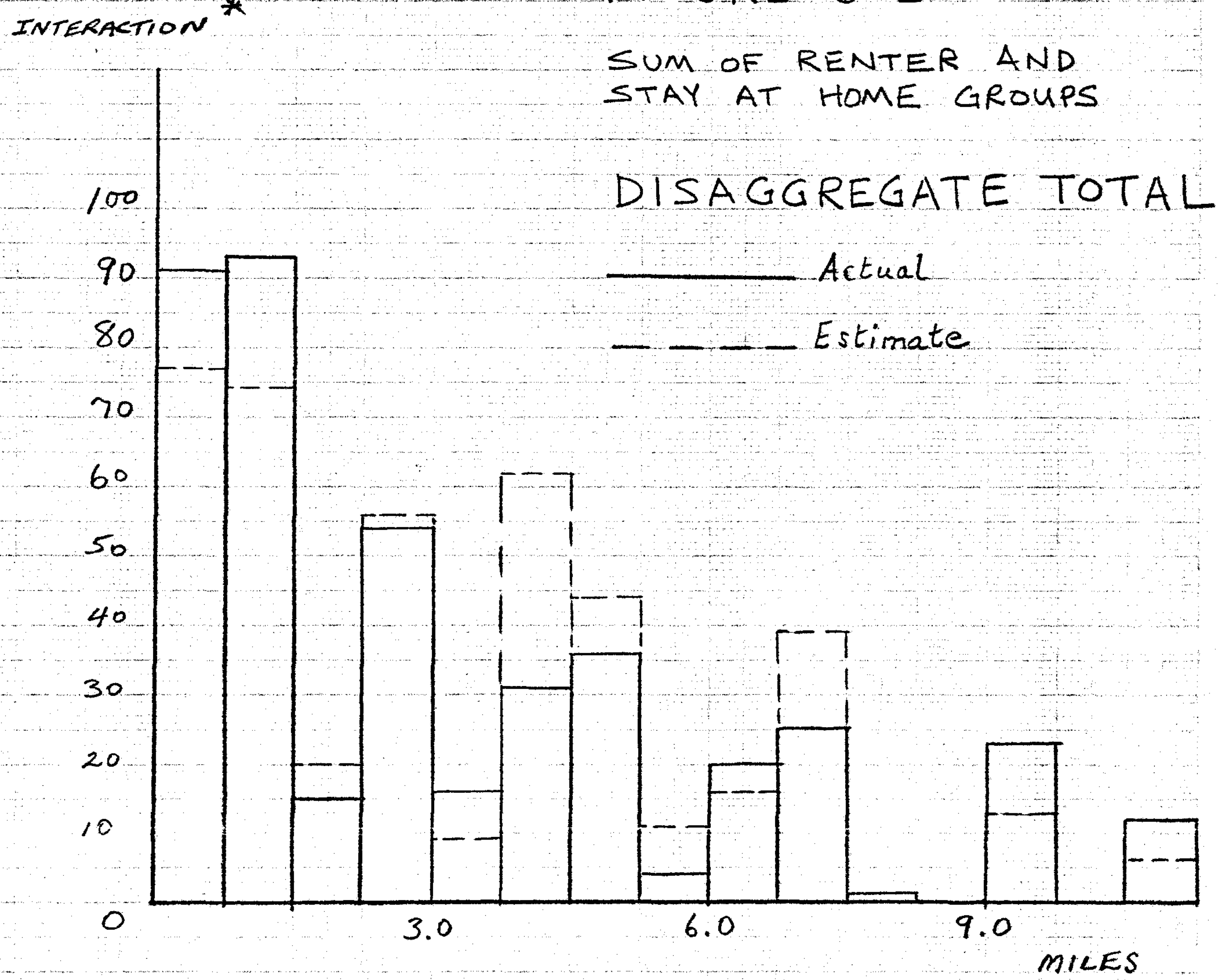
* SEE FIGURE 6-1

\+ ESTIMATE IS POOR BECAUSE EUCLIDEAN DISTANCE USED.

SAMPLE TRIP-LENGTH DISTRIBUTION
VS.
ESTIMATED TRIP-LENGTH DISTRIBUTION

FIGURE 6-3

SUM OF RENTER AND
STAY AT HOME GROUPS

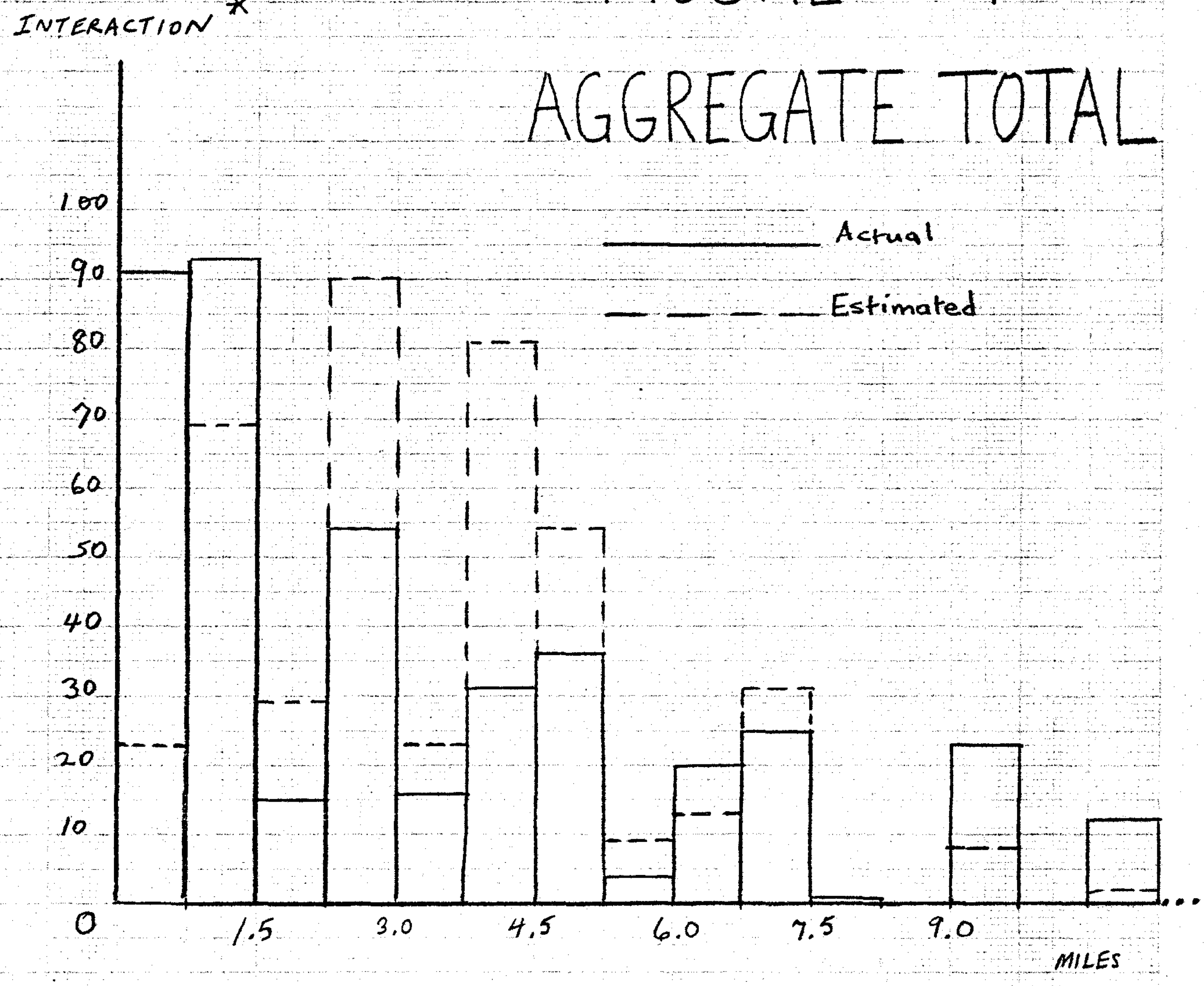


* SEE FIGURE 6-1

SAMPLE TRIP-LENGTH DISTRIBUTION
VS.
ESTIMATED TRIP-LENGTH DISTRIBUTION

FIGURE 6-4

AGGREGATE TOTAL



* SEE FIGURE 6-1

occupied tenancy to come from more peripheral locations.

Figures 6-3 and 6-4 show the distributions resulting from a disaggregate and aggregate approach respectively. Clearly Figure 6-3 has the better fit while Figure 6-4 is typified by large differences between actual and observed trip length.

TABLE 6-1 EUCLIDEAN TRAVEL COST FUNCTION

Calibrated Beta Values

Run Name	N	Beta	R^2	Mean Trip Length
Aggregate Model	435	.344231	.59722053	3.48363 miles
Renters	172	1.186035	.95693305	1.01159 "
Stay at Home	263	.155312	.66061991	5.06990 "
Disaggregate Total	435	Not applicable	.8937	3.46523 "

The values of beta in Table 6-1 are consistent with the hypothesis advanced earlier regarding mean trip length and residential tenure. A low mean trip length for the renter group results in a high value for beta. Likewise a high mean trip length for the stay at home group results in a low value for beta. Predictably, the aggregate model had an intermediate value for beta and was strongly pulled towards the value of the dominant stay at home group.

Table 6-2 shows the results of the analysis when travel time is used instead of euclidean distance. While in Table 6-1 it is apparent that euclidean distance gives a higher R^2 value to the renter group, Table 6-2 indicates that automobile travel times give a higher R^2

value to the stay at home group.

TABLE 6-2 TRAVEL TIME COST FUNCTION

Calibrated Beta Values

Run Name	N	Beta	R^2	Mean Trip Length
Aggregate Model	435	.15223	.59025363	11.16640 minutes
Renters	172	.418935	.79968111	5.38958 "
Stay at Home	263	.091862	.80032068	14.94440 "
Disaggregate Total	435	Not applicable	.8001	11.16640

When auto travel time was used, the stay at home group improved from an R^2 value of .6606 in Table 6-1 to an R^2 value of .8003 in Table 6-2. Similarly the renter group had an R^2 value of .9569 when straight line distance was used but this dropped to .7997 when travel time was employed.

In the second chapter of this report we predicted that automobile travel times would more accurately represent the longer distance commuter while straight line distance would better represent the travel cost of groups, such as student renters, who use public transit to travel over shorter distances. The stay at home group averaged a much greater trip length than the renter group. This group's greater dependence on automobiles explains the tendency for the stay at home group to have the better fit when automobile travel time is being used. Similarly, since the renter group locates nearby to the university, the group exhibits a better fit when straight line distance is employed. The findings indicate that this separation of groups according to travel cost function could improve the fit of the model by almost twenty-five per cent.

CHAPTER 7

CONCLUSIONS

(i) McMaster Parking Department

In the introduction it was suggested that this paper could investigate problems of a practical nature. With respect to parking, this study has endeavoured to determine the distributional characteristics of the commuter. While there has been no attempt to discern the attitudes of commuters towards alternate forms of transportation, the fact that the trip length of parking permit holders is almost the same as non-permit holders indicates that attitudes may be of paramount concern. The only other obvious factor is one's accessibility to bus service. Figure A-1 in the Appendix shows the distribution of parking permit holders. There appears to be a sharp difference in parking permit ownership according to one's access to public transit. This study recommends that the university compile a map showing the residences of all parking permit holders. A geographer or engineer could then proceed to locate the best route for one or two bus lines. Provided the potential ridership was high enough to warrant costs, the university could then make a request to the Hamilton Regional Transportation Committee that this additional passenger line be added to the existing service.

(ii) Hamilton-Wentworth Regional Planning Department

Without a questionnaire it was impossible to examine the daily generation rates of students, faculty and staff. However, the appendix includes all the data regarding the spatial distribution of the sample and measures of attractiveness used to model the 'renters' and 'stayers at home'. While 'daily' generation rates were not investigated, the modelling effort showed how spatial production factors could be included in the trip distribution phase. McMaster is a large enough community that the planning department could monitor its distribution through five-year horizon dates. The model could be exactly the same as that used in this study. Information regarding own/rent status should, however, be included for the whole sample. The University Personnel and Parking Departments could then be solicited to provide and/or collect the information required. In the trip assignment phase, the McMaster trips could be loaded on the network and link loadings for all traffic could be calculated.

(iii) General Conclusions

Many of the trip length hypotheses generated in Chapter 2 were verified. Parking permit holders averaged a higher mean trip length than non-permit holders. However, the degree of this relationship was much less than expected. This suggests that access and attitudes to and towards public transit may be of paramount concern. The fact that 'rent' and 'stay at home' came out so strongly is an indication of the strength of a housing supply consideration when modelling spatial interaction. Other variables such as duration of service or study, occupation and parking permit status did not prove to be very helpful in delineating commuter trends. Occupation was obscured by the tendency towards mixed land use in a peripheral urban area. Duration of service was not spatially significant because both long term and short term employees are locating close to the university. However, the analysis of variance does not consider direction. Therefore we are implicitly assuming a concentric ring theory of urban growth. The distribution may well be much more sectoral and/or nucleated especially where occupation and length of service are involved. Future modelling research should attempt to build travel cost functions which incorporate notions of direction and integrate this with a zonal attractiveness measure based on commuter group housing preference.

The hypothesis that renters will average a lower mean trip length than those who stay at home is central to this paper. This 'a-priori' hypothesis was verified both on the modelling and the variable levels of analysis. The variable analysis proved to be a useful means of verifying the choice of residential tenure for model disaggregation.

It was hypothesized that staff and faculty would tend to move closer to the university as duration of service increased. This relationship emerged only slightly. Cross sectional data may not reflect such trends accurately. Long duration groups such as administration and professors and many full-time staff are located nearby to the university. However, large numbers of new staff and faculty have also located nearby to the university, thereby offsetting the significance of the hypothesized relationship. One might suspect that the number of staff and faculty living in West Hamilton is increasing absolutely and that the housing turnover is becoming increasingly internalized within the community. It is appropriate that the modelling analysis focussed on the student body. It is the student group, particularly the stay at home group, which puts the most stress on the commuting system and on McMaster parking facilities. Furthermore, Table 5-11 suggests that it is the group of stay at home commuters who will demand increasing parking facilities on campus. The renter group, on the other hand, has a much smaller mean trip length than the stay at home group. This group would appear to be much more dependent on public transit and therefore less of a problem for the McMaster Parking Department.

Part-time students averaged a much greater mean trip length than full-time students. As suggested in Chapter 2, the location of part-timers is not strongly constrained by the university.

It is interesting that travel time is significant where euclidean distance fails. This is attributable to the fact that the stay at home group is better distributed using an automobile travel time. Seventy per cent of the sample is composed of this group, and therefore mean trip length analysis showed a stronger relationship for travel time than straight-line distance. Renters are distributed more successfully using a straight-line distance measure. The important point is that the rationale for this relationship is qualitative, not quantitative. Travel time was associated with the stay at home group and euclidean distance with the renter group for behavioural reasons.

This qualitative relationship complements the attractiveness term which is disaggregated on the basis of housing preferences between these two distinct commuter groups. Hathaway's suggestion that travel cost should be disaggregated on an areal basis lacks a strong behavioural rationale. This paper, on the other hand, has demonstrated that qualitative disaggregation of zonal attractiveness will result in very significant improvements in goodness of model fit. Inadvertently this paper has also demonstrated that disaggregation of travel cost will bring significant increases in goodness of fit provided the correspondence with the locational variables is strong.

APPENDIX

DATA FOR DISAGGREGATE MODELLING

ZONE**	Euclidean Distance (miles)	Network Distance (minutes)	Census (95-709) Owner Occupied Dwellings	Renter Occupied Dwellings	Total Number of Households	Renter Scaled* Sample Interchange	Stay at Home Scaled* Sample Interchange	Total Scaled* Sample Interchange
1. L9G	4.176	16.725	3080	300	3380	0	155	155.4
2. L9H	2.207	12.1	3085	1245	4330	89	244	333
3. L8S	0.945	5.0	3850	2715	6565	1043	1021	2065
4. MAC	0.2	-	-	1700	1700	1998	22	2020
5. L8P	2.411	7.275	3230	7190	10420	178	577	755
6. L8R	2.353	9.85	1815	1995	3810	133	311	444
7. L8L	4.361	14.671	7732	5440	13172	44	200	244
8. L8H	6.861	21.34	7270	4670	11940	0	133	133
9. L8E	9.247	30.57	1295	1562	2857	0	44	44
10. L8G	9.545	31.36	710	633	1343	0	67	67
*** 12. L8M	4.872	15.825	3182	2895	6077	89	311	400
13. L8N	3.381	11.8	1223	3813	5036	133	222	355
14. L9C	4.713	14.814	4896	739	5635	0	266	266
15. L9A	4.126	15.833	5178	2276	7454	44	244	289
16. L8V	4.997	19.2	4375	3162	7537	0	89	89
17. L8T	6.09	22.0	4315	1983	6298	22	377	400
18. L8W	6.563	22.5	685	215	900	0	22	22
19. L9B	6.364	18.767	602	164	766	0	22	22
20. L7T	7.159	15.1	3110	910	4020	22	155	178
21. L7S	9.148	20.9	850	1335	2185	0	67	67
22. L7R	9.645	20.9	2375	2565	4940	0	178	178
23. L7N	10.939	20.9	1995	915	2910	0	133	133
24. L7L	13.026	23.433	4825	700	5525	0	200	200
25. L7M	10.838	20.5	180	45	225	0	89	89

continued on next page

ZONE**	Euclidean Distance (miles)	Network Distance (minutes)	Census (95-709) Owner Occupied Dwellings	Renter Occupied Dwellings	Total Number of Households	Renter Scaled* Sample Interchange	Stay at Home Scaled* Sample Interchange	Total Scaled* Sample Interchange
26. L7P	9.35	20.5	2185	825	3010	0	155	155
27. Ancaster Twp.	7.89	23.38	545	70	615	0	22	22
28. Glanbrook	10.85	35.7	2230	285	2515	0	44	44
29. Rural Dundas	4.74	13.4	500	100	600	0	44	44
30. Grimsby	19.50	39.95	3400	1060	4460	0	89	89
31. Saltfleet	13.02	35.47	4025	840	4865	0	22	22
32. West Flamboro	5.52	21.0	1925	310	2235	0	44	44
33. Waterdown	5.92	13.40	1770	415	2185	0	44	44
***11. L8K	7.358	23.7	6080	2645	8725	22	222	244

*Due to the relatively small size of the sample (N = 754), small towns like Lynden, Freelton, and even Ancaster, are bound to be underestimated. The figures in this column were scaled by a factor of 22.2 from a 4.5% sample.

**Equivalencies to Census Tracts provided upon request.

***This line omitted previously, see p. 56

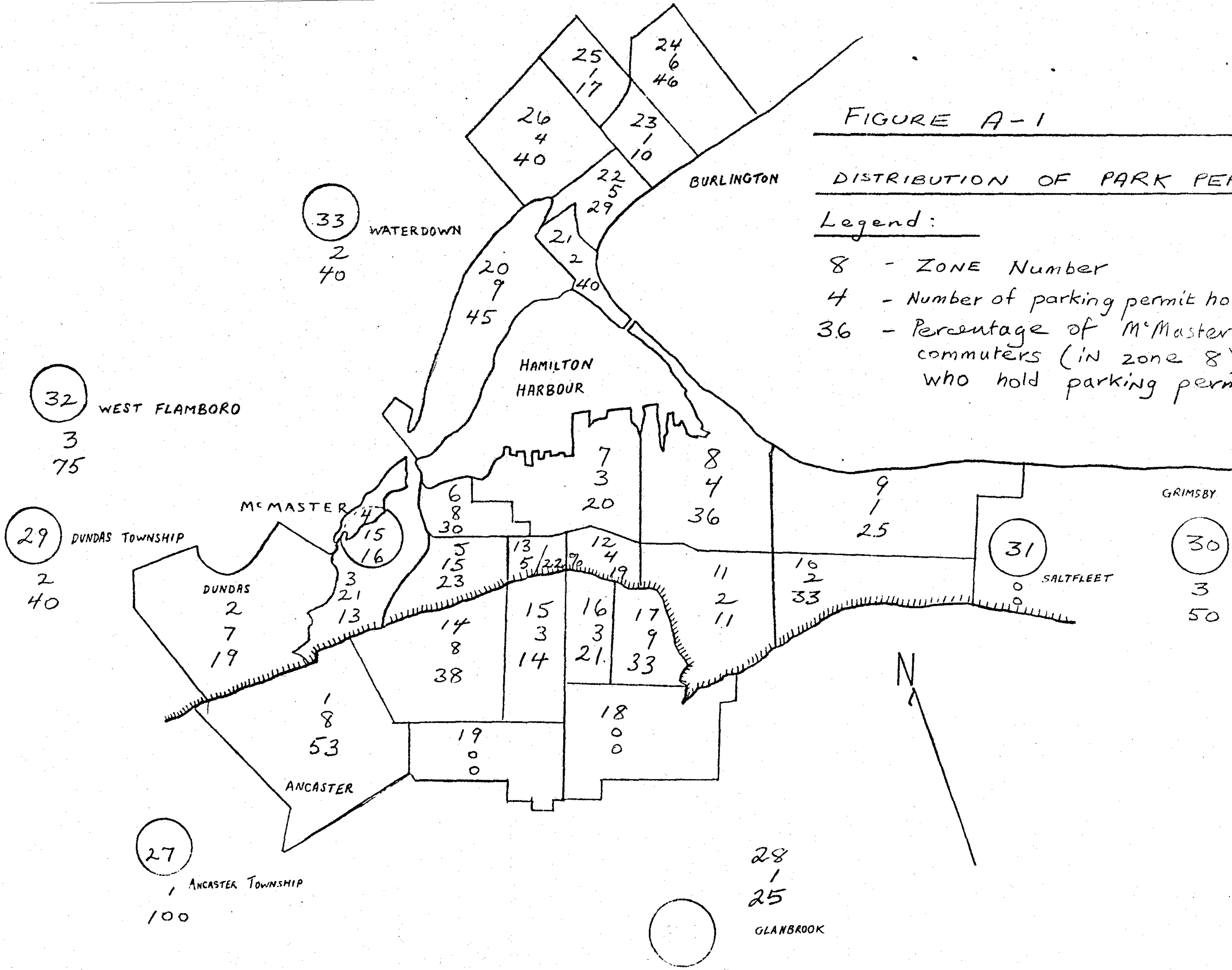


FIGURE A-1

DISTRIBUTION OF PARK PERMIT

Legend:

8 - ZONE Number

4 - Number of parking permit holders

36 - Percentage of McMaster commuters (in zone 8) who hold parking permits.

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