OCCUPATIONAL STRATIFICATION OF URBAN WORK-TRIPS IN METROPOLITAN ADELAIDE, 1971

BY

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This thesis embodies the results of supervised project work making up two-thirds of the work for the degree.
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To the best of the candidate's knowledge and belief, this thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

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SUMMARY

This study examined the suitability of the gravity-based formula for trip distribution which was proposed by the U.S. Bureau of Public Roads (1965) for use in modelling the journey to work in Adelaide in 1971. The BPR formula was developed into a computer programme which can be calibrated for data on trips between the Local Government Areas of Adelaide.

The model was assessed as a predictor of all work-trips then the trip data was separated into male/female and several occupational categories each of which was modelled separately. The accuracy of prediction for each category was assessed then the predicted numbers of trips were aggregated to assess the benefit of separately modelling several categories of worker.

The major findings of the study were:

(1) Actual patterns of trip distribution can be modelled to a very high level of correlation by the Gravity Model; provided reliable data is available on travel-times; and numbers of trips originating and terminating per zone.

(2) Numbers of trips to the CBD can be reliably estimated by the Gravity Model;

(3) Outer suburbs cannot be modelled as accurately as the more stable inner suburbs;

(4) Small increases in accuracy of modelling can be created by separation of data into occupational categories; and

(5) Commonly used goodness-of-fit statistics such as chi-squared values are not reliable indicators of the accuracy of a model. Correlation analysis proved to be a most useful measure of

goodness-of-fit and high levels of correlation were found between square roots of observed and estimated numbers of trips.

It was also noted that:

Workers in different occupations and different sexes can have noticeably different work-trip distributions, but the gravity model can be calibrated to replicate a wide range of distributions.

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TABLE OF SYMBOLS

Terms with constant definition throughout this work include:

T_{ij} = number of trips which originate in zone i and terminate in zone j;

P_i = number of trips which originate in zone i;

A_j = number of trips which terminate in zone j;

F_{ij} = factor which expresses the deterrence effect of zonal separation on the number of trips;

K_{ij} = an adjustment factor included to allow for socio-economic variables not normally included in a trip model.

1. INTRODUCTION

1.1 THE CONVENTIONAL TRANSPORT ANALYSIS PROCESS

The science of modelling future transport needs has been refined to a standard procedure which is commonly referred to as the conventional Transport Analysis Process. This procedure consists of the following clearly-defined though not independent steps:

(1) Analysis and prediction of present and future land uses;

(2) Generation of numbers of trips produced by or attracted to these land uses;

(3) Distribution of these numbers of trip-ends to individual zone-to-zone movements;

(4) Division of numbers of zone-to-zone trips between different modes of transport; and

(5) Assignment of the trips to various routes on the appropriate transport networks.

This study is concerned with step (3) which is referred to as the "Trip Distribution Phase".

1.2 THE TRIP DISTRIBUTION PHASE

The object of the trip distribution phase is to distribute the known number of trips produced in each origin zone between all the destination zones in such a way that each zone receives the known number of attracted trips.

Many mathematical formulae, known as "trip distribution models', have been developed to perform this distribution. This study has concentrated on a type of trip distribution model known as the gravity model which is based on the principle that the number of trips between two zones will be proportional to the size of each zone and inversely proportional to some function of the distance between the two zones.

The trip distribution phase involves "calibration" of the selected model: determination of constants of proportionality and the form of the function of distance which are appropriate for the selected data. To do this it is necessary to obtain a known distribution of trips for the study area and develop an iterative procedure which successively alters the parameters of the model until it produces a distribution similar to the known distribution.

Methods of assessing the degree of similarity have varied widely throughout the literature. This study examined a new method of assessment as well as using some standard statistics. Throughout the study the numbers of trips produced by the model are referred to as "predicted" or "synthetic" numbers and the values obtained from the census data are referred to as "observed" or "actual" values. Much of the study involves comparison of the predicted and observed numbers of trips using statistics for "goodness-of-fit".

1.3 THE MODAL SPLIT PHASE

The division of numbers of trips between private and public transport is known as the "modal split phase". There has been much discussion about the appropriate stage at which to perform this phase. The decision-making process which the transport analyst hopes to model involves the simultaneous decision by the potential trip maker of three things: (i) whether to make a trip, (ii) where to travel to, and (iii) what form of transport to use. Given that each of these decisions must be modelled separately the point of conjecture is whether it is more appropriate to model the destination decision before or after the choice of transport mode.

If the modal split is performed before trip distribution it is necessary to calibrate a separate trip distribution model for each mode. According to Hansen (1962) it is then more appropriate to distribute vehicle-trips than person trips. This would involve estimation of car occupancy (generally about 1.3 persons/car) for different areas.

If modal split is performed after the distribution of trips, as recommended by Stopher and Meyburg (1975), only one calibration of the distribution model is required. It is then more appropriate to distribute person-trips than vehicle-trips but this involves the assumption that all trips are made by car or that the relative journey times by all modes are equal.

For this study the available data was in terms of person-trips and the assumption of equal relative journey times in Adelaide involved less error than the calculation of car occupancy values so no modal split was performed.

The modal split phase and the assignment of traffic to the various transport networks throughout the city of Adelaide were beyond the scope of the study and remain as logical extensions of this work.

1.4 AIMS OF THE STUDY

This study involved the development of a particular trip distribution model to the stage where it could be used to replicate the observed data on the journey to work in Adelaide.

The aims of the study were to:

(i) select an appropriate trip distribution model;

(ii) develop a satisfactory procedure for calibration of the model;

(iii) calibrate the model to reproduce the distribution of all trips to work in Adelaide in 1971;

(iv) assess the accuracy of the model's predicted distribution;

(v) separate the journey to work data into male and female and occupational categories, calibrate the model separately for each category and assess the accuracy of the predicted distributions; and

(vi) aggregate the predicted distributions for the separate categories into predictions for all workers, assess their accuracy relative to the accuracy of the prediction in (ii) above and hence determine the value of modelling separate categories of data.

1.5 STRUCTURE OF THE REPORT

The report consists of six chapters after this introduction: Chapter 2 contains a review of some recent literature on the usefulness of the gravity model and differences in travel behaviour between males and females in different occupational categories. Chapter 3 discusses the development of the trip distribution model used in this study and Chapter 4 describes the data used.

Chapter 5 contains a detailed analysis of the accuracy of the trip distribution predicted by the gravity model when calibrated for all workers. Standard measures of accuracy are discussed and a new method for analysis of modelling accuracy is introduced - analysis of correlation.

Chapter 6 examines the ability of the model to replicate the trip distributions of the selected occupational groups of male and female workers. The different calibration parameters and goodness-of-fit statistics obtained for different groups are discussed and compared. Four predicted trip distributions for all workers were calculated by adding the distributions predicted for the separate categories of worker and the comparative accuracy of each of these predictions is discussed to determine the benefits of separating data into categories before modelling the trip distribution.

Chapter 7 presents the final conclusions.

Three appendices give the list of occupations in each category, the fundamentals of the statistical formulae used in the report and a listing of the computer program for calibrating the gravity model together with the results of a calibration of the model for all workers.

2. REVIEW OF LITERATURE

2.0 INTRODUCTION

The essential form of a gravity model is that the traffic (trips) between an origin zone and a destination zone is proportional to the product of the sizes of the two zones and inversely proportional to some function of the separation between the zones. Many such functions have been developed and separation has been measured in many ways.

This chapter reviews some of the models that have been used and the data for which they were calibrated. It then reviews previous work on separation of data into categories and concludes with a brief review of the effects of catagory of occupation in determining residential patterns and distances travelled to work.

The U.S. Bureau of Public Roads (1965) presented a detailed procedure for calibrating the Gravity Model expressed as:

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum_j A_j F_{ij} K_{ij}} \quad . \tag{1}$$

This model, which was selected for use throughout this study, is subsequently referred to as the "BPR model".

2.1 GRAVITY MODELS

Traditionally the transport gravity model was expressed as

$$T_{ij} = k \frac{P_i A_j}{d_{ij}^2} \tag{2}$$

subject to the constraints:

$$\sum_j T_{ij} = P_i \tag{3}$$

$$\sum_i T_{ij} = A_j \tag{4}$$

where k is a constant.

This was analogous to Newton's law of the gravitational force F_{ij} between two masses m_i and m_j separated by a distance d_{ij}, viz.:

$$F_{ij} = G \frac{m_i m_j}{d_{ij}^2} \tag{5}$$

where G is a constant.

Wilson (1967) provided a theoretical justification of the gravity model based on the principles of statistical mechanics. He assumed that the conventional constraints, (3) and (4) above, applied and that a further constraint:

$$\sum_i \sum_j T_{ij} c_{ij} = C \tag{6}$$

could be applied where c_{ij} is the generalized cost of travel between zone i and zone j and C is the total amount spent on transport in the region. Wilson considered the probability of a particular distribution of trips $\{T_{ij}\}$ occurring, expressed it as a function of the number of distributions possible and derived a most probable distribution. This, he refers to as "entropy maximisation". He found that on his assumptions the most probable distributions could be expressed as:

$$T_{ij} = B_i C_j P_i A_j \exp(-\beta c_{ij}) \tag{7}$$

where

$$B_i = [\sum_j C_j A_j \exp(-\beta c_{ij})]^{-1} \tag{8}$$

$$C_j = [\sum_i B_i P_i \exp(-\beta c_{ij})]^{-1} \tag{9}$$

which is an alternative expression for the gravity model and its constraints.

Wilson effectively showed that, given (i) the total number of trip origins and destinations for each zone for a homogeneous person-trip purpose category, (ii) costs of travelling between zones, and (iii) there is some fixed total expenditure on transport in the region, then there is a most probable distribution of trips between zones, and the gravity model when calibrated correctly will replicate this distribution.

2.1.2 Examination of the Gravity Model.

The gravity model has been tested in many cities of various sizes, particularly in the United States. One of the earliest of these tests was described by Voorhees and Morris (1959) who expressed satisfaction with the ability of the BPR Model to reproduce the 1957 traffic in Baltimore, U.S.A.

For work trips, in particular, the size of an attraction zone was measured by the number of people employed in it; the size of a residential zone was measured by its population. Adjustment factors (K_{ij}) were estimated during calibration according to the occupational classes of the home zones.

The accuracy of the model's results were checked by creating screen-lines dividing the Metropolitan Area into large segments and collecting information on place of residence from employees of several large industrial plants: traffic crossing the screen-lines was counted. It was found that the model's predictions were generally correct to within ten percent and it was concluded that existing travel was adequately synthesized.

The following advantages were claimed for the gravity model:

1. It created an understanding of the factors that influence

traffic patterns;

2. It provided a factual basis for plans, and the possibility of effectively testing and evaluating alternatives;

3. Due to effective analysis of factors influencing traffic, the resulting traffic plans were more realistic; and

4. it was inexpensive ($25,000 for the Baltimore study), technically simple and required only a small staff.

Hansen (1962) claimed that the BPR model satisfactorily reproduced existing patterns of travel in Washington D.C. in 1955 when trips were divided by purpose into six groups viz:- home-based to work, to shop, social, to school, miscellaneous, and non-home-based; and the model was applied to each type of trip separately.

He made the modal split after the zone-to-zone distribution of person-movements, rather than construct separate models for public and private transport which would have required determination of the modal-split during the trip generation phase.

Zonal separation was represented by minimum off-peak driving time plus terminal times. Terminal times were estimated from the type and intensity of land use within each zone and were included because:

(i) People consider total travel-time rather than only driving-time associated with a particular trip;

(ii) Previous research had indicated a variation of the distance exponent when terminal time was not included in measurement of zonal separation.

Terminal times varied from siz minutes, in the central portion of the region, to three minutes in outlying suburban areas.

During calibration, it was found that the travel-time factors (F_{ij}) for all purposes, except work-trips could be approximated using a single exponent of travel time i.e. $F_{ij} = 1/d_{ij}^{n}$. Comparison of calculated and observed trips found that the model predicted too many work-trips to the central area and not enough to the outlying zones. This was explained by the understatement of the time of travel to the Central Business District due to the use of off-peak driving-times. Adjustment factors (K_{ij}) were necessary for trips through geographic barriers such as the crossing of the Potomac River.

Frequency distributions of work-trips by travel-time were reproduced with particular accuracy. The importance of adjustment factors (K_{ij}) was shown by comparing unadjusted and adjusted work-trip crossings of cordon-lines.

He claimed that the gravity model could serve as a framework for forecasting urban traffic for any city; and that, in cases of specific modelling difficulty, justifiable adjustment factors should be used.

Clark and Peters (1964), however, claimed that the number of journeys is controlled by "opportunities" and not by distance. To support this proposition they applied the "Competing Opportunities Model" (COM), developed by Tomazinis (1962), to work-trips in London in 1951. The COM is based on the principle that the Logarithm of the number of journeys <u>to or beyond</u> any specific point is proportional to the number of "opportunities" <u>at or beyond</u> that point.

They concluded that:

1. The Gravity Model was unsatisfactory while the COM worked well in describing trips by both public transport and private cars;
2. Female workers were much less willing to work at a distance from their homes than males; and

3. Manual workers, clerical workers, and executives have appreciably different travel patterns.

Howe (1960, 1962, 1963a and 1963b) was critical of the techniques used to synthesize work-trips with the gravity model and proposed his own "Field" theory of movement - the Electrostatic Model, saying that human beings are like electrons, being attracted to many different "positively charged" land use centres. For work-trips the model was:

$$T_{ij} = \frac{P_i A_j / R_{ij}}{\sum_{j=1}^{m} A_j / R_{ij}} \tag{10}$$

where: R_{ij} is the straight-line distance from zone i to zone j, which is simply the gravity model with straight-line distance as the measure of separation.

Based on successful predictions of trips to work in Minneapolis-St. Paul, Howe claimed that this model can be used in any urban area to predict travel patterns from land-use patterns "more accurately than the Gravity Model" - a curious conclusion considering the Electrostatic Model is a form of Gravity Model.

Bouchard and Pyers (1965) examined the ability of the BPR Model to reproduce the Washington D.C. travel pattern of 1955 and to forecast the travel pattern of 1948 from the 1955 travel data.

Calibration of the model with 1955 data was checked by:

1. Comparing the shape and average travel-times of the predicted and observed frequency distributions of trips by travel-time;
2. Determining the root-mean-square-errors of the differences between the predicted and observed flows in major corridors;

3. Comparing the estimated trip numbers with actual numbers for each trip purpose. Predicted and observed zone-to-zone numbers of trips were grouped according to the magnitude of the observed number of trips and the root-mean-square-error of each group was calculated as a percentage of the average size of that group; and

4. Comparing the numbers of trips between sectors (groups of zones).

The reliability of prediction was found to increase with the number of trips.

Using the 1955 travel-time factors with trip attraction and production data available for 1948, the 1948 travel pattern was satisfactorily reproduced. Hence, they claimed that, if appropriate productions and attractions are known or can be reliably estimated, the gravity model is capable of reproducing existing conditions and of predicting future conditions, over short time periods.

Heanue and Pyers (1966), working with data for Washington D.C. from 1948 and 1955, tested the BPR Model against:-

1. Frator Growth Factor Procedure

$$T_{ij} = t_{ij} G_i G_j \left(\frac{L_i + L_j}{2}\right) \qquad (11)$$

where T_{ij} = Future year trips from zone i to zone j,

t_{ij} = Base year trips from zone i to zone j,

G_i = Growth factor for zone i,

L_i = Locational factor

$$= \frac{t_i}{\sum_{j=1}^{n} t_{ij} F_j}$$

t_i = Base year trip ends at zone i.

2. Intervening Opportunities Model (IOM) (Stouffler, 1940)

$$T_{ij} = O_i \{\exp(-LD) - \exp[-L(D+D_j)]\} \tag{12}$$

where O_i = Trip origins in zone i,

D = Trip destinations considered prior to zone j,

D_j = Trip destinations in zone j,

L = Measure of probability that a random destination will satisfy the needs of a particular trip.

3. Competing Opportunities Model (Tomazinis, 1962)

$$T_{ij} = O_i \rho_{aj} \rho_{sj} \tag{13}$$

where ρ_{aj} = Probability of attraction to zone j

= destinations in zone j divided by sum of destinations available in "time" bands up to and including band m

$$= \frac{D_j}{\sum_{K=0}^{m} D_k}$$

ρ_{sj} = Probability of satisfaction

= 1 minus the sum of the destinations available in time bands up to and including "time" band m divided by the sum of total destinations in study area

$$= 1 - \frac{\sum_{K=0}^{m} D_K}{\sum_{K=0}^{n} D_K}$$

K = any time band

m = time band into which zone j falls

D_K = destinations available in time band K

n = last time band as measured from origin zone i

D_j = destinations available in zone j

O_i = number of trips with origin in zone i.

The models were compared on the basis of:

1. ability to match the trip length frequency distribution, from the O-D survey;
2. ability to produce volumes at river crossings that matched O-D survey volumes;
3. ability to match O-D survey trip movement by corridors to and from the CBD; and
4. accuracy of model as measured by the root-mean-square-errors between numbers of O-D survey trips and model trips assigned to a spider network.

In all respects the Gravity Model was at least as good as the other three.

In predicting the 1955 data from the 1948 data base the Gravity and Intervening Opportunities Models were about equal in reliability and utility, but it is difficult to use the IOM calibration parameter (L) for predicting future trips as nothing is known about its stability with time;

The Fratar growth factor procedure correctly expanded trips for stable areas but was unsatisfactory when the origin areas were experiencing changes in land use; and

It was not possible to calibrate the Competing Opportunities Model for trips between areas as small as those used in Washington D.C.

Lawson and Dearinger (1967), working with work-trips in Lexington, Kentucky, compared the BPR Model with:-

1. Electrostatic Model (Howe, 1960)

$$T_{ij} = \frac{\dfrac{A_j}{d_{ij}} P_i}{\sum_j \dfrac{A_j}{d_{ij}}} \qquad (14)$$

2. Competing Opportunities Model (Tomazinis, 1962)

$$T_{ij} = O_i \rho_{aj} \rho_{sj} \qquad (13)$$

3. Multiple Regression Model

$$T_{ij} = a_0 + a_1 X_1^{b_1} + \ldots + a_K X_K^{b_K} \qquad (15)$$

where a_K and b_K are constants, and

X_K is a regression variable.

They tested the predicted number of trips by comparison of:

(i) the shapes and average travel-times of the predicted and observed frequency distributions of numbers of trips by travel-time; and

(ii) the mean square errors in the predictions of observed numbers of trips.

They concluded that the Competing Opportunities and Electrostatic Models did not reliably reproduce observed trip patterns, while the Gravity and Multiple Regression Models did: the Gravity Model was selected as the most practical model because of its simplicity, relative ease of application and sensitivity to changes in travel time.

Blunden (1971) compared the predictions of trips in Sydney in 1961 by Bell (1966) who used the Gravity Model, and by Connors (1968) who used a Linear Programming method. He concluded that the linear programming solution which minimized the sum of trip times produced an ideal situation but not the actual situation; the gravity model, however, generated a solution with a sum of trip times close to the actual value.

Fisher and Patterson (1972) argued that the concepts of entropy theory applied to social systems by Wilson (1971) in his derivation of the Gravity Model do not apply. They claim that cities are examples of open systems which do not converge to a state of maximum disorder but import energy to maintain internal differentiation i.e. cities exhibit negative entropy; thus a model seeking to maximise entropy departs from the fundamental organizational characteristics on which cities are based.

The further argued that the Gravity Model is over simple because:

(i) it estimates trip numbers and distributes trips in two separate steps, whereas the decision to make a trip and the decision on the trip end are simultaneous;

(ii) the balancing constants of Wilson's Gravity Model cannot be calculated; and

(iii) the cost constraint

$$C = \sum_{i=1}^{n} \sum_{j=1}^{n} T_{ij} C_{ij} \tag{6}$$

is not realistic.

However these arguments concern the theoretical validity of the Gravity Model. In practice the balancing constants can be calculated by making appropriate assumptions (Edens, 1970 and Cesario, 1974) and the theoretical error of separate trip generation and distribution is irrelevant if the model works.

After reviewing Land Use/Transportation studies in Australia, Black (1974) concluded that in the trip distribution stage most studies used the BPR Model, while Growth Factor and Intervening Opportunities Models were rarely used. Some studies used the Gravity Model with the BPR "friction factors" (F_{ij}) replaced by impedance functions such as:

$$f(d_{ij}) = d_{ij}^{-n} \quad \text{(Voorhees, 1955)} \tag{16}$$

or

$$f(d_{ij}) = \exp(-\lambda d_{ij})/d_{ij}^{n} \qquad \text{(Tanner, 1961).} \tag{17}$$

All studies showed that trips with different purposes have different average lengths, and Black concluded that a more accurate distribution pattern is likely to result with a model stratified by purpose.

Beardwood and Kirby (1975) analyzed some properties of the gravity model and endorsed the theoretical soundness of the model. They explained mathematically the following properties:

1. "Separability" - if a zone is excluded from the region then the remaining inter-zonal and intra-zonal trips are unchanged;
2. "Compressibility" - by suitably averaging travel-times, the predictions made after aggregating zones into larger units are consistent with the predictions made using the original zones; and
3. "Excludability" - if data for some interzonal transfers are omitted at both origin and destination, the predictions made by the gravity model are consistent with those that would have been obtained had they been present.

In practice this means that it is quite reasonable to confine predictions to the trips within a study area, and treat it as a closed system. Also, if all cells for which information is missing were omitted completely from the calibration the synthesized partial matrix would be the same as the appropriate sections of the synthesized whole matrix, provided the omitted trip volumes were not large enough to affect the travel-times between the remaining zones. Work done in this study showed this to be true with the above proviso.

2.1.3 Generalizing the Gravity Model.

Tanner (1961) suggested that for a trip distribution formula to be acceptable, it must apply to both short and long trips within towns and to trips between-towns. He demonstrated mathematically that the conventional gravity model of the form:

$$T_{ij} = \frac{K \; P_i \; P_j}{d_{ij}^n} \tag{18}$$

cannot adequately describe both short and long trips with the same values of constants. It was apparent from work done in this study that different values of n were appropriate for different travel times.

To overcome this restriction, Tanner proposed the formula

$$f(d_{ij}) = \exp(-\lambda . d_{ij})/d_{ij}^n \tag{17}$$

as a descriptor of the effect of distance between two places on the number of journeys to work between them.

He tested both the conventional and modified formulae by calibration with the 1951 census data for the whole of the United Kingdom and concluded that to explain short trips, long trips and trips between towns with a single formula the exponential term was required.

He found that for short trips within a town the parameter n was usually found to be 1.0. Larger values (up to 3.0) were generally appropriate for longer trips only. In this study all trips within Adelaide were short intra-city trips so a value of $n = 1.0$ was appropriate.

In order to remove the dependency on population density from the model, and thus enable the model to represent travel between towns as well as travel within towns, Tanner introduced two additional constants, c_i and c_j, which represent exponentially weighted average population densities. His final model was:

$$T_{ij} = \frac{mP_i P_j \exp(-\lambda . d_{ij})}{d_{ij}} \left[\frac{1}{c_i} + \frac{1}{c_j}\right] \tag{19}$$

with:

$$c_i = \sum_j P_j . \exp(-\lambda . d_{ij}) \tag{20}$$

and

$$c_j = \sum_i P_i . \exp(-\lambda . d_{ij}) \tag{21}$$

where m is a constant, and

P_i and P_j are the populations, or other measures of size, of the two places.

Edens (1970) described a modified version of the BPR Model which involved the grouping of zones according to "accessibility" which was defined for zone j as:

$$AC_j = \sum_{all\ i} \frac{A_j}{d^n_{ij}} \tag{22}$$

i.e. a function of the size of a zone and its separation from all other zones. The equation of his modified gravity model was:

$$T_{ij} = P_i A_j Ef_{pi} f_{aj} \tag{23}$$

where f_{pi} and f_{aj} are functions of the separation, d_{ij}, between the production zone i and the attraction zone j. Families of f_{pi} curves and f_{aj} curves were derived from an iterative procedure based on matching observed and calculated trip length frequency distributions: each zone was assigned one curve from each family according to its accessibilities.

Whereas conventional prediction for a future design year had assumed that the functional form of F_{ij} remains constant over periods of time, Edens proposed that only for zones of constant accessibility should F_{ij} be considered of constant form over the prediction time period. The modified model takes into account some of the land use changes occurring during the planning period by assigning to each zone new f_{pi} and f_{aj} curves accorded to the zone's predicted accessibilities.

Edens showed that the BPR model is a special case of this more general model and the F_{ij} curve can be considered as an area-wide average of the f_p and f_a curves.

Baass (1974) claimed that travel-time factors for each zone-to-zone interchange, are given by:

$$F_{ij} = \frac{t_{ij}\, t}{P_i\, A_j} \tag{24}$$

where: t_{ij} is the observed number of trips from zone i to zone j, and

t is the total number of trips.

This formula led to exact values of the travel-time factors but it was necessary to relate the factors to travel-time using a curve-fitting technique. The result was in fact similar to the BPR method.

The BPR calibration procedure involves developing a suitable friction factor curve by iterative trial and error and calibrating adjustment factors, K_{ij} , by some ad hoc procedure usually based on differences between predicted and observed numbers of trips. Cesario (1974) proposed that the adjustment factors could be calculated from observed data only by decomposing them into origin and destination components:

$$K_{ij} = L_i\, M_j \qquad i,j=1,2,\ldots,N. \tag{25}$$

thus

$$T_{ij} = \frac{(L_i P_i)(M_j A_j) F_{ij}}{\sum_j L_i M_j A_j F_{ij}} \quad (26)$$

which can be re-written:

$$T_{ij} = GU_i V_j F_{ij} \quad (27)$$

where: G = a normalizing factor;

U_i = emissiveness of i = propensity of zone i relative to other origins to emit trips; and

V_j = attractiveness of j = propensity of zone j relative to other destinations to attract trips

which is equivalent to the formula developed by Edens (1970) (equation 23).

Cesario (1977) further developed the concepts of emissiveness and attractiveness and related them to accessibility thus drawing the same conclusion as was drawn by Edens (1970): that the amount of travel between two places depends on the accessibility of each of the zones.

From the papers discussed in this section it was concluded that the gravity model can be used to model the distribution of trips in any city. The form in which the model is expressed, the relations to be established between adjustment or balancing factors and data on land-use, and the method of calibration can be selected by the user to suit the available data. The basic premise remains, however, that travel between two zones is proportional to the level of activity at the two zones and inversely proportional to some function of the time of travel between the two zones.

Mathematical foundations have been presented for the balancing factors and evidence has been presented of previous successful use of the gravity model.

2.2 DISAGGREGATION OF DATA

In attempting to increase the accuracy of modelling the distribution of trips whilst maintaining simplicity, most transportation studies separate trips into categories, and apply the model separately to each catagory. This separation will be referred as "disaggregation".

The most common basis for disaggregation has been "purpose of trip" using categories suggested by the U.S. Bureau of Public Roads (1965), viz:-

1. Home-based to work
2. Home-based to shop
3. Home-based to social-recreation
4. Home-based to school
5. Home-based to miscellaneous
6. Non-home-based.

Dickey and Hunter (1970) investigated the use of trip-purpose as a basis for disaggregating trips. They developed a procedure for calculating the optimal number and composition of groups of trip categories. Their procedure balances two conflicting desires viz:-

1. Classification groups should consist only of trip categories which are homogeneous in terms of travel-time distributions, and
2. The number of groups and hence the cost of running the model should be minimized.

Trips from the Waco Urban Transportation Study (Texas Highway Dept. 1965) were categorized initially by purpose and by land use at destination. From 80 such initial categories their grouping procedure generated 5 groups. The groups were examined for intuitive reasonableness and explanations were wought for apparent anomalies.

Almost all trips to work appeared in the same group: they usually occur in a limited peak period and are therefore particularly significant.

It has been universally accepted that journeys-to-work are similar enough to each other and sufficiently different from trips made for other purposes to be treated as a single group. However, separation of work-trips into smaller categories using variables such as age, sex and occupation has been investigated with a view to increasing the accuracy of trip distribution modelling.

Ashford and Holloway (1972), Clemente and Sunners (1974) and Paaswell and Edelstein (1976) investigated the variation of trip-making behaviour with age. It was found that variables such as average length of trip and percentage of trips made for the purpose of work varied with age and other factors such as income, sex and marital status.

Hathaway (1975) investigated the benefits of disaggregation using data from London in 1966. Trips were classified by sex, age, marital status, socio-economic group, occupational group and standard industrial classification of the trip-maker. He found that significant differences can exist between the distribution of trips made by people in different categories. Results of his analysis of data disaggregated by occupation and by sex will be examined here in some detail.

Hathaway fitted to his data a trip distribution model of the form:

$$T_{ij}^{K} = B_i^K C_j^K P_i^K A_j^K \exp(-\lambda^K c_{ij}) \tag{28}$$

subject to the usual constraints for all zones i and j:

$$\sum_i T_{ij}^K = A_j^K \tag{29}$$

$$\sum_j T_{ij}^K = P_i^K \tag{30}$$

where: K represents the category of trip-maker;

B_i and C_j are balancing factors;

c_{ij} is the cost of travel from zone i to zone j; and

λ is a calibration parameter.

Hathaway's aims were (i) to see how well the model fitted the data for each category and (ii) to compare the accuracy of the model, when applied separately to the data for each category and the results summed, with the accuracy obtained from a single application of the model to the aggregated data.

Peak-hour public transport work-trips in the north-east section of the London Transport Survey Area were examined using trip data derived from the 10% sample 1966 census of London. The cost of travel was assessed in terms of travel time.

Hathaway examined the possibility that difference in average travel-time between categories could be explained by sampling error. He stated that if the average travel-times had been based on a 100% sample (as in the full census), the differences between categories would necessarily be significant.

Hathaway considered that the Student's t-test could be used to test whether differences in average travel-time between categories indicated actual differences in travel patterns or whether sampling error was responsible. This involved the assumptions that all the categories have normal trip length distributions with the same variance

Table 2.1 gives the mean and variance of the travel-time for each category and shows that the variances were indeed similar - all values between 234 and 346 min^2.

A series of t-tests was used to investigate the significance of small differences in mean travel-time. At the 90% confidence level, both Professional workers and Clerical workers were significantly different from all other workers, also Male workers were significantly different from Female workers, but no other two groups were significantly different from each other.

The decay constants shown in Table 2.1 were obtained using a Maximum Likelihood calibration method to fit the model to the data for each category.

TABLE 2.1 Trip data and decay constants by occupation and by sex (Hathaway, 1975).

Category	Number of trips	Average travel-time (min)	Variance of travel-time (min^2)	Decay Constant λ^K (min^{-1})	Decay Constant $1/\lambda^K$ (min)
1. Manual	11362	46.6	338	0.0632	15.8
2. Professional	2238	59.5	253	0.0503	19.9
3. Clerical	10331	53.9	234	0.0625	16.0
4. Transport	2202	47.6	289	0.0571	17.5
5. Service	2613	46.2	303	0.0700	14.3
6. Other	2974	46.8	346	0.0620	16.1
Male	16955	52.1	320	0.0544	18.4
Female	12911	47.9	286	0.0687	14.5
All	28866	50.4	310	0.0616	16.2

Using a Relative Likelihood Method to compare the decay constants in Table 2.1, Hathaway showed that the correlation between $1/\lambda$ and average travel-time which is apparent in Table 2.1 was statistically significant i.e. the model was properly sensitive to changes in the observed distribution of trips.

Hathaway generated numbers of trips between zones using the calculated value of the decay constant and the observed trip end numbers for each of the categories and the following measures of departure were calculated:-

(1) The mean percentage difference in trip numbers defined as:

$$\frac{1}{N} \sum_i \sum_j |n_{ij} - m_{ij}| \quad * \qquad (31)$$

(2) The chi-squared statistic defined as:

$$\sum_i \sum_j \left(\frac{n_{ij} - m_{ij}}{n_{ij}}\right)^2 \quad * \qquad (32)$$

(3) The root-mean-square error defined as:

$$\frac{1}{N} \sum_i \sum_j (n_{ij} - m_{ij})^2 \quad * \qquad (33)$$

where: n_{ij} is the observed number of trips from zone i to zone j,

m_{ij} is the calculated number of trips from zone i to zone j, and

N is the number of observations.

Hathaway considered that it is possible to compare fits between categories using the chi-squared values. However there are two sound theoretical reasons why chi-squared should not be used. First, the chi-squared test was developed to test whether a sample of a population came from a theoretical distribution with any differences being due to

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* These definitions as given by Hathaway are not correct - the correct formulae are given in Appendix B.

sampling error; and secondly the chi-squared statistic should not be used with less than 5 trips in any one observation.

In Hathaway's work a 10% sample was used so the errors indicated by his chi-squared values was a combination of sampling error and modelling inaccuracy which is not truly indicative of the efficiency of the model. There were also numerous observations of less than 5 trips which invalidated Hathaway's chi-squared values in any case.

Chi-squared was not used in this thesis as there were many observations of less than 5 trips and because 100% census data was used so there was no measurable sampling error. Besides which it is the errors in the model that are of interest not the sampling errors.

TABLE 2.2 Comparisons between observed and Synthesized trip matrices. (Hathaway, 1975).

Category	Number of trips	Chi-squared value*	Mean Percentage Error*
1. Manual	11362	9526	53.8
2. Professional	2238	3218	49.3
3. Clerical	10331	6367	32.4
4. Transport	2202	3886	69.9
5. Service	2613	4376	63.7
6. Other	2974	4921	70.3
Male	16955	9461	44.1
Female	12911	12971	48.5
All	28866	17447	42.4

*The values of chi-squared and mean percentage error given in this table appear to have been calculated using the correct definitions as given in Appendix B not the incorrect definitions in equations (31)-(33).

Direct comparison of fit between categories requires a measure of goodness-of-fit which is independent of the total number of trips such as the mean percentage error. It is apparent from Table 2.2 that the mean-percentage-error value appears to vary inversely with the number of trips indicating that large observations are easier to model accurately than small observations. This was also found to be true in this study.

Hathaway concluded that his model was unsatisfactory because the mean percentage error was too high (about 40%). However as discussed in section 5.2.1 the values obtained for the mean percentage errors were markedly affected by the large number of small observations. Analysis of the percentage errors in the major movements (as in section 5.4) would in the author's opinion have shown Hathaway's model to have been satisfactory.

Table 2.3 gives the results of comparing the observed trip distribution with, in turn, the predicted distributions obtained from the sum of nine socio-economic groups, the sum of the six occupational categories, the sum of the eight categories of industry, the sum of the part-time and full-time workers, the aggregated data for all workers and the sum of the seven age/sex categories.

TABLE 2.3 Comparisons between predicted and observed trip distributions (Hathaway, 1975)

Variable	Number of categories	Chi-squared value	Mean percentage error
Socio-economic group	9	15768	38.9
Occupation	6	16304	39.0
Industry	8	15826	40.1
Part-time/Full-time	2	16883	42.2
No variable	1	17447	42.5
Age/sex	7	16303	42.6

Table 2.3 indicates that some small improvement in modelling accuracy was possible through the introduction of additional parameters it is difficult to judge their significance. It was apparent to the author that a more sensitive measure of comparison was necessary. Hence analysis of correlation was used in this work in addition to the mean-percentage-error statistic used by Hathaway.

2.3 OCCUPATION AND TRAVEL BEHAVIOUR

The usefulness of occupational categories has been extensively researched, in particular the effect on trip-making behaviour. A brief summary of some of this research is presented here in view of the investigation of the effects of separating data into occupations on accuracy of modelling the distribution of trips.

Duncan and Duncan (1955), using data from Chicago, 1950, found that: workers in the professional and managerial classification lived only in certain areas of the city and operatives, service workers and labourers lived only in others while salesmen, clerks and craftsmen lived throughout the city.

Duncan (1956) found that the distance between work-place and residence of workers in Chicago, 1951, showed definite correlation with the category of occupation (Table 2.4).

TABLE 2.4 Average work-residence separation by major occupation group (Duncan, 1956)

Occupation	Number of workers	Average separation (miles)
Professional	80	7.0
Managerial	68	6.4
Sales	64	6.4
Clerical	191	5.1
Craftsmen	181	4.6
Operatives	338	3.6
Service	87	3.8
Labourers	33	3.3
Total	1042	4.7

On the other hand, Reeder (1956) found that in Spokane, Washington, in 1952, people in the Professional and Managerial occupations spent less time travelling to work than did operatives and labourers.

Reasons for the apparently conflicting results of Duncan and Reeder could include: differences between cities (geographical and demographic); differences between occupational groups with respect to preferred mode of travel; differences between road networks and public transport networks with respect to levels of service; and the relation between average distance and travel time. However, there is little doubt that differences can occur between occupational groups with respect to the separation of residence and place of work.

Udy (1962) suggested that people in occupations giving access to wealth power and influence would be able to benefit more quickly from technological change than others less fortunate.

Goldstein and Mayer (1964) using data from Providence-Pawtucket, Rhode Island, 1960, found that: of the workers who lived in the suburbs, the percentage working in the city varied directly with the social status of their occupations and the percentage working in the suburbs decreased with increasing social status.

In an extensive analysis of previous research, Wheeler (1967) found that most metropolitan transportation studies agreed that those in high status occupations generally travel further to work than those in low-status categories. Wheeler commented that in large cities "white collar" workers live in the suburbs and work in the Central Business District, whereas "blue collar" workers tend to live close to where blue-collar jobs are available. However, the size of the city is important: in smaller cities, professional and managerial workers often live in the suburb in which they work while manufacturing employees may be attracted from other suburbs: in this case the lower-status workers tend to travel further than high status workers.

Using data from Pittsburgh, 1958, Wheeler found that mean work-trip distance increased with occupational status. Also, within high-status occupations, average work-trip distance was found to increase with distance between residence and city. Low-status occupation workers exhibit the opposite behaviour; those living in the suburbs work near home, while those living near the city have scattered work-places.

It is apparent from the average work-trip distances displayed in Table 2.5 that no correlation exists between social status and distance travelled to work by female workers; however due to the large demand for office-workers in the CBD, female clerical workers have a much higher average distance to work than the other occupations.

TABLE 2.5 Mean distances from home to work for Pittsburgh in 1958 (Wheeler, 1967).

Occupation	Distance to work (miles)		
	All Destinations	CBD Destinations	Female Workers
Professionals	4.07	5.41	2.77
Managers	3.47	4.88	2.87
Sales workers	3.77	4.94	2.82
Clerical workers	3.58	4.50	3.46
Craftsmen-foremen	3.51	4.70	2.74
Operatives	3.13	3.64	2.84
Service workers	2.61	3.20	2.56
Labourers	2.76	3.20	2.48
Total	3.43	4.58	3.06

Forster (1975) found that in Adelaide in 1971 workers in different categories of occupation and different sexes had very different distributions of homes and workplaces.

Manning (1978) analysed the 1971 census data on journey to work in Sydney, and found that the distance travelled to work was related to age, income, occupation, sex, marital status and whether an individual has a fixed dwelling or fixed workplace when searching for the other.

He found that the proportion of the workforce that work and live in the same locality varied with the occupation. People with lowly paid occupations tended to live close to their work. Using the ratio of the number of people that actually work locally to the number of people that could work locally to represent people's willingness to travel long distances to work, he found that workers earning more are willing to travel further.

The proportion of workers working in the city centre varied with occupation and sex: however, the residential distribution of city workers did not vary between occupations. There was, however, a variation between the residential distributions of the two sexes: male city workers of all occupations were drawn predominantly from the Kur-ring-gai and harbourside suburbs, while female city workers of all occupations were drawn from the western suburbs.

3. DEVELOPMENT OF THE GRAVITY MODEL

3.0 INTRODUCTION

From the many distribution models described in Chapter 2 the Gravity Model as presented by the Bureau of Public Roads (1965) (hereafter referred to as the BPR Model) was selected. A computer program which incorporated the procedure for calibrating this model was written in Fortran for a CDC 6400 computer and was applied to an examination of the 1971 journey-to-work data for the City of Adelaide. The model and the calibration procedure were refined as improvements in some sections permitted improvements in others. This chapter describes the development of the final model.

3.1 DEVELOPMENT OF THE MODEL AND CALIBRATION PROCEDURE

3.1.1 The BPR Model

The BPR model is:

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum\limits_{j=1}^{n} A_j F_{ij} K_{ij}} ,$$

subject to the constraints

$$P_i = \sum_{j=1}^{n} T_{ij} \quad \text{for all} \quad i; \quad \text{and}$$

$$A_j = \sum_{i=1}^{n} T_{ij} \quad \text{for all} \quad j.$$

The first constraint is automatically satisfied by the calculation of numbers of trips from the trip production data, while the second constraint is satisfied by a procedure of iterative multiplication using trip attraction factors.

3.1.2 Categorization of trips

The BPR recommends that trips be categorized by purpose: this study examined trips of only one purpose viz. home-based work trips.

The B.P.R. also recommends that trips be separated into:

(a) Internal trips: with both ends in the study area;

(b) External trips: with one end in the study area and one end outside the study area; or

(c) Through trips: with neither end in the study area.

In this work, only trips internal to the Adelaide Statistical Division were considered. This included 99% of the 299000 trips that originated in the study zone and 99% of the trips that ended in the study zone.

3.1.3 Data

The BPR model required matrices of

(i) observed trips and

(ii) travel times between zones.

Whereas the BPR suggests an origin-destination sample survey as the source of trip data, this work used census data.

Terminal times and inter-zonal travel times were calculated in the manner suggested by the BPR. The intra-zonal travel times however required a closer examination as discussed in section 4.2.2.

3.1.4 The Calibration Process

3.1.4.1 The trip length frequency distribution.

In the BPR method a frequency distribution of the number of trips and percentage of all trips in each one-minute increment of travel time is calculated from the table of trip numbers and the travel times. However the travel times used in this study were not considered to be accurate to within one minute thus intervals of two minutes between 3 min. and 49 min. were used with "under 3 min" and "over 49 min" categories in all frequency distributions. Of the observed trips 4% were under 3 min. and 0.1% were over 49 min.

3.1.4.2 Travel time factors.

Development of a set of travel time factors (F_{ij}) by an iterative process is the core of the BPR calibration process. Initially either a set of travel time factors found to be appropriate for a similar sized urban area are used, or all initial travel time factors are set to unity; the initial estimates are relatively unimportant, although they can affect the cost of computing by changing the number of iterations required. In this work all initial travel time factors were set to unity.

3.1.4.3 Calculation of predicted number of trips.

Substitution of the known values of the trip productions (P_i), and trip attractions (A_j) and the estimated travel time factors (F_{ij}) into the gravity model formula:

$$T'_{ij} = \frac{P_i A_j F_{ij}}{\sum_{j=1}^{n} A_j F_{ij}} \qquad (\text{all } K_{ij} = 1)$$

produces a matrix of predicted trip numbers (T'_{ij}). From this are calculated:

(i) a frequency distribution by travel time of numbers of trips estimated by the gravity model for comparison with the frequency distribution of observed trips calculated as described in section 3.1.4.1; and

(ii) a table of synthesized numbers of trips attracted to each zone (A'_j) obtained by summing the appropriate numbers in the trip matrix for comparison with the observed trip attractions (A_j).

3.1.4.4 Comparison of frequency distributions.

The BPR recommends that the predicted and actual frequency distributions of trip numbers by travel time be compared with respect to shape and average trip length and if they do not satisfy visual comparison or do not have average travel times within three percent of each other, the travel time factors should be adjusted as described in section 3.1.4.5.

In this work the BPR calibration criteria were quantified to:

(i) for at least 80% of the travel time intervals (i.e. 20 out of 25) the percentage of predicted trips in an interval must lie within ± 0.5 percentage points of the actual percentage of trips in that interval. Travel times were allocated into 23 cells of 2 minute span between 3 and 49 minutes with a cell for over 49 minutes and a cell for under 3 minutes.

(ii) the average predicted travel time must be within 3% of the actual value.

3.1.4.5 Adjustment of travel time factors.

When the frequency distribution of synthetic trips fails to match the frequency distribution of actual trips as described above, the BPR method uses the following method to adjust the travel time factors:

The travel time factor used for each value of travel time is multiplied by the ratio of the observed percentage of trips to the currently predicted percentage of trips for that travel time i.e.

$$F(t,n+1) = F(t,n) \times p(t)/q(t)$$

where $F(t,n+1)$ = travel time factor for time t to be used in the next iteration;

$F(t,n)$ = travel time factor for time t used in the current iteration;

$p(t)$ = observed percentage of trips of time t; and

$q(t)$ = percentage of trips of time t predicted by the current iteration.

The adjusted travel time factors are then plotted against travel time on a log-log scale, and a smooth curve of best fit is drawn. A new value of travel time factor for each travel time is taken from that curve.

This adjustment process is repeated until a set of travel time factors is obtained which gives a frequency distribution of trips by travel time satisfying the criteria of comparison in 3.1.4.4.

In this study the BPR's manual curve-fitting procedure was replaced by a segment of the computer program and the whole calibration process was completed in a single computer run. Much time was spent investigating the form of the curve to be fitted. Initially the log-log parabolic function:

$$Ln(F_{ij}) = A + B\ Ln(d_{ij}) + C(Ln(d_{ij}))^2$$

taken from the shape of the travel time factor curve presented by the BPR (1965) for Washington D.C., 1955 was tried. With this function the programme was unable to satisfy the calibration criteria of section 3.1.4.4.

The function suggested by Tanner (1961)

$$F_{ij} = \exp(-\lambda d_{ij})/d_{ij}^{b}$$

was tested and found to be acceptable. However in describing his model Tanner explained that the exponent b in the denominator is required to describe inter-city trips; intra-city trips were generally found to produce a value of b close to unity.

The simpler Tanner function suitable for intra-city trips:-

$$F_{ij} = C \exp(-\lambda d_{ij})/d_{ij}$$

was finally adopted in this work. The parameters were obtained during calibration by the process described above.

3.1.4.6 Comparison of trip attractions.

The BPR suggests manual comparison of the predicted trip attractions (A_j') with the actual trip attractions (A_j) after the comparison of frequency distributions has been satisfied. In this study the criterion of comparison was quantified and included in the computer program. It was required that at least 80% (25 out of 31) of the synthetic trip attractions (A_j') must lie within 10% of the corresponding actual trip attractions (A_j).

3.1.4.7 Adjustment of trip attraction values.

When the predicted trip attractions are not sufficiently close to corresponding actual values the BPR suggests manual adjustment of each trip attraction value, used in the current application of the gravity model, by the ratio of the actual trip attraction (A_j) to the predicted trip attraction (A_j'). For each zone j :

$$A(j,n+1) = A(J,N) \times A_j / A_j'$$

where A(j,n+1) = the trip attraction value for zone j to be used in the next iteration; and

A(j,n) = the trip attraction value for zone j used in the current iteration.

This procedure is performed automatically by the calibration program described in this work.

Generally only one such adjustment of trip attraction factors is necessary to achieve agreement of trip attractions between survey and model.

3.1.5 Adjustment Factors.

The BPR used adjustment factors (K_{ij}) to allow for various social and economic conditions not related to travel time such as topographical barriers or congestion. Because of the stringent requirement to quantitatively justify the use of adjustment factors they were not used in this study.

3.1.6 Testing the Gravity Model.

The BPR recommends that the overall accuracy of the predicted trip distribution produced by the gravity model be tested with the following statistics: the mean difference, the sum of the squares of the differences, the standard deviation, and the root-mean-square-error. If these errors are within acceptable limits of accuracy the model is deemed to be satisfactory.

The statistics used in this work were the mean percentage error, root-mean-square-error, the differences and ratios between corresponding numbers of trips and analysis of correlation as described in Chapter 5.

3.2 THE FINAL MODEL

This section summarizes the procedure used in the remainder of the study to calibrate the model for various sets of trip data.

Calibration involved the following steps:

1. read in the travel time matrix;
2. read in the observed trip matrix;
3. calculate trip productions (P_i) and trip attractions (A_j) by totalling appropriate cells of the trip matrix;
4. calculate the frequency distribution of trips by travel-time for 2 minute intervals of travel time between 3 and 49 minutes (section 3.1.4.1);
5. calculate the observed average travel time by summation of number of trips by travel time for all pairs of zones;
6. set initial travel time factors for all values of travel time to unity (section 3.1.4.2);
7. calculate the matrix of travel time factors (F_{ij}) from the initial table of travel time factors (step 6) or from the travel time factor versus travel time function (step 13);
8. calculate the matrix of predicted trip numbers from the Gravity Model formula using the trip production values from Step 3, the actual or adjusted trip attraction values from Step 3 or Step 17, and the current travel time factors from Step 7 (section 3.1.4.3);
9. calculate the frequency distribution by travel time of the predicted numbers of trips (section 3.1.4.3) and the average predicted travel time;
10. compare the frequency distributions of predicted and observed trips for all travel times (section 3.1.4.4). If the comparison is satisfactory proceed directly to step 15. If the comparison criteria are not satisfied proceed to step 11.
11. Adjust the value of the travel time factor for each interval of travel time using the formula described in section 3.1.4.4.

12. Fit to the data resulting from step 11 a curve of the form:

$$F_K = C.\exp(-\lambda.d_K)/d_K$$

where F_K, C, λ and d_K are as defined in section 3.1.4.5;

13. Replace the values from step 11 with the values of the travel time factor, F_K, defined by the equation of step 12 so that the final set of values of F_K lies on a smooth curve;

14. return to step 7 and repeat steps 7 to 13 up to four times, or until the comparison of step 10 is satisfied; then proceed to step 15;

15. calculate the synthetic trip attraction values (A_j') by summing the columns of the matrix of predicted numbers of trips (section 3.1.4.3);

16. compare the synthetic and actual trip attraction values. If the comparison criterion of section 3.1.4.6 is satisfied proceed directly to step 19. If the comparison criterion is not satisfied proceed to step 17;

17. modify the actual trip attraction values for all zones as described in section 3.1.4.7;

18. Return to step 8 and repeat steps 8 to 17 up to two times or until the comparison in step 17 is satisfied; then proceed to step 19.

19. The calibration is now finished; calculate error statistics for comparing the predicted and actual trip distributions.

4. INPUT DATA

4.0 INTRODUCTION

There are three major sets of input data:

(i) the zone definitions;

(ii) the travel time matrix; and

(iii) the work-trip matrix for each of sixteen occupational and sex categories of trip-maker.

The following sections describe the collection and preparation of these data.

4.1 WORK-TRIP MATRICES

the 1971 Australian census obtained data on the "place of work", "place of residence", "occupation" and "sex" of each worker. Comprehensive journey-to-work tables were compiled from this by the Australian Bureau of Statistics (ABS).

The Adelaide Statistical Division (SD) was divided into 391 origin zones and 322 destination zones. The boundaries of origin and destination zones do not coincide, but both can be aggregated into 95 study zones, which in turn aggregate to 31 Local Government Areas (LGA's). At all three levels of spatial resolution (origin/destination zones, study zones, LGA's) tables are available showing numbers of trips from home to work cross-tabulated with the occupation, industry group, age and sex of the workers involved.

The LGA level of spatial resolution was used in this study because the use of 95 study zones would have required the manual calculation of the unreasonable number of some 4560 values of travel time. Also when disaggregated by occupation and by sex, many of the elements of the journey-to-work matrices were too small. Although it is desirable to maintain a fine level of detail, a mathematical model is of little use if the errors inherent in the model are larger than the numbers being modelled. Even at the LGA level of resolution, many zone-to-zone numbers of trips were zero or close to zero. It was decided to attempt to model LGA-to-LGA movements as a smaller number of larger zones would have produced insufficient detail.

The 31 LGA's are listed in Table 4.1 and depicted in Figure 4.1. Table 4.2 gives the number of workers in each (ABS) occupational category; Appendix B shows the occupations which comprise each category. As the categories of Farmers (#5), Miners (#6), Armed Servicemen (#10) and inadequately described (#11) contained only a total of 5.5% of the total number of workers they were aggregated into a single category of "Other" (#12). The remaining categories were maintained as given. The resulting occupational categories and numbers of workers in the categories used in this study are given in Table 4.3. There are three reasons for the discrepancies between the numbers in Table 4.2 and the numbers in Table 4.3. First approximately two percent of the labour force was unemployed and made no journey to work. Secondly, approximately ten per cent of the answers to the question on place of work fell into the categories of Not Applicable, Outside Study Zone or Not Stated. Finally, the tables include only those employed persons who were "usual residents" of the dwelling in which they were enumerated, resulting in an estimated loss of 3.3 per cent of the employed workforce (Australian Bureau of Statistics, 1975). The nett result of those facts was that about sixteen percent of the Adelaide labour force was not included in the analysis. As it is not known exactly where these errors occur, it was assumed that the errors are dispersed throughout the trip matrices and that no single value was significantly affected,

TABLE 4.1: LOCAL GOVERNMENT AREAS IN ADELAIDE STATISTICAL DIVISION

No.	LGA	No.	LGA	No.	LGA
1	Adelaide	12	Hindmarsh	23	Salisbury
2	Brighton	13	Kensington & Norwood	24	Stirling
3	Burnside	14	Marion	25	Tea Tree Gully
4	Campbelltown	15	Meadows	26	Thebarton
5	Col. Light Gdns	16	Mitcham	27	Unley
6	East Torrens	17	Munno Para	28	Walkerville
7	Elizabeth	18	Noarlunga	29	West Torrens
8	Enfield	19	Payneham	30	Willunga
9	Gawler	20	Port Adelaide	31	Woodville
10	Glenelg	21	Prospect		
11	Henley & Grange	22	St. Peters		

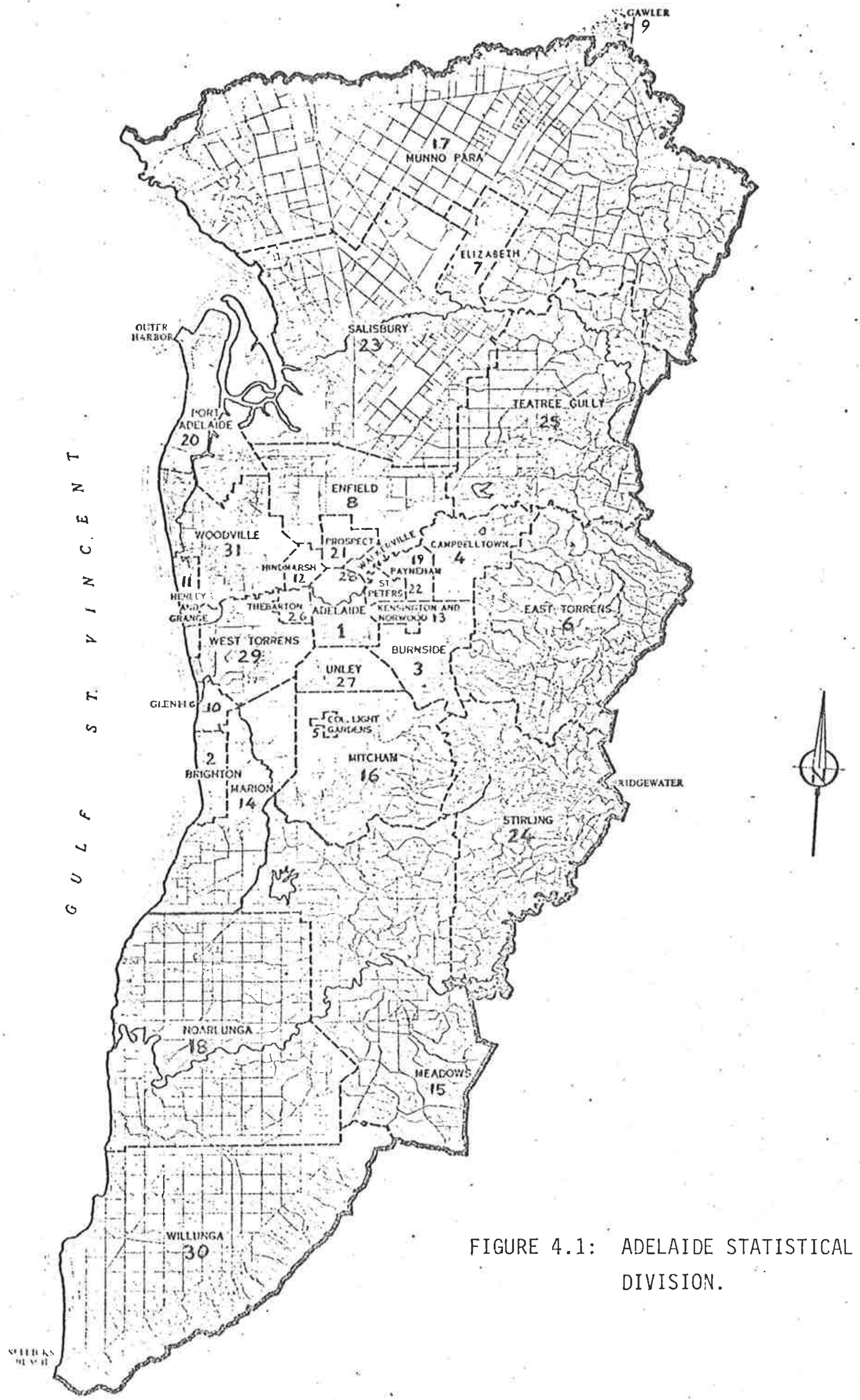


FIGURE 4.1: ADELAIDE STATISTICAL DIVISION.

TABLE 4.2: NUMBERS OF WORKERS RESIDENT IN THE ADELAIDE SD, AS GIVEN IN THE 1971 CENSUS (AUST. BUREAU OF STATISTICS).

OCCUPATION		Male Workers		Female Workers		All Workers	
		No.	% of Male Total	No.	% of Female Total	No.	% of Total
1.	Professional	22,678	10	17,819	15	40,497	11
2.	Administrative	21,054	9	3,166	3	24,220	7
3.	Clerical	21,971	10	36,611	30	58,582	17
4.	Sales	15,493	7	15,674	13	31,167	9
5.	Farming	5,274	2	1,208	1	6,480	2
6.	Mining	440	0	1	0	441	0
7.	Transport/ Communication	14,865	6	2,352	2	17,217	5
8.	Crafts	107,758	46	15,764	13	123,522	35
9.	Service	9,169	4	19,748	16	28,917	8
10.	Armed Services	2,460	1	122	0	2,582	1
11.	Inadequately Stated	7,512	3	4,458	4	11,970	3
	Unemployed	3,643	2	2,922	2	6,565	2
	TOTAL	232,317	100	119,843	100	352,160	100

TABLE 4.3: NUMBERS OF WORKERS IN OCCUPATIONAL CATEGORIES USED IN THIS STUDY.

OCCUPATION		Male Workers		Female Workers		All Workers	
		No.	% of Male Total	No.	% of Female Total	No.	% of Total
1.	Professional	20,340	10	15,650	15	35,990	12
2.	Admistrative	19,063	10	2,850	3	21,913	7
3.	Clerical	20,526	10	33,830	33	54,356	18
4.	Sales	13,789	7	13,820	14	27,609	9
7.	Transport/ Communication	11,870	6	2,082	2	13,952	5
8.	Crafts	93,900	48	14,332	14	108,232	36
9.	Service	8,118	4	17,148	17	25,266	9
12.	Other	7,242	4	2,080	2	9,322	3
13.	TOTAL	194,848	100	101,791	100	296,640	100

but detailed comparisons involving small numbers were avoided.

The values of zonal trip productions (representing resident workforces) and zonal trip attractions (representing zonal employment numbers) are presented in Table 4.4 and 4.5. When analysed by zone, by occupation and by sex, certain trends became apparent both in the trip production figures and in the trip attraction figures.

1. the occupational categories of Professional, Administrative, Transport, Craft and Other had high proportions of males in almost all zones; while the categories of Clerical Sales and Service workers had larger proportions of females than of males in most zones;
2. the Industrial areas of Elizabeth, Enfield, Hindmarsh, Kensington, Port Adelaide, Thebarton and Woodville have zonal trip attractions much larger than their respective trip production figures. In all other zones the trip productions exceed attractions indicating that these zones are predominantly residential;
3. in all occupations the Adelaide CBD provides far more jobs than it has resident workers;
4. Occupations such as Craftsmen, in particular, dominate the trip attraction and production figures in the more industrial areas of Enfield and Port Adelaide whereas the occupations of Professional and Administrative predominate in the more typically residential suburbs such as Burnside and Walkerville.

Forster (1975) discussed these differences in great depth.

4.2 THE TRAVEL TIME MATRIX

4.2.1 Inter-zonal Driving Times

Times to travel sections of the Metropolitan Adelaide Road network in the off-peak period were measured in 1974 by the South

TABLE 4.4: TRIP PRODUCTIONS BY ZONE, SEX AND OCCUPATION

ZONE	SEX	1. PROF	2. ADMIN	3. CLERIC	4. SALES	7. TRANS	8. CRAFT	9. SERV	12 OTHER	13 TOTAL
1	M	509	281	219	159	133	1097	377	96	2871
	F	1372	89	507	173	55	162	451	17	2626
2	M	805	877	725	567	227	1628	206	120	5155
	F	558	101	1059	380	53	157	384	40	2732
3	M	1924	1363	1002	783	274	1880	250	204	8180
	F	1410	205	1694	533	80	207	580	61	4770
4	M	943	928	897	651	576	3963	375	350	8683
	F	585	132	1412	632	70	583	821	122	4357
5	M	83	71	107	61	47	373	40	25	807
	F	72	24	136	51	10	43	60	8	404
6	M	124	93	56	53	35	230	20	277	888
	F	71	9	115	41	9	17	54	53	369
7	M	702	374	675	378	415	4413	272	254	7483
	F	460	88	1065	604	72	720	586	64	3659
8	M	1105	1120	1732	1039	1556	10879	817	470	18718
	F	934	225	2930	1415	194	1611	2165	120	9594
9	M	91	121	110	77	121	584	41	64	1209
	F	83	20	180	115	21	81	90	19	609
10	M	413	452	445	353	139	1263	182	86	3333
	F	321	78	773	285	42	161	348	22	2030
11	M	483	537	524	380	178	1558	161	83	3904
	F	337	69	897	297	55	171	269	47	2142
12	M	76	107	149	114	151	1605	88	70	2360
	F	66	25	337	124	18	314	264	29	1177
13	M	259	162	238	168	166	1155	125	75	2348
	F	329	35	388	181	19	167	313	14	1445
14	M	1600	1685	2190	1448	1040	7440	692	454	16549
	F	1023	201	3165	1331	200	1063	1284	127	8394
15	M	161	146	130	112	59	487	41	172	1308
	F	89	15	233	68	14	51	59	57	586
16	M	2271	2086	1622	1146	526	4072	396	316	12435
	F	1487	227	2363	780	136	501	773	95	6362
17	M	221	156	248	188	255	2353	118	764	4303
	F	127	35	449	257	31	457	252	199	1807
18	M	469	486	526	495	326	3860	222	282	6666
	F	277	82	868	465	64	779	433	78	3046
19	M	406	349	388	277	259	2011	178	117	3985
	F	302	61	672	243	35	272	442	26	2053
20	M	378	456	824	326	784	5885	564	216	9433
	F	326	127	1364	639	91	968	836	63	4414
21	M	517	428	544	306	290	2345	207	130	4767
	F	405	75	935	322	60	324	517	43	2681
22	M	279	152	185	152	146	1050	120	33	2167
	F	276	41	376	133	15	125	290	21	1277
23	M	934	814	1073	796	894	7362	464	657	12994
	F	557	126	1852	1002	148	1014	1023	202	5924
24	M	359	248	180	157	112	597	64	145	1862
	F	179	35	264	151	15	36	122	43	845
25	M	995	857	793	747	517	4023	286	269	8487
	F	509	100	1503	637	84	444	660	60	3997
26	M	104	120	196	128	171	1692	132	85	2628
	F	85	31	344	185	20	378	241	31	1315
27	M	1263	902	1033	657	472	3290	424	347	8388
	F	1139	163	1763	553	118	486	1119	84	5425
28	M	400	269	208	123	63	382	52	75	1572
	F	254	36	334	86	15	42	117	17	901
29	M	1302	1579	1629	988	738	5467	544	301	12548
	F	845	176	2653	930	148	966	903	107	6728
30	M	36	60	30	22	49	182	12	140	531
	F	28	11	68	31	9	22	37	28	234
31	M	1128	1284	1848	938	1151	10774	648	515	18286
	F	1144	208	3130	1176	181	2010	1655	183	9687

TABLE 4.5: TRIP ATTRACTIONS BY ZONE, SEX AND OCCUPATION

ZONE	SEX	1. PROF	2. ADMIN	3. CLERIC	4. SALES	7. TRANS	8. CRAFT	9. SERV	12 OTHER	13 TOTAL
1	M	8044	6157	11095	5932	3493	11881	2984	809	50395
	F	5313	786	17713	4908	1152	2166	5371	352	37761
2	M	201	218	63	137	95	964	84	55	1817
	F	292	52	228	192	9	94	390	19	1276
3	M	1000	433	410	271	245	1290	189	204	4042
	F	1018	119	734	374	36	178	829	54	3342
4	M	177	296	50	128	117	937	117	182	2004
	F	283	60	287	279	9	127	249	72	1366
5	M	11	17	14	14	20	72	7	11	166
	F	28	5	41	25	2	2	10	1	114
6	M	32	24	7	11	22	59	4	262	421
	F	13	4	20	20	4	6	36	48	151
7	M	351	344	398	229	215	5803	229	108	7677
	F	467	71	489	515	32	753	429	34	2790
8	M	1089	1221	1050	656	763	10431	538	418	16166
	F	843	150	1300	546	79	850	1102	64	4934
9	M	61	120	38	78	91	287	32	85	792
	F	89	24	136	121	14	126	109	24	643
10	M	99	211	94	136	70	420	148	29	1207
	F	278	62	292	358	7	46	401	19	1463
11	M	85	112	18	52	49	305	36	45	702
	F	182	43	111	121	4	22	192	20	695
12	M	185	606	315	458	356	3209	111	83	5323
	F	113	43	662	187	39	557	205	36	1842
13	M	379	566	265	379	226	2365	141	119	4440
	F	316	77	689	233	36	518	331	54	2254
14	M	959	1009	703	613	348	7563	256	338	11789
	F	607	135	1122	892	67	938	699	77	4537
15	M	8	61	4	42	11	152	41	138	457
	F	7	11	41	62	2	7	45	48	223
16	M	956	772	353	410	324	3481	245	311	6852
	F	981	145	1002	489	44	847	747	95	4350
17	M	88	99	37	39	66	410	29	417	1185
	F	109	23	87	112	14	151	80	153	729
18	M	222	241	116	119	96	1894	109	192	2989
	F	184	58	221	263	19	345	218	61	1369
19	M	93	230	78	125	120	851	53	62	1612
	F	171	49	204	192	12	132	236	18	1014
20	M	632	939	1388	501	1202	6986	705	323	12676
	F	351	131	1126	548	85	244	593	41	3119
21	M	161	355	135	233	163	942	85	50	2124
	F	254	60	373	230	43	226	273	15	1474
22	M	167	210	85	156	211	741	46	44	1660
	F	190	48	272	121	5	141	228	19	1024
23	M	1617	464	634	263	386	3417	242	990	8013
	F	470	100	1009	493	52	293	503	224	3144
24	M	55	69	22	37	63	264	28	122	660
	F	67	15	65	86	7	26	92	41	399
25	M	142	278	71	126	155	812	76	180	1840
	F	181	62	303	410	13	39	255	39	1302
26	M	366	388	350	300	373	2763	403	136	5079
	F	166	36	516	146	24	338	166	23	1415
27	M	499	671	304	462	334	1810	213	418	4711
	F	706	144	911	427	57	377	1025	72	3719
28	M	333	129	192	79	50	354	57	31	1225
	F	162	20	184	65	12	51	199	10	703
29	M	774	1311	985	822	1267	8669	369	414	14611
	F	457	133	1638	525	75	1627	751	114	5320
30	M	23	63	23	21	56	194	10	183	573
	F	44	11	48	31	11	16	60	35	256
31	M	1531	1449	1229	960	883	14574	531	483	21640
	F	1308	173	2005	849	117	3089	1324	198	9063

Australian Highways Department as part of the Metropolitan Adelaide Transport Study. The road network was analysed in the manner suggested by the BPR (1965). All major streets were mapped, numbers were assigned to the centroids of every intersection as well as to the centroids of all districts and distances and average speed of traffic flow between pairs of adjacent intersections were recorded.

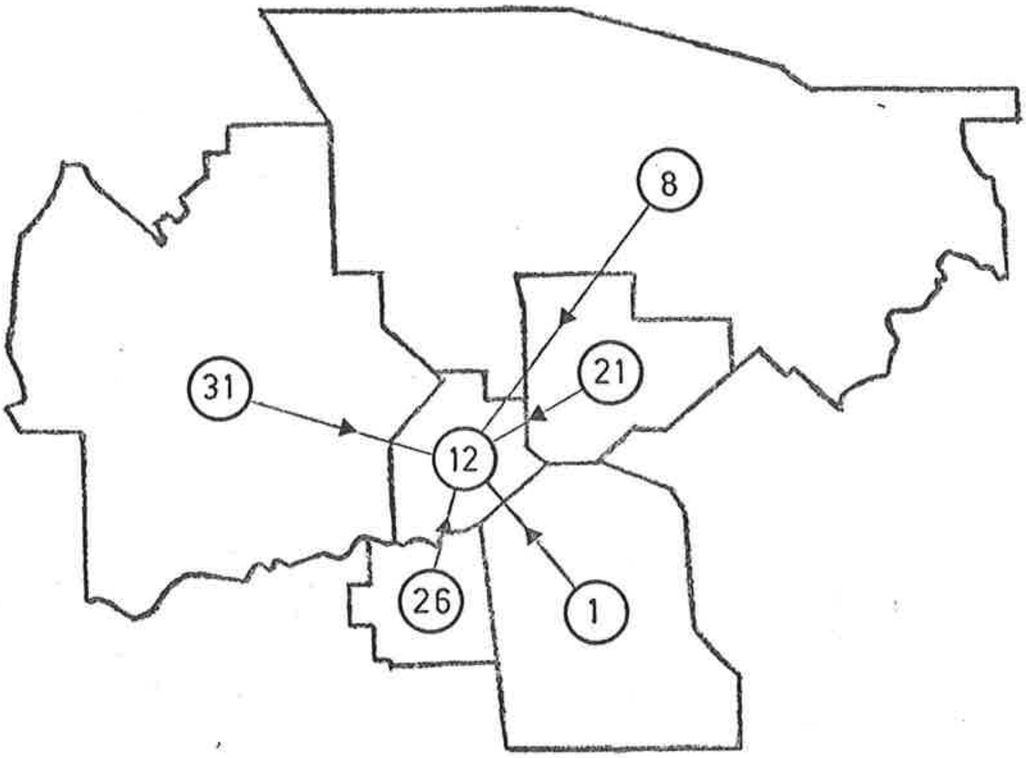
Centroids of the thirty-one Local Government Areas (zones) were located by estimating the geographical centre of the built-up area of each zone. The network node closest to each zone centroid was used to represent that zone throughout the analysis.

The shortest route between pairs of centroids was selected by visual inspection of a map of the road network and zone centroids. The driving time between each pair of zones was calculated by summation of the times of travel of all the street sections of the selected route. In the cases of the outlying zones of Willunga, Stirling and Gawler the time of travel from the zone centroid to the nearest node on the outer limits of the metropolitan network was estimated by the time taken to travel by road from the centroid to the node at an average speed of forty miles per hour.

4.2.2 Intra-zonal Driving Times

Intra-zonal driving times were estimated using the method suggested by the U.S. Bureau of Public Roads (1965), i.e. the average driving time for intra-zonal trips was considered to be one half of the mean value of the trips from the centroid of the zone to the centroids of adjacent zones as shown in Figure 4.2.

However a large proportion of intra-zonal journeys-to-work in the predominantly rural outlying suburbs result from farmers working at home. Thus in these rural zones an intra-zonal travel time of two minutes was considered appropriate.



Centroids	Driving time (minutes)
12 → 1	7.47
12 → 8	10.89
12 → 21	9.54
12 → 26	5.15
12 → 31	8.30
	40.35

$$\frac{40.35}{5} = 8.07 \text{ minutes}$$

$$\frac{8.07}{2} = 4.03 \text{ minutes}$$

(use 4.0 minutes)

FIGURE 4.2: DETERMINATION OF INTRA-ZONAL DRIVING TIME FOR HINDMARSH (12)

Figure 4.3 showing the extent of urban Adelaide in 1971 clearly indicates the zones which were either almost totally rural or were separate urban centres and which were assigned intra-zonal travel times of two minutes: East Torrens, Gawler, Meadows, Munno Para, Noarlunga, Stirling, Tea Tree Gully and Willunga. Only 36747 trips (12% of all trips) were produced by these eight zones so the overall effect of these intra-zonal travel times was small. However each of the eight rural zones had a relatively high proportion of intra-zonal trips and the use of these more appropriate intra-zonal travel times significantly improved the ability of the model to match the distributions of trips from these eight zones.

4.2.3 Terminal Times

The time of travel between each pair of zones was calculated by adding to the inter-zonal driving time a "terminal time" for each end zone. As suggested by the U.S. Bureau of Public Roads (1965), these terminal times were obtained as subjective estimates of the time required to locate and secure a parking place based on the writer's experience. It was estimated that in the Central Business District approximately five minutes would be spent searching for a parking space and walking to the final destination, while in outlying zones a terminal time of zero minutes was used and intermediate values were allocated to zones with moderate amounts of commercial activity.

However it was considered that a large proportion of those trips recorded as intra-zonal result from people working at home; in which case zero terminal times are appropriate. Hence terminal time values of zero were used for all intra-zonal travel times.

The Travel Time Matrix used with the Gravity Model was produced by collecting values of driving times between all pairs of zones and

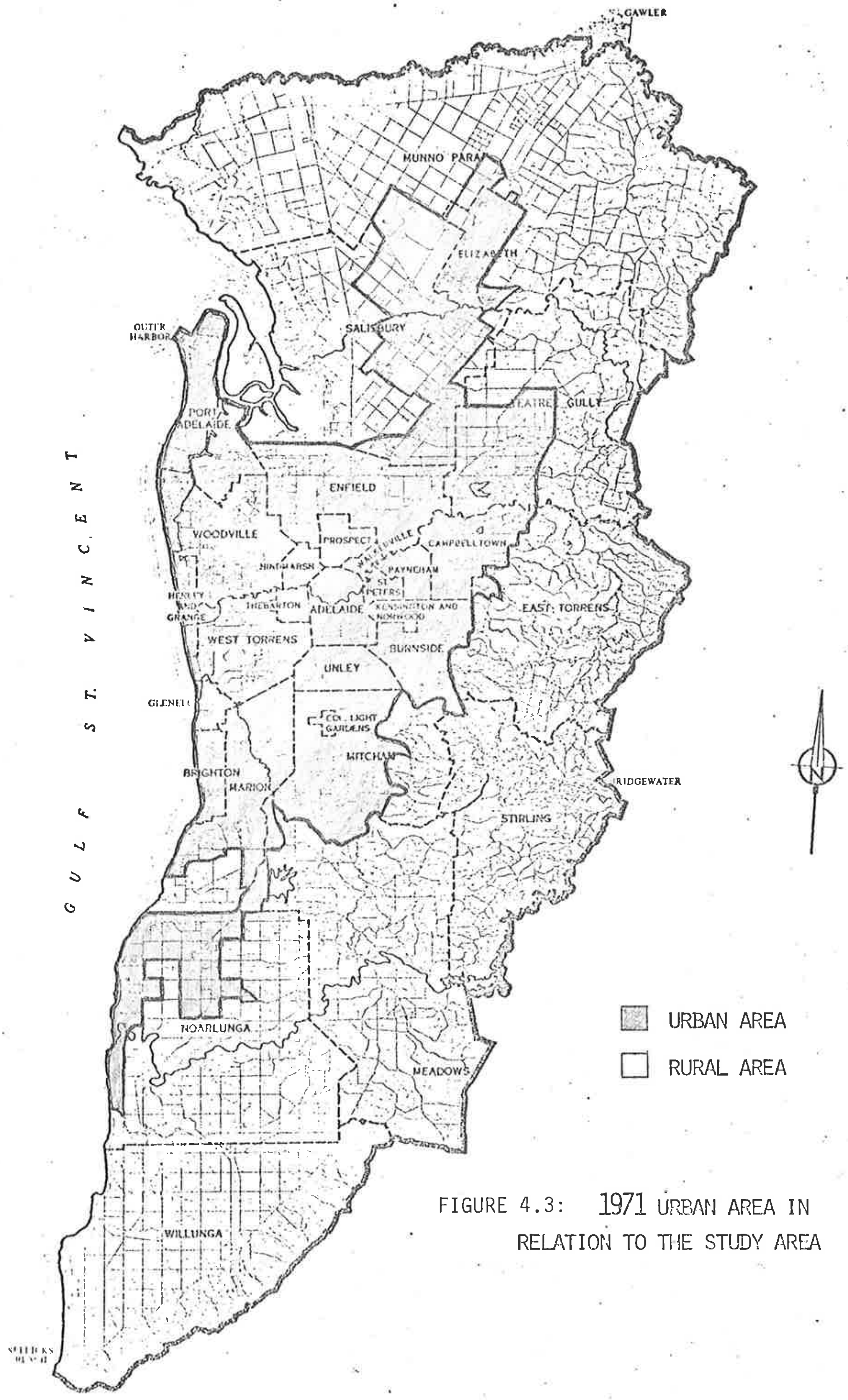


FIGURE 4.3: 1971 URBAN AREA IN RELATION TO THE STUDY AREA

intra-zonal driving time values for all zones and increasing the times by appropriate terminal times.

Zone terminal times and intra-zonal driving times are shown in Table 4.6.

4.2.4 Accuracy of Travel Times

The driving time for each section of road was quoted to the nearest one-hundredth of a minute (2% of the average time of 30 seconds) by the S.A. Highways Department. However, the travel time for each section was calculated from the section length using an assumed speed. Thus it was considered improper to claim that all times were accurate to within 2% as implied above. Precision to one-hundredth of a minute was maintained throughout the summation process, but the final travel times were accepted only to the nearest minute. With travel times of about 16 minutes this corresponded to accuracy of 6%.

After trial applications of the model it became apparent that the times were not, in fact, accurate to the nearest minute but were accurate to plus or minus one minute (or approximately ± 12%). Thus it was expected that the model's final prediction could be no more accurate than to within 12% and since the model is not linear even larger uncertainties were expected.

Perhaps more commonly used as a measure of separation between zones is the "generalized cost". This is a function of the time of travel, distance and cost of travel between the zones. In this work, however, it was not possible to calculate the generalized cost between zones as no data was available on cost of travel between zones. Also since the time of travel data was calculated from measurements of distance and average speed it would have been incorrect to propose a generalized function of the two.

TABLE 4.6 Terminal Times and Intra-zonal Travel Times.

ZONE	Intra-zonal times BPR (min)	Intra-zonal times Modified (min)	Terminal Times (min)
1. Adelaide	4.4	4.4	5
2. Brighton	2.6	2.6	3
3. Burnside	5.3	5.3	2
4. Campbelltown	6.2	6.2	2
5. Col. Light Gdns	1.6	1.6	2
6. East Torrens	8.0	2.0	0
7. Elizabeth	4.6	4.6	2
8. Enfield	6.3	6.3	3
9. Gawler	3.1	2.0	0
10. Glenelg	6.4	6.4	3
11. Henley & Grange	5.1	5.1	2
12. Hindmarsh	4.0	4.0	3
13. Kensington & Norwood	2.7	2.7	3
14. Marion	5.8	5.8	2
15. Meadows	10.6	2.0	0
16. Mitchum	6.2	6.2	2
17. Munno Para	8.0	2.0	0
18. Noarlunga	7.6	2.0	0
19. Payneham	4.1	4.1	2
20. Port Adelaide	6.0	6.0	2
21. Prospect	3.3	3.3	3
22. St. Peters	2.3	2.3	2
23. Salisbury	6.1	6.1	0
24. Stirling	9.4	2.0	0
25. Tea Tree Gully	8.5	2.0	0
26. Thebarton	4.0	4.0	3
27. Unley	4.8	4.8	2
28. Walkerville	3.5	3.5	3
29. West Torrens	6.0	6.0	2
30. Willunga	9.4	2.0	0
31. Woodville	5.4	5.4	2

Thus time of travel was the sole variable used to represent the separation of zones. It is believed that this lack of data may have generated errors which further affected the final accuracy of the model.

5. CALIBRATION AND ASSESSMENT OF THE GRAVITY MODEL

5.0 INTRODUCTION

The Gravity Model described in chapter 3 was calibrated with the data in chapter 4 and used to generate a predicted trip interchange matrix whose values were compared with the observed numbers. The values of the various statistics which measure "goodness-of-fit" between the predicted and actual trip matrices are presented and their significance discussed in this chapter.

5.1 CALIBRATION OF THE GRAVITY MODEL

5.1.1 Determination of Friction Factors.

Calibration of the gravity model involved the calculation of the parameters C and λ in the travel time factor function of section 3.1.4.5.

When using data for all journeys to work the values of the parameters were found to be $C = 57.0$ and $\lambda = 0.061\ \text{min}^{-1}$ (i.e. $1/\lambda = 16$ min). This produced the relation between travel time factor and travel time shown in Table 5.1 and Figure 5.1. It will be seen that the travel time factors obtained in 1960 from New Orleans (pop. = 627,000), when multiplied by a constant factor to equate the values at 8.0 mins, are similar to those obtained for Adelaide in 1971 while those obtained for Sioux Falls (pop. = 65000) in 1960 differ. As Adelaide in 1971 had a population of 843000 the similarity of travel time factors between Adelaide and New Orleans confirms the suggestion of the Bureau of Public Roads (1965) that cities with populations of similar size would have similar relations between travel time factors and travel time.

5.1.2 Frequency Distribution of Trips by Travel Time.

Using the parameters C and λ obtained above the means and standard deviations of the predicted and observed trip times were:-

TABLE 5.1: COMPARISON OF WORK TRIP TRAVEL TIME FACTORS FOR DIFFERENT CITIES.

Travel Time (Min)	Work-Trip Travel Time Factors					
	Adelaide 1971		New Orleans 1960		Sioux Falls 1960	
	Original	Adjusted*	Original	Adjusted*	Original	Adjusted*
0 - 3	15.83	1583	1150	1759	255	678
3 - 5	8.42	842	540	826	220	585
5 - 7	5.33	533	345	528	180	479
7 - 9	3.67	367	240	367	138	367
9 - 11	2.66	266	170	260	102	271
11 - 13	1.99	199	126	193	75	199
13 - 15	1.53	153	97	148	55	146
15 - 17	1.20	120	77	118	36	96
17 - 19	.95	95	62	95	18	48
19 - 21	.76	76	50	76	2	5
21 - 23	.62	62	42	64		
23 - 25	.50	50	35	54		
25 - 27	.41	41	29	44		
27 - 29	.34	34	25	38		
29 - 31	.28	28	21	32		
31 - 33	.23	23	18	28		
33 - 35	.20	20	16	24		
35 - 37	.16	16	14	21		
37 - 39	.14	14	12	18		
39 - 41	.12	12	10	15		
41 - 43	.10	10	9	14		
43 - 45	.08	8	8	12		
45 - 47	.07	7	7	11		

* Adjusted to a common value at 8 mins travel time.

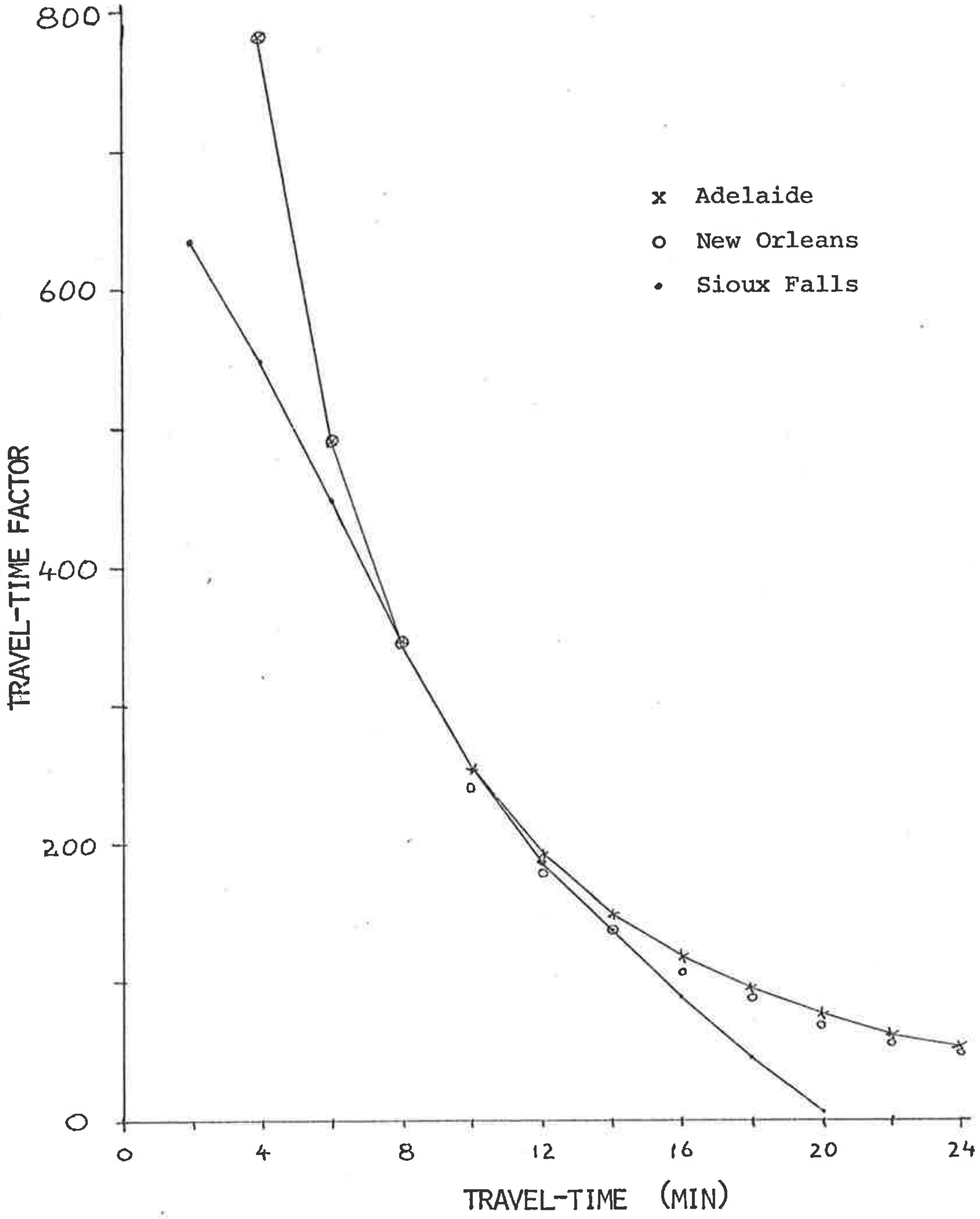


FIGURE 5.1: TRAVEL-TIME FACTORS ADJUSTED TO COMMON VALUES AT 8 MINUTES

	Mean	Std. Dev.
observed	16.6 min	9.19 min
predicted	16.2 min	9.10 min

In 20 of the 25 intervals of travel time the percentage of predicted trips was within ±0.5 of the observed percentage (i.e. for the total of 296639 trips, the predicted number of trips in each of 20 intervals was within 1483 trips of the corresponding observed number). The largest difference was in the interval 13-15 min where the difference was 3365 trips (observed = 21623 trips, predicted = 24988 trips) or, 1.13% of all trips. Table 5.2 and Figure 5.2 show the distributions by travel time of the observed and predicted trips.

5.2 STATISTICS FOR GOODNESS-OF-FIT

5.2.1 Single Parameter Statistics.

The goodness-of-fit obtained between the predicted and observed trip data was indicated by the following statistics (as defined in Appendix B):

Root-mean-square error	222 trips
Mean percentage error	100%
Number of trips	296640 trips.

The root-mean-square error suggested that there was an "average" error of 222 trips in each predicted trip movement. With 961 trip movements and 296640 trips the average movement was 309 trips. Thus the root-mean-square error was 72% of the average movement.

The mean percentage error of 100% suggested that the predicted number of trips for any pair of zones could have been anywhere between zero and twice the observed number of trips. However this statistic was markedly affected by small observed values of which there are many:

TABLE 5.2: DISTRIBUTIONS BY TRAVEL TIME OF OBSERVED AND PREDICTED TRIPS (ALL TRIPS).

Time Interval (min)	Observed Trips	Observed %	Predicted Trips	Predicted %	Obs.-Pred. Trips	Obs.-Pred. %
0 - 3	12127	4.09	11968	4.03	159	0.06
3 - 5	14060	4.74	13691	4.62	369	0.12
5 - 7	50101	16.89	52752	17.78	-2651	-0.89
7 - 9	2708	0.91	3575	1.21	-867	-0.30
9 - 11	11150	3.76	11164	3.76	-14	0
11 - 13	18942	6.39	19570	6.60	-628	-0.21
13 - 15	21623	7.29	24988	8.42	-3365	-1.13
15 - 17	25090	8.46	25798	8.70	-708	-0.24
17 - 19	13313	4.49	13029	4.39	284	0.10
19 - 21	36776	12.40	35770	12.06	1006	0.34
21 - 23	23437	7.90	22082	7.44	1355	0.46
23 - 25	11431	3.85	13493	4.55	-2062	-0.70
25 - 27	21940	7.40	18917	6.38	3023	1.02
27 - 29	9373	3.16	7308	2.46	2065	0.70
29 - 31	5401	1.82	4726	1.59	675	0.23
31 - 33	7334	2.47	6235	2.10	1099	0.37
33 - 35	2163	0.73	1842	0.62	321	0.11
35 - 37	2576	0.87	2600	0.83	-24	-0.01
37 - 39	3718	1.25	3594	1.21	124	0.04
39 - 41	1220	0.41	940	0.32	280	0.09
41 - 43	787	0.27	896	0.30	-109	-0.03
43 - 45	649	0.22	606	0.20	43	0.02
45 - 47	123	0.04	168	0.06	-45	-0.02
47 - 49	307	0.10	391	0.13	-84	-0.03
over 49	290	0.10	536	0.18	-244	-0.08
Total	296639	100	296639	100	0	0

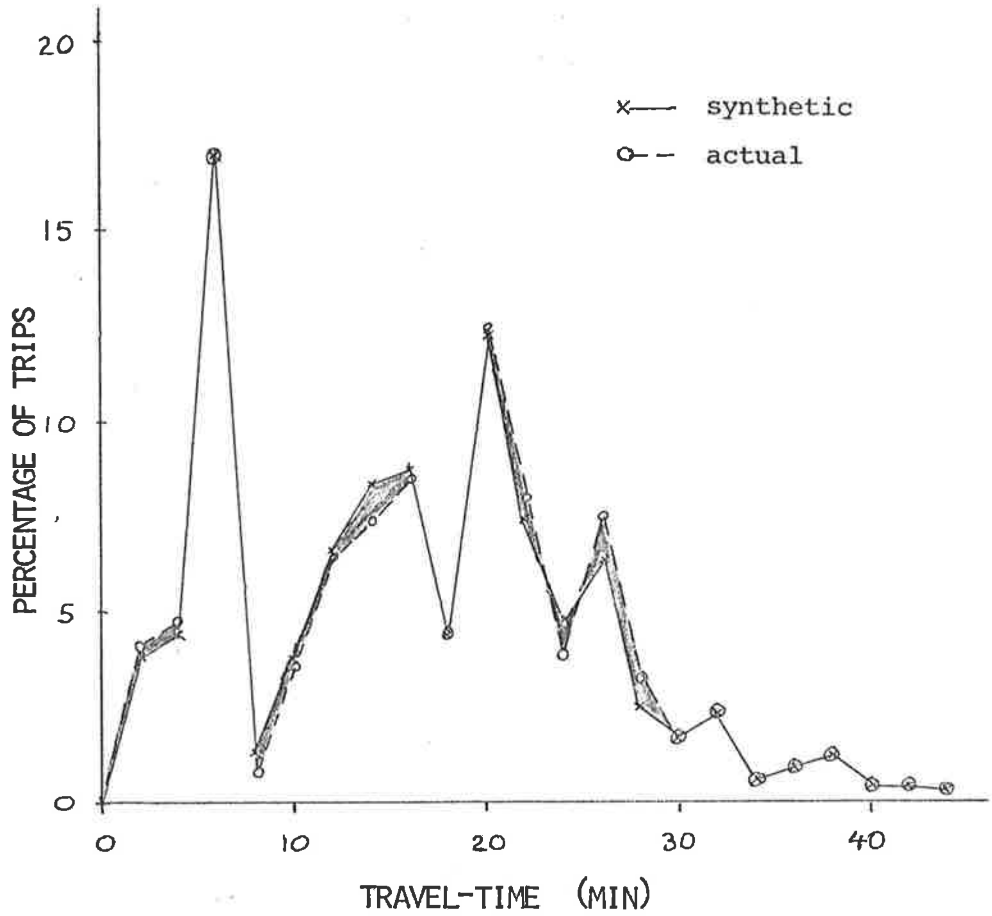


FIGURE 5.2: ACTUAL AND PREDICTED TRIP LENGTH FREQUENCY DISTRIBUTIONS FOR ALL TRIPS.

for example a predicted value of five trips with an observed value of one gives a 400% error.

5.2.2 Analysis of Correlation.

A regression analysis was performed to establish the relation between the predicted numbers of trips and the observed numbers of trips as plotted in Fig. 5.3.* Ideally the line of best fit should be Y = X i.e. a slope of +1.0 and passing through the origin. The coefficient of correlation as defined in Appendix B measures the spread of points about the line-of-best-fit, and if the line-of-best-fit is very close to Y = X it measures the spread of points about the line Y = X and can be used as a measure of the acceptability of the model.

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* It should be noted that Fig. 5.3 and all subsequent graphs were generated by computer using the Statistical Package for Social Sciences (SPSS) and involve a simplistic method of representation. An asterisk indicates a single point whilst a numeric digit indicates the occurrence of that number of points at that print position. Where more than 9 points occur at the one print position the digit 9 is shown. The overall picture given by the graph is distorted in that huge cluster of points near the origin is insufficiently indicated and the significance of the few high values is artificially enhanced.

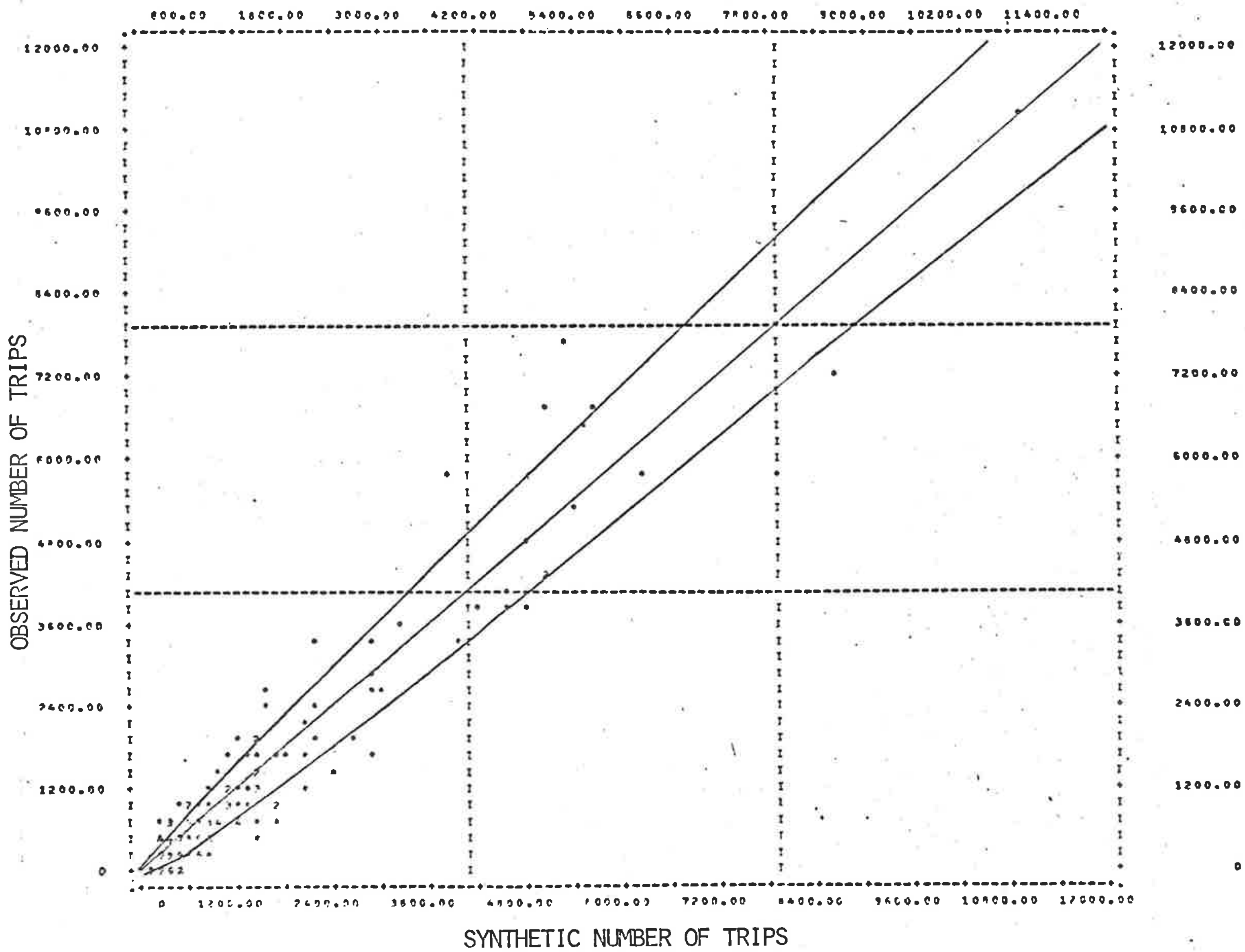

FIGURE 5.3: TOTAL NUMBERS OF TRIPS

The goodness-of-fit is hence measured by three parameters:

(i) the proximity of the slope to unity;

(ii) the proximity of the intercept on either axis to zero;

and (iii) the proximity of the coefficient of correlation to unity.

The equation of the line of best fit in Fig. 5.3 was:

$$Y = -0.15 + 1.000\ X \quad \text{for} \quad 0 < X < 1200 \quad \text{trips.}$$

i.e. the slope was unity (perfect agreement) and the error of intercept was insignificant in relation to the average number (300) of trips between zones.

The coefficient-of-correlation (R) was found to be 0.972, and thus 94.5% (R^2) of the variation in numbers of observed trips between zones could be replicated by the model. This high correlation coefficient in conjunction with the satisfactory values of the regression coefficients above indicate very close agreement. The standard error of the estimate (deviation from the line of best fit) was found to be 218 trips.

Confidence limits on predictions can be determined if the error terms are normally distributed and independent of the magnitude of the prediction. Clearly the error term in figure 5.3 increases as the numbers of trips increase.

The same data was replotted in Figure 5.4 with both scales showing the square roots of the numbers involved: the spread about the line-of-best-fit is much more nearly independent of the magnitude of the variables and can reasonably be taken as uniformly and normally distributed.

The equation of the line of best fit in figure 5.4 was

$$\sqrt{Y} = -0.84 + 1.02\sqrt{X} \quad \text{for} \quad 0 < \sqrt{X} < 120$$

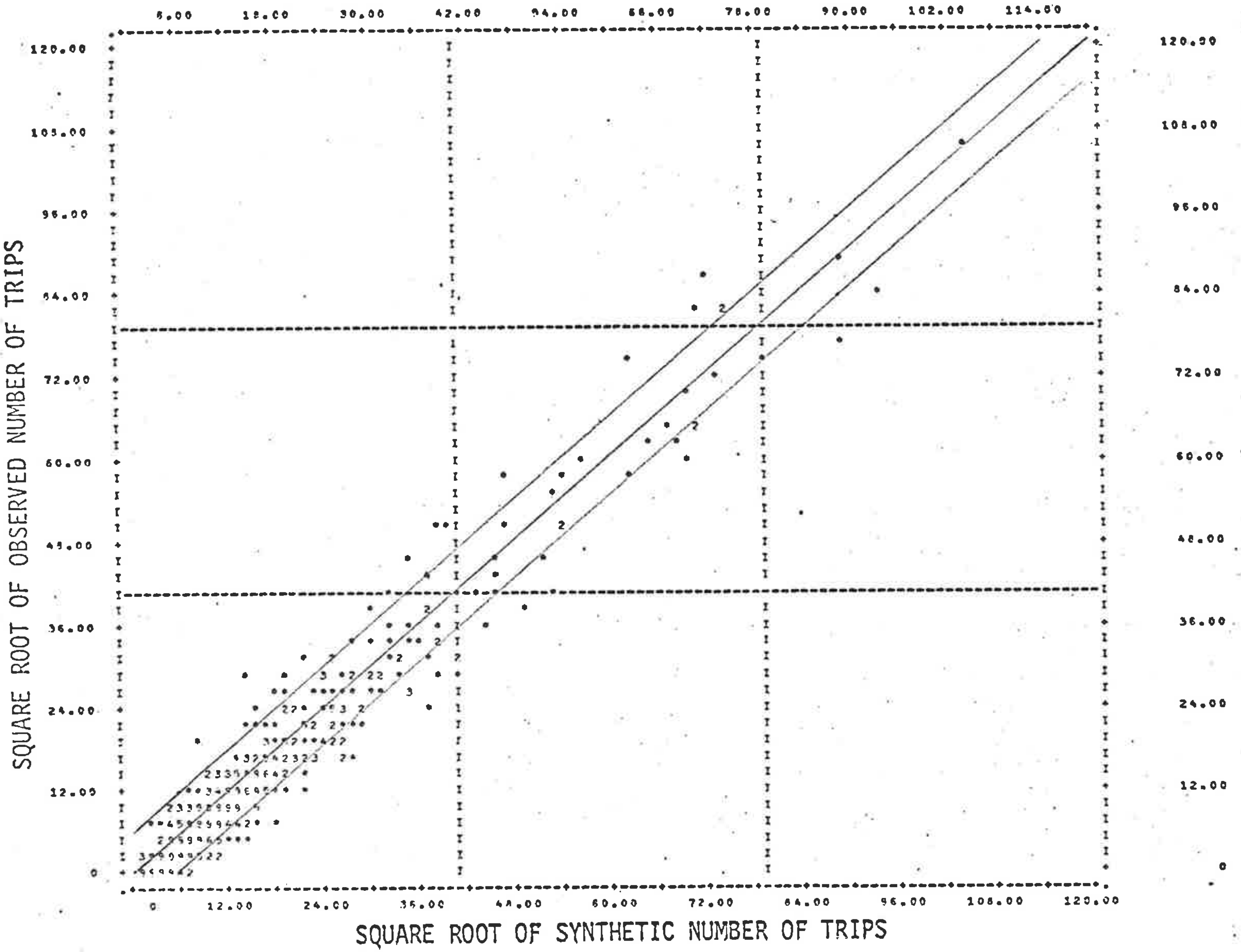

FIGURE 5.4: SQUARE ROOTS OF TOTAL NUMBERS OF TRIPS.

with a coefficient of correlation $R = 0.976$ $(R^2 = 0.953)$ and a standard error of estimate (SEE of $\sqrt{Y}$) of 3.00. As before the intercept is very small and the slope is close to unity.

The upper and lower 95% confidence limits for $\sqrt{Y}$ can be expressed as

$$\sqrt{Y} = A + B\sqrt{X} \pm 2e$$

where: Y = predicted number of trips

X = observed number of trips

$A = -0.84$ = the intercept on $\sqrt{Y}$ when $\sqrt{X} = 0$

$B = 1.02$ = the slope of the line

$e = 3.00$ = the standard error of the estimate.

Thus the equation in the X,Y space of the upper limit is:

$$Y = B^2X + 2B(A+2e)\sqrt{X} + (A+2e)^2$$

and the lower limit is:

$$Y = \begin{cases} 0 & \text{if } X < [(2e-A)/B]^2 \\ B^2X + 2B(A-2e)\sqrt{X} + (A-2e)^2 & \text{otherwise} \end{cases}$$

or substituting values

$$Y_{min} = \begin{cases} 0 & \text{if } X < 45 \\ 1.04X - 14.0\sqrt{X} + 46 & \text{if } X \geqslant 45 \end{cases}$$

and $$Y_{max} = 1.04X + 10.5\sqrt{X} + 26 .$$

These confidence limits are plotted in figure 5.3 and shown in Table 5.3.

The value of $R^2 = 0.953$ indicates that 95% of the variation in the observed numbers of trips has been replicated by the model: an extremely high correlation.

TABLE 5.3: 95% CONFIDENCE LIMITS FOR ACTUAL NUMBERS OF TRIPS.

Predicted number of trips	Expected value of observed number of trips		
	Lower Limit*	Mean	Upper Limit*
0	0	0	26
25	0	25	104
100	10	100	235
400	182	400	652
1600	1150	1600	2110
6400	5582	6400	7522
10000	9046	10000	11476

* There is 95% confidence that the observed number of trips will be between these limits.

5.3 INVESTIGATION OF SIGNIFICANT DISCREPANCIES

Two matrices, one of the ratios of predicted to observed numbers of trips, and the other of the differences between predicted and observed numbers were obtained after calibration of the model as shown in Appendix C. Ideally all ratios should be 1.0: the majority lay between 0.5 and 3.0 but extreme values of 23 and 0.1 were obtained. Ideally all differences should be zero and many were small with extreme values of -2511 and +1731 being obtained.

These statistics are misleading because the large ratio of 23 resulted from a difference of only 22 trips and the large error of -2550 trips represented only 32% of the observed number of 7778 trips. The movements which had large errors with both of these statistics were identified.

Only three out of the 961 movements were found to have ratios less than 0.3 and differences less than -200, or ratios greater than 3.0 and differences greater than 200 trips. The numbers of intra-zonal trips in East Torrens and Stirling were under-estimated and the number of trips from Noarlunga to Burnside was over-estimated as shown in Table 5.4.

Furthermore only thirty movements were found to have ratios less than 0.5 and differences less than -100 trips, or ratios greater than 2.0 and differences greater than 100 trips. Thus 931 movements out of 961 were reproduced to within ±100 trips and a factor of 2.0. These 931 movements contained 287188 trips or 97% of all trips.

Details of the poorly predicted movements are shown in Table 5.4: twenty-one of the thirty movements have one end in the developing fringe suburbs. Forster (1975) has commented that gravity models can satisfactorily represent the travel behaviour of workers from well-

TABLE 5.4: SIGNIFICANT ERROR LOCATIONS - absolute difference more than 100 and ratio not between 0.5 and 2.0.

TRIP ENDS						Observed number of trips	Difference Pred-obs	Ratio Pred/obs
25	Tea Tree Gully*	-	23	Salisbury*		580	+816	2.4
2	Brighton	-	31	Woodville		331	+421	2.3
10	Glenelg	-	31	Woodville		296	+407	2.4
3	Burnside	-	16	Mitcham*		312	+393	2.3
25	Tea Tree Gully*	-	16	Mitcham*		154	+307	3.0
18	Noarlunga*	-	3	Burnside		67	+247	4.7
7	Elizabeth*	-	20	Port Adelaide		184	+196	2.1
31	Woodville	-	10	Glenelg		47	+164	4.5
9	Gawler*	-	7	Elizabeth		145	+158	2.1
16	Mitcham*	-	24	Stirling		25	+154	7.2
20	Port Adelaide	-	23	Salisbury		89	+144	2.6
17	Munno Para*	-	20	Port Adelaide		79	+132	2.7
2	Brighton	-	20	Port Adelaide		118	+131	2.1
7	Elizabeth*	-	9	Gawler		76	+124	2.6
24	Stirling*	-	16	Mitcham*		118	+124	2.0
16	Mitcham*	-	22	St Peters		103	+123	2.2
3	Burnside*	-	24	Stirling		18	106	6.9
16	Mitcham*	-	19	Payneham		50	104	3.1
25	Tea Tree Gully*	-	22	St Peters		162	-113	.30
1	Adelaide	-	29	West Torrens		234	-134	.43
1	Adelaide	-	8	Enfield		220	-135	.39
28	Walkerville	-	28	Walkerville		279	-155	.44
25	Tea Tree Gully*	-	29	West Torrens		538	-308	.43
31	Woodville	-	7	Elizabeth*		542	-350	.35
6	East Torrens*	-	6	East Torrens*		436	-370	.15
11	Henley	-	11	Henley		655	-428	.35
18	Noarlunga*	-	16	Mitcham*		817	-502	.39
10	Glenelg	-	10	Glenelg		893	-530	.41
17	Munno Para*	-	23	Salisbury*		1052	-592	.44
24	Stirling*	-	24	Stirling*		831	-637	.23

....

* fringe zone.

established areas, but are less satisfactory for trips to or from areas of rapidly changing population.

5.4 MAJOR MOVEMENTS

Dividing the total number of trips (296639) by the total number of movements (961) the average number of trips per movement was 309. Attention was therefore concentrated on movements with observed numbers of trips greater than thirty (10% of the average). There were 521 such movements involving 290300 or 99% of all trips. The mean percentage error (predicted-observed) ÷ observed from these movements was found to be 37% which was considered to be more realistic than the 100% quoted in section 5.2.1.

Further examination showed that about 191000 trips or 65% of all trips were involved in movements having more than 1000 trips of which there were 63. The mean percentage error in prediction of these movements was 23%. Of these 63 movements 16 were intra-zonal (shown in Fig. 5.5) and the remainder were inter-zonal, 22 being to the CBD (shown in Fig. 5.6) and 25 to other zones (also shown in Fig. 5.5).

Significant intra-zonal movements are shown in Table 5.5: major discrepancies between predicted and observed values were Marion (+37%), Adelaide (+28%), Port Adelaide (-22%) and Unley (-42%). The average percentage error in the remaining twelve movements was less than 20%. The intra-zonal movements are however of little planning significance of the regional level as they are generally short, local and diffuse.

The major inter-zonal movements are listed in Table 5.6 (non-CBD trips) and Table 5.7 (trips to CBD) in order of decreasing

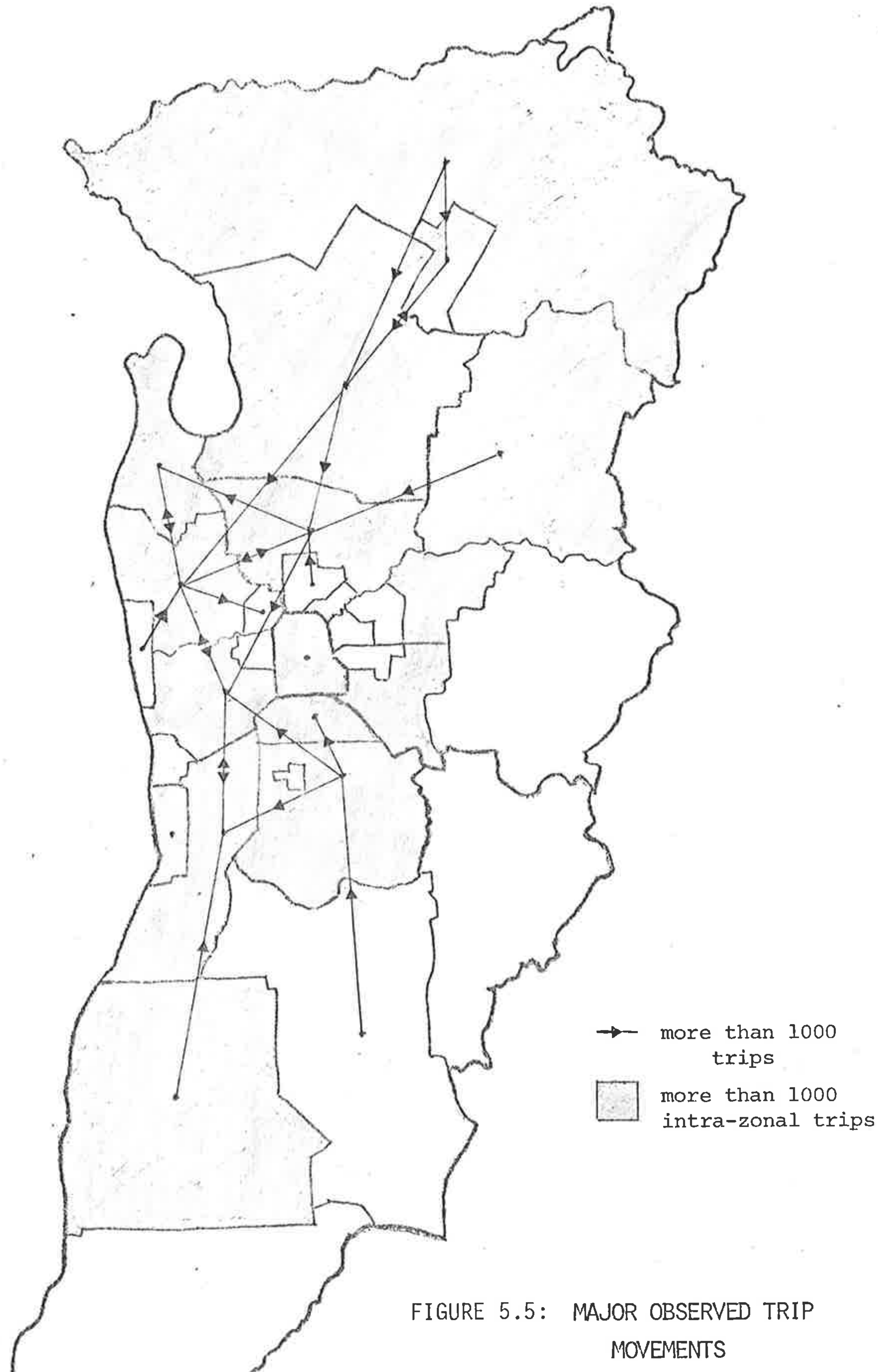

FIGURE 5.5: MAJOR OBSERVED TRIP MOVEMENTS

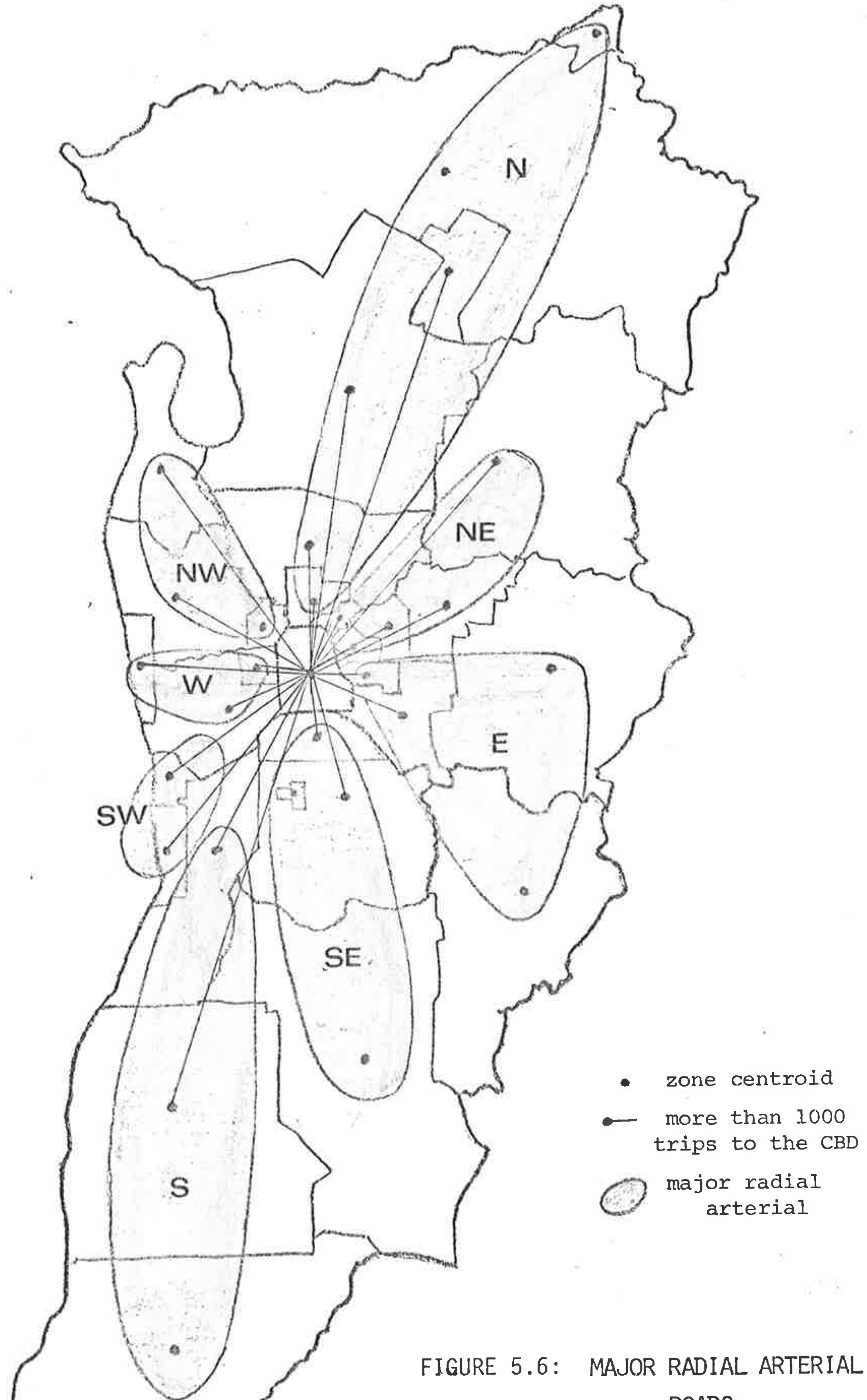

FIGURE 5.6: MAJOR RADIAL ARTERIAL ROADS

TABLE 5.5: MAJOR INTRA-ZONAL MOVEMENTS (MORE THAN 1000 TRIPS).

Zone		Intra-zonal trips			
Number	Name	Observed	Predicted	Difference	% Diff.
14	Marion	5951	8165	+2214	+37
1	Adelaide	3871	4953	+1082	+28
17	Munno Para	1103	1396	+ 293	+27
8	Enfield	7285	9016	+1731	+24
23	Salisbury	4321	5306	+ 985	+22
2	Brighton	1258	1521	+ 263	+21
7	Elizabeth	4032	4855	+ 823	+20
18	Noarlunga	3384	4059	+ 675	+20
25	Tea Tree Gully	1851	2068	+ 217	+12
16	Mitcham	3978	4437	+ 459	+11
29	West Torrens	4928	4989	+ 60	+ 1
31	Woodville	11167	11294	+ 127	+ 1
3	Burnside	2197	2159	- 38	- 2
20	Port Adelaide	6814	5309	-1505	-22
4	Campbelltown	1912	1430	- 482	-25
27	Unley	2624	1534	-1090	-42

TABLE 5.6: MAJOR INTER-ZONAL MOVEMENTS (MORE THAN 1000 TRIPS).

Trip ends						Number of trips			
						Observed	Predicted	Difference	% Diff
16	Mitcham	-	27	Unley		1105	1709	604	+55
29	West Torrens	-	31	Woodville		1564	2362	798	+51
31	Woodville	-	29	West Torrens		1369	1972	603	+44
11	Henley	-	31	Woodville		1006	1117	111	+11
14	Marion	-	29	West Torrens		2744	3043	299	+11
8	Enfield	-	20	Port Adelaide		1382	1448	66	+5
23	Salisbury	-	7	Elizabeth		1825	1820	5	+0
16	Mitcham	-	29	West Torrens		1122	1104	-18	-2
29	West Torrens	-	14	Marion		1163	1107	-56	-5
20	Port Adelaide	-	31	Woodville		3079	2852	-227	-7
17	Munno Para	-	7	Elizabeth		1603	1469	-134	-8
25	Tea Tree Gully	-	8	Enfield		1399	1225	-174	-13
21	Prospect	-	8	Enfield		1227	1061	-166	-13
31	Woodville	-	20	Port Adelaide		3439	2948	-491	-14
23	Salisbury	-	8	Enfield		2582	2165	-417	-16
31	Woodville	-	8	Enfield		1389	1000	-389	-28
16	Mitcham	-	14	Marion		1891	1341	-550	-29
14	Marion	-	16	Mitcham		1992	1366	-626	-30
31	Woodville	-	12	Hindmarsh		1289	893	-396	-31
8	Enfield	-	31	Woodville		3394	2077	-1317	-39
8	Enfield	-	29	West Torrens		1170	682	-488	-42
23	Salisbury	-	31	Woodville		1721	990	-731	-42
7	Elizabeth	-	23	Salisbury		2131	1256	-875	-42
18	Noarlunga	-	14	Marion		1643	914	-731	-44
17	Munno Para	-	23	Salisbury		1052	459	-593	-56

TABLE 5.7: MAJOR MOVEMENTS TO THE CBD (MORE THAN 1000 TRIPS)

Production Zone		Trips to CBD			
		Observed	Predicted	Difference	% Diff.
26	Thebarton	1005	1686	+681	+68
20	Port Adelaide	1721	2806	+1085	+63
19	Payneham	2104	2769	+665	+32
22	St. Peters	1228	1566	+338	+28
4	Campbelltown	4460	5315	+855	+19
21	Prospect	2673	3012	+339	+13
13	Kensington	1236	1380	+144	+12
23	Salsibury	4281	4685	+404	+9
31	Woodville	5816	6311	+495	+8
11	Henley	2010	2170	+160	+8
27	Unley	5437	5607	+170	+3
8	Enfield	8146	8126	-20	0
28	Walkerville	1108	1091	-17	-1
7	Elizabeth	1823	1689	-134	-7
25	Tea Tree Gully	3760	3351	-409	-11
18	Noarlunga	1647	1382	-265	-15
29	West Torrens	6719	5726	-993	-15
16	Mitcham	6928	5753	-1175	-17
10	Glenelg	1928	1452	-476	-25
14	Marion	7778	5267	-2511	-32
3	Burnside	5798	3971	-1827	-32
2	Brighton	2772	1586	-1186	-43

percentage error of estimation. The maximum percentage errors were 68% high (Thebarton-Adelaide) and 56% low (Munno Para - Salisbury) but the average percentage error was only 25%. The largest absolute difference between predicted and observed was the 1827 trips error in the Burnside-Adelaide prediction. Predicted numbers were generally within a few hundred of the observed.

As well as showing the major zone-to-CBD movements Fig. 5.6 shows a schematic grouping of all zones into eight areas which are served by major arterial roads. These eight roads and the numbers of trips that might be made on them (both observed and predicted) are shown in Table 5.8. The average percentage error of prediction was 18%, underestimates being obtained for trips from the South, South-west, West, East and South-east and over-estimates from the North-west, North and North-east.

5.5 SUMMARY

This chapter examined the performance of the gravity model developed in chapter 3 when applied to the aggregated data on Adelaide work-trips described in chapter 4.

Section 5.1.1 presented the parameters of the friction factor function determined during calibration of the model with all trips to work: $C = 57$ and $1/\lambda = 16$ minutes.

The resulting travel time factor function was appropriately similar to functions determined for two other cities.

In section 5.1.2 it was noted that the frequency distribution of predicted trips by travel time closely matched that of the observed trips. However that was a necessary result of the calibration procedure and serves only to show that the method of calibration does converge towards the observed distribution of trips.

TABLE 5.8: MAJOR RADIAL ARTERIAL ROADS AND TRIPS TO THE CBD.

Direction	Arterial	Zones	Trips to the CBD			
			Obser-ved	Predicted	Diff-erence	% Diff
S	Main South Rd.	30,18,14.	9478	6738	-2740	-29
SW	Anzac Hwy.	2,10.	4700	3038	-1662	-35
W	Henley Beach Rd.	11,29,26.	9734	8582	-1152	-12
NW	Port Road	20,31,12.	8014	10387	+2373	+30
N	Main North Rd.	9,17,7,23,8, 21.	17846	18722	+876	+5
NE	Main North East Rd.	25,4,19,22, 28.	12660	14092	+1432	+11
E	Greenhill Rd.	24,6,3,13.	8246	6937	-1309	-15
SE	Belair Rd.	15,16,5,27.	13278	12200	-1511	-8

In section 5.2.2 the line-of-best-fit between predicted and observed numbers of trips was determined to be $Y = X$, then the coefficient of correlation was calculated to be $R = 0.972$. Thus 95% of the variation between observed numbers of trips could be accounted for by the gravity model. It was also shown that a predicted number of trips can be expected to be accurate to within approximately fifteen times its square root.

Section 5.3 showed that ninety-seven per cent of the individual movements (involving 97% of all trips) were reproduced to within either 100 trips or a factor of two, and that most of the remaining three per cent of trips were made to or from outer zones.

Section 5.4 investigated the prediction of significant movements. Ninety-nine per cent of all trips were involved in movements of more than 30 trips. These movements were modelled to within 37% (mean percentage error). Furthermore some 65% of trips were involved in 63 movements of more than 1000 trips and these were modelled to within 23%.

6. MODELLING SEPARATE CATEGORIES OF WORKER

6.0 INTRODUCTION

In the previous chapter the effectiveness of the gravity model and its calibration process in synthesizing the observed distribution of total work-trips was discussed. No model of total work-trip numbers can do more than model the "average" worker's trip to work. As reported in section 2.4, workers in different occupations and different sexes can have very different distributions of trips. Hathaway (1975) suggested that separate modelling of work-trips in each of several categories and subsequent additions should produce a more accurate over-all model.

As described in section 4.1 the data on observed distribution of work-trips in Adelaide was separated into categories at three different levels of disaggregation:

1. by SEX - MALE trips were separated from all FEMALE trips i.e. two categories;
2. by OCC - All trips were divided into the eight categories of occupation described in section 4.1 producing eight separate trip matrices; and
3. by SEX & OCC - the eight occupational trip matrices were further subdivided into MALE and FEMALE trips, producing sixteen distinct trip matrices.

The Gravity Model was calibrated 27 times, once for each category given above. The ability of the model to reproduce the particular trip distribution of each category was tested as in chapter 5 using the coefficient of correlation, between the square roots of predicted and observed numbers of trips.

The predicted numbers of trips between zones from each of these 27 calibrations were aggregated over sex, occupation and both sex and occupation to produce three additional predictions of the total number of trips between each pair of zones. The accuracy of each of these predictions was compared to the accuracy of the prediction from chapter 5 using the statistics of chapter 5.

6.1 CALIBRATION FOR EACH CATEGORY

6.1.1 Calibration Parameters

When the gravity model was calibrated with the data for each category of trip-maker, the values shown in Table 6.1 were obtained for the parameters C and $1/\lambda$(min). The reciprocal of λ was preferred for comparison purposes as it has the units of minutes and is some measure of the propensity of the trip-makers to travel longer journeys.

The values of parameters varied from $C = 1260$, $1/\lambda = 5$ min for the small number of female transport workers whose trips were mainly intra-zonal to $C = 34$ and $1/\lambda = 28$ min for male professional workers whose trips were more evenly spread between all zones. Table 6.2 and Figure 6.1 show how markedly different these two extreme friction factor functions are.

6.1.2 Analysis of Correlation

Analysis of correlation between observed and predicted numbers of trips was based on the square roots of numbers of trips as discussed in section 5.2.2.

Statistics of correlation for the 27 categories are presented in Tables 6.3 to 6.5; Figures 6.2 and 6.3 are typical graphs of the relationship between the square roots of predicted and observed

TABLE 6.1: CALIBRATION PARAMETERS FOR DIFFERENT CATEGORIES OF TRIP-MAKER.

Category	Male		Female		Aggregated by sex	
	$1/\lambda$ (min)	C* (trips)	$1/\lambda$ (min)	C* (trips)	$1/\lambda$ (min)	C* (trips)
1. Professional	28	34	15	52	22	40
2. Administrative	21	37	7	275	19	39
3. Clerical	21	38	12	83	16	56
4. Sales	20	46	10	110	14	70
7. Trans/Comm.	16	56	5	1260	17	55
8. Craft	17	65	10	154	16	71
9. Service	13	70	10	69	11	67
12. Other	15	43	8	180	15	40
13. Aggregated by Occupation	19	54	11	78	16	57

* Note: the value of the parameter C has no effect on the trip distribution (since it occurs in the numerator and denominator of the trip distribution function) but that it is an essential part of the calibration process is obvious from the wide range of values.

TABLE 6.2: FRICTION FACTOR FUNCTIONS OF EXTREME VALUES.

Time Interval (min)	Friction Factor		
	Female Trans/Comm.	Male Professional	
		Calculated	Adjusted
0 - 3	239	10.2	102
3 - 5	99	5.7	57
5 - 7	49	3.8	38
7 - 9	27	2.7	27
9 - 11	15	2.1	21
11 - 13	8.6	1.6	16
13 - 15	5.1	1.3	13
15 - 17	3.1	1.1	11
17 - 19	1.9	.91	9
19 - 21	1.2	.77	8
21 - 23	.75	.65	7
23 - 25	.47	.56	6
25 - 27	.30	.48	5
27 - 29	.19	.42	4

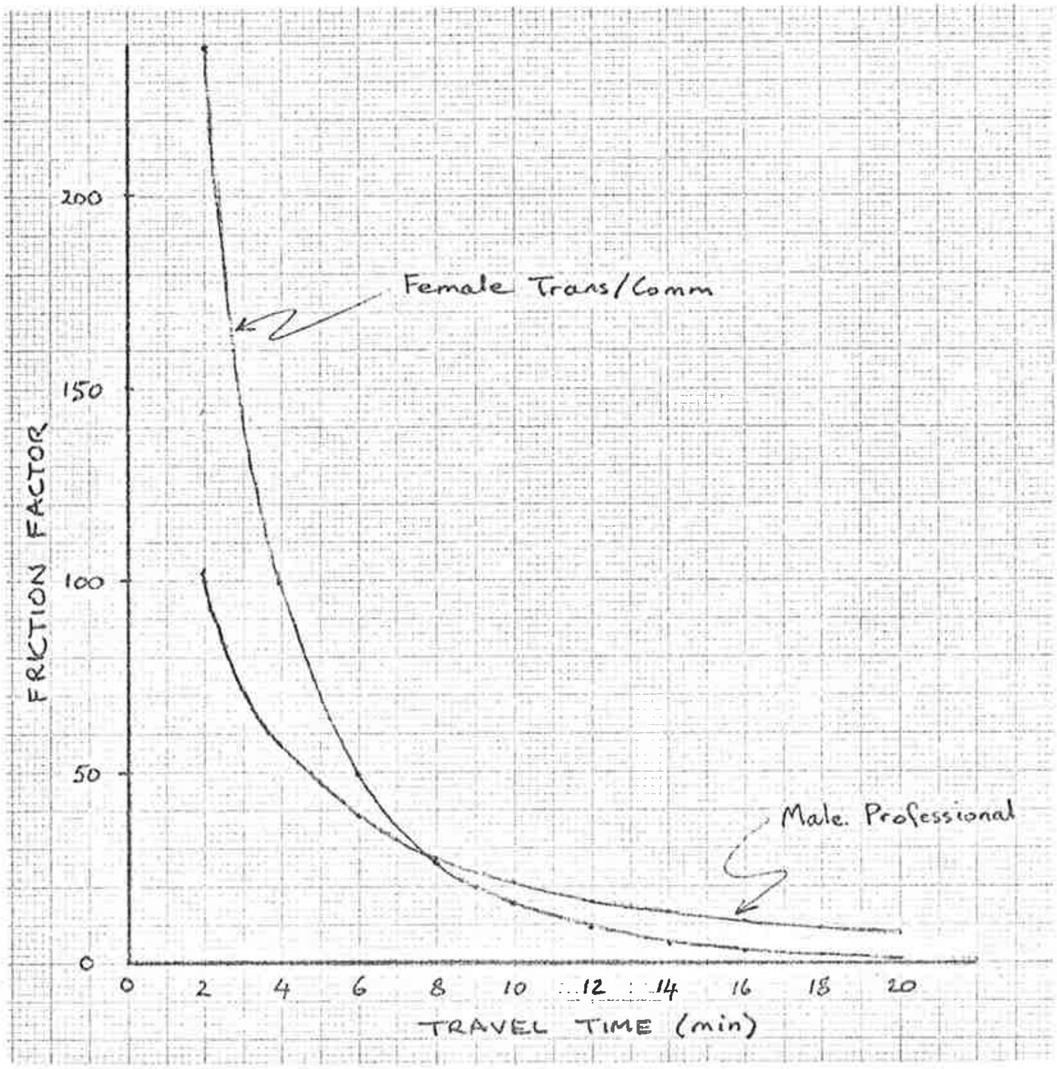

FIGURE 6.1: EXTREME FRICTION FACTOR FUNCTIONS.

TABLE 6.3: STATISTICS OF CORRELATION OF SQUARE ROOTS OF NUMBERS OF TRIPS MADE BY MALE WORKERS WHEN DISAGGREGATED BY OCCUPATION.

Category of Occupation	Number of trips	Corr. Coeff. (R)	Intercept (A)	Slope (B)	Standard Error (Se)	Max-value of $\sqrt{Y}$
1 Professional	20340	.970	-.07	.990	.90	32
2 Administrative	19063	.963	-.18	1.002	.96	29
3 Clerical	20526	.976	.07	.976	.85	32
4 Sales	13789	.965	-.09	.993	.81	25
7 Trans/Comm.	11870	.956	-.12	.993	.84	22
8 Craft	93900	.963	-.18	1.015	1.86	43
9 Service	8118	.954	-.02	.975	.74	20
12 Other	7242	.908	-.14	.971	.96	21
13 Total	194848	.977	-.03	.988	2.37	81

TABLE 6.4: STATISTICS OF CORRELATION OF SQUARE ROOTS OF NUMBERS OF TRIPS MADE BY FEMALE WORKERS WHEN DISAGGREGATED BY OCCUPATION.

Category of Occupation	Number of trips	Corr. Coeff. (R)	Intercept (A)	Slope (B)	Standard Error (Se)	Max-value of $\sqrt{Y}$
1 Professional	15450	.996	-.09	.992	.85	25
2 Admin-istrative	2850	.922	.06	.931	.59	9
3 Clerical	33830	.978	-.42	1.020	1.08	41
4 Sales	13820	.958	-.21	.998	.95	26
7 Trans/Comm.	2082	.913	.12	.901	.55	10
8 Craft	14332	.948	.01	.961	1.06	24
9 Service	17148	.961	-.23	1.000	1.01	29
12 Other	2080	.894	.05	.912	.59	12
13 Total	101791	.978	-.25	1.000	1.79	63

TABLE 6.5: STATISTICS OF CORRELATION OF SQUARE ROOTS OF NUMBERS OF TRIPS MADE BY TOTAL WORKERS WHEN DISAGGREGATED BY OCCUPATION ONLY.

Category of Occupation	Number of trips	Corr. Coeff. (R)	Intercept (A)	Slope (B)	Standard Error (Se)	Max-value of $\sqrt{Y}$
1 Professional	35990	.976	-.22	1.007	1.07	38
2 Administrative	21913	.963	-.24	1.008	1.03	30
3 Clerical	54356	.982	-.37	1.015	1.19	54
4 Sales	27609	.969	-.33	1.015	1.10	32
7 Trans/Comm	13952	.960	-.07	.985	0.87	24
8 Craft	108232	.969	.00	.980	2.09	76
9 Service	25266	.967	-.24	1.003	1.10	34
12 Other	9322	.918	-.21	.987	1.04	24
13 Total	296693	.976	-.84	1.016	3.00	106

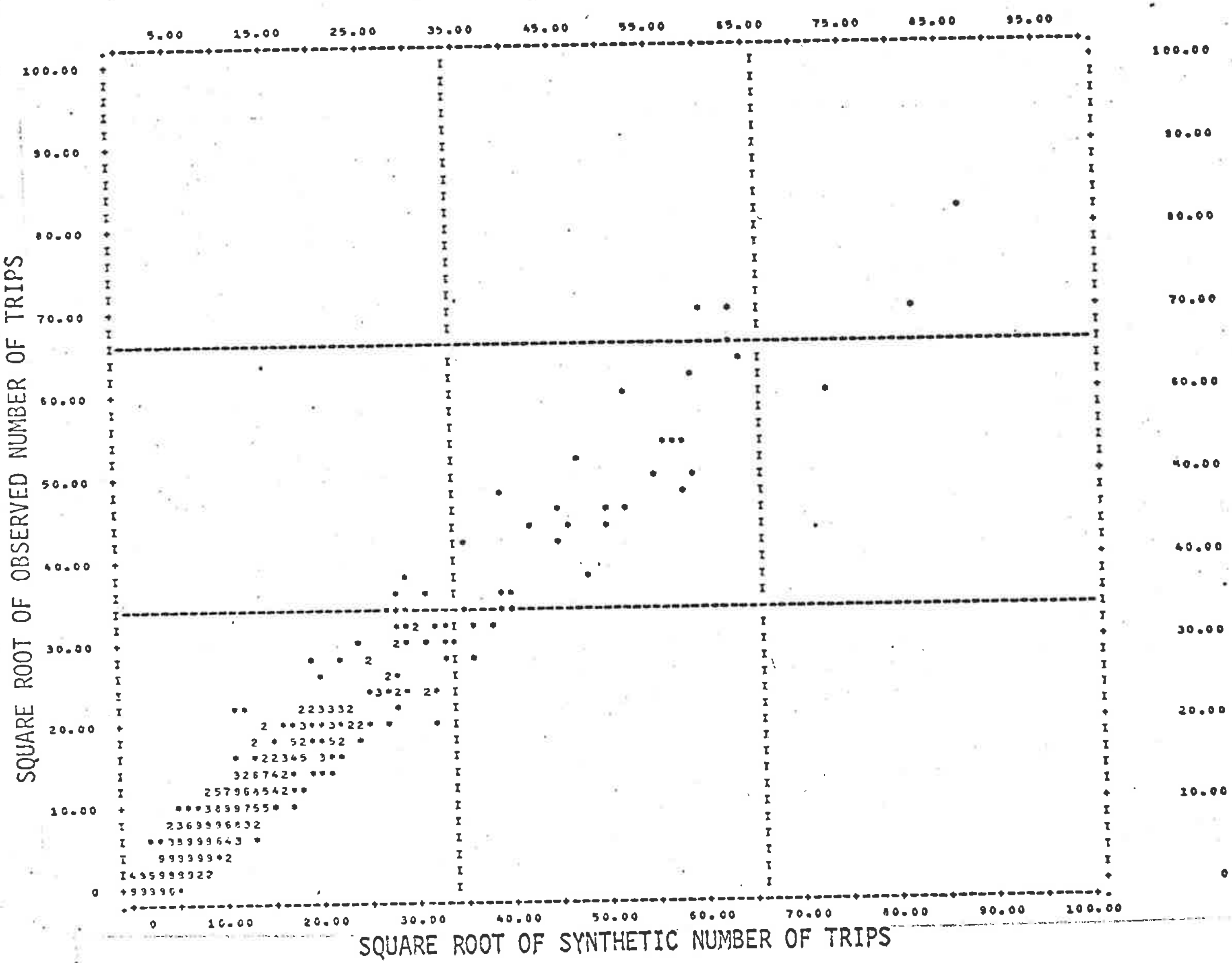

FIGURE 6.2: ALL MALE WORKERS

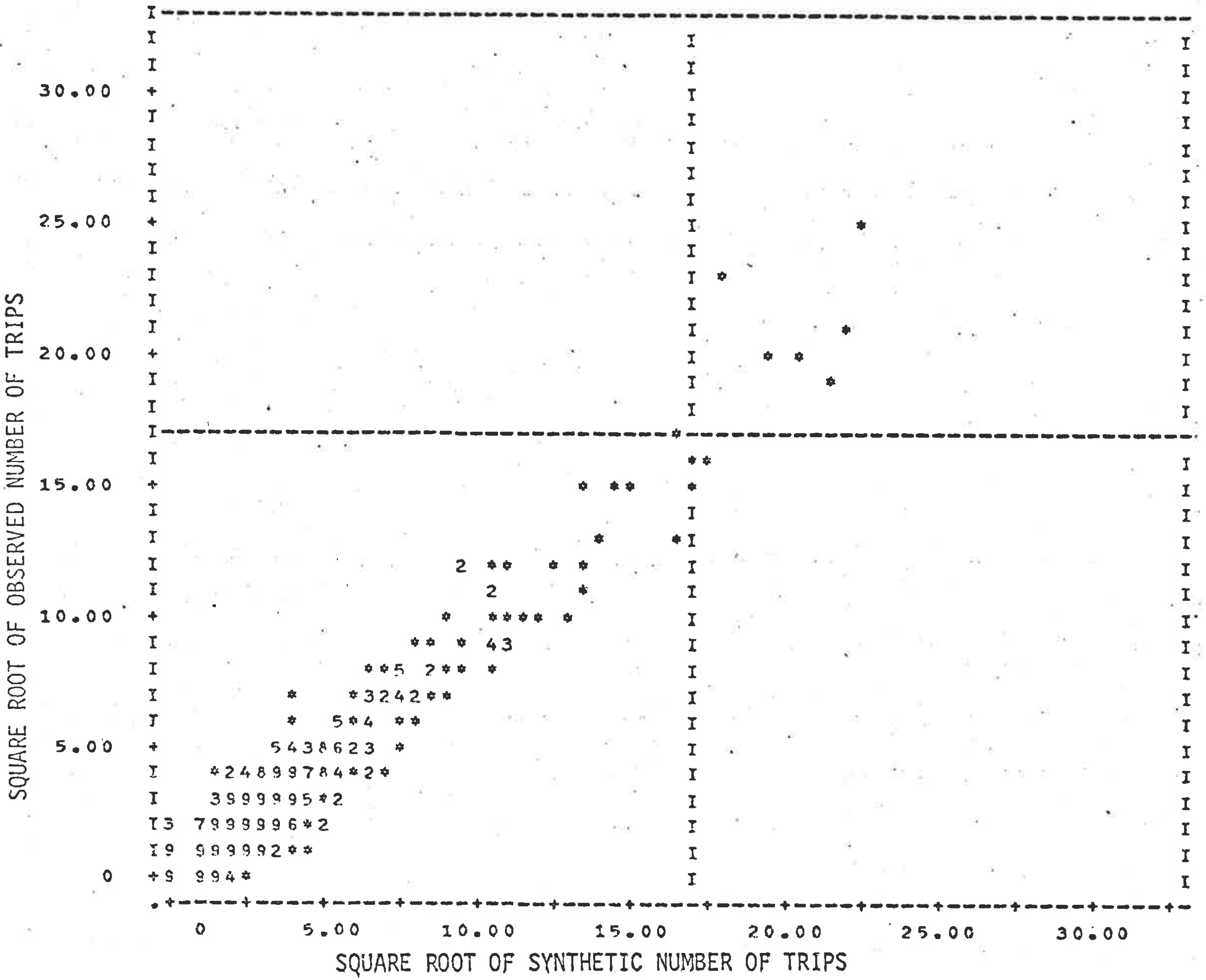

FIGURE 6.3: FEMALE PROFESSIONAL WORKERS.

numbers of trips. The clustering of points around the line $\sqrt{Y} = \sqrt{X}$ shown in these graphs occurred in all 27 categories.

The line-of-best-fit was calculated for each category and in all cases the intercept was very close to zero and the slope of the line was very close to 1.0: Values of the slope are shown in Tables 6.3 - 6.5. Apart from the categories; female administrative (slope = 0.931), female transport (0.901), and female other (0.912); the slope varies between 0.975 and 1.021, i.e. the central estimate of the observed value lies within 2.5% of the predicted value, whatever the magnitude. Hence proximity to the line of best fit represents proximity to the line $\sqrt{Y} = \sqrt{X}$ with little error in all categories.

The coefficient of correlation (R) is very close to unity for all categories except those containing small numbers of workers, viz. female transport/communication 2082 trips, female administrative 2850 trips, female other 2080 trips and male other 7242 trips. These categories have coefficients of correlation as low as $R = 0.89$ but in the overall planning context these are of small importance. In general higher coefficients of correlation were obtained for categories with larger numbers of trips.

The standard error of the estimate of $\sqrt{Y}$ (Se), which is a measure of the size of the variation from the line of best fit due to random errors inherent in any modelling process, varied between 0.74 and 1.19 in all categories except those with very large or very small total numbers of trips. For the large categories the standard error was higher than average and the small categories all had low standard errors - Table 6.6.

TABLE 6.6: STANDARD ERROR VALUES FOR VERY SMALL AND VERY LARGE CATEGORIES.

Category	Number of trips	Maximum $\sqrt{Y}$ value	Standard Error	Correlation coefficient
Female Admin.	2850	9	0.59	0.922
Female Transprot	2082	10	0.55	0.913
Female Other	2080	12	0.59	0.894
Male Craftsmen	93900	43	1.86	0.963
All Female	101791	63	1.79	0.978
All Craftsmen	108232	76	2.09	0.969
All Male	194848	81	2.37	0.977
All Workers	296639	106	3.00	0.976

The values in Table 6.6 show that the coefficient of correlation varies with the size of the standard error relative to the range of values of the ordinate (maximum $\sqrt{Y}$ value). Although very small standard errors (about 0.59) were obtained for the categories with very few trips (female admin., female transport and female other) the correlation coefficients were lower than average (about $R = 0.91$) because the range of the ordinate was very small in each case. On the other hand the larger categories of male craftsmen, all female, all craftsmen, all male and all workers had higher coefficients (about $R = 0.98$) and the standard errors were lower relative to the maximum $\sqrt{Y}$ values.

The 95% confidence limits of prediction calculated as described in section 5.2.2 for typical categories are given in Table 6.7. It is apparent that the range of confidence when expressed as a percentage of the central estimate decreases as that estimate increases. As movements of more than 1000 trips were considered significant, the confidence ranges on predictions of that order ($X = 900$ was used for case of calculation) were presented in Table 6.7. The male professional, female clerical, female sales and all administrative categories, which all have typical numbers of trips, all have 95% confidence ranges within ±16% at $X = 900$ trips. The male craftsmen category which at 93900 trips is by far the largest single category achieved a confidence range of ±27%. Thus for each cateogry there was a significant improvement in predictive accuracy (at $X = 900$ trips) over the ±42% from modelling all workers.

6.2 FOUR PREDICTED TRIP DISTRIBUTIONS

The predicted numbers of trips were aggregated over the two sexes, the eight occupational categories and the sixteen sex/occupation

TABLE 6.7: 95% CONFIDENCE LIMITS OF PREDICTION FOR SOME TYPICAL CATEGORIES.

Category	95% Confidence limits of prediction		95% Conf. range		Total number of trips (000's)
	General	at X = 900 trips	Trips	% of X	
Male Professional	$<.98X+3.4\sqrt{X}+3$	<987	+87	+10	20
	$>.98X-3.7\sqrt{X}+4$	>775	-125	-14	
Male Craftsmen	$<1.02X+7.1\sqrt{X}+12$	<1143	+243	+27	94
	$>1.02X-7.9\sqrt{X}+15$	>700	-200	-22	
Female Clerical	$<1.04X+3.6\sqrt{X}+3$	<1047	+147	+16	34
	$>1.04X-3.2\sqrt{X}+7$	>847	-53	-6	
Female Sales	$<1.00X+3.4\sqrt{X}+3$	<1004	+104	+12	14
	$>1.00X-4.2\sqrt{X}+4$	>778	-122	-14	
All Administrative	$<1.02X+3.7\sqrt{X}+3$	<1032	+132	+15	22
	$>1.02X-4.7\sqrt{X}+5$	>785	-115	-13	
All Workers	$<1.04X+10.5\sqrt{X}+26$	<1277	+377	+42	297
	$>1.04X+10.5\sqrt{X}+26$	>562	-338	-37	

categories to produce three additional (i.e. additional to the prediction obtained by calibrating the model for all workers) predictions of the total number of trips between each pair of zones.

The accuracy of the four predictions was compared using the analysis of correlation between square roots of numbers of trips described in section 5.2.2.

Graphical presentations of the relationship between the square roots of the predicted and observed numbers of trips are given in Figs. 6.4 to 6.7. Table 6.8 contains a summary of the statistics of correlation obtained from these graphs.

It can be seen from Table 6.8 that each of the predictions had a line of best fit with a slope very close to 1.0 and intercept not significantly different from zero. The slope for each of the three predictions from disaggregated data was closer to 1.0 than for the prediction from fully aggregated data, indicating some improvement in accuracy.

As discussed in section 5.2.2 the proximity of the coefficient of correlation to unity, given by the value of (1-R), is a comparative measure of goodness-of-fit. It can be seen from Table 6.8 that disaggregating data by sex and by occupation caused a 12% decrease in the value of 1-R from the fully aggregated prediction. This decrease comprised a 16% decrease due to disaggregation by occupation and a 4% increase due to disaggregation by sex. Thus a significant increase in accuracy resulted when data for workers in different occupations were modelled separately, and a less significant decrease in accuracy resulted when data for male and female workers were modelled separately.

The 95% confidence limits of prediction at X = 900 trips indicate that disaggregation by sex (±43%) decreases accuracy slightly

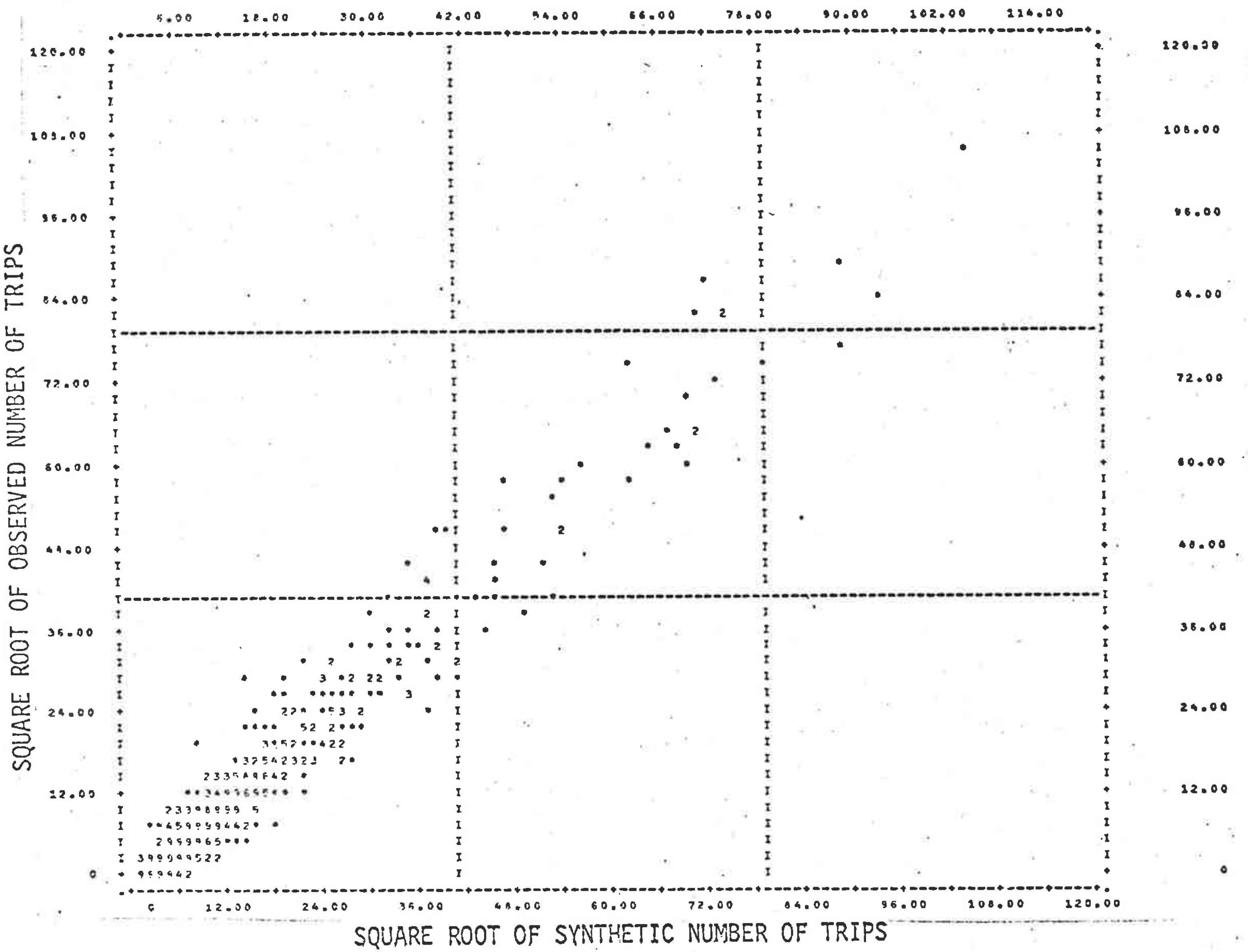

FIGURE 6.4: ALL WORKERS-AGGREGATED DATA.

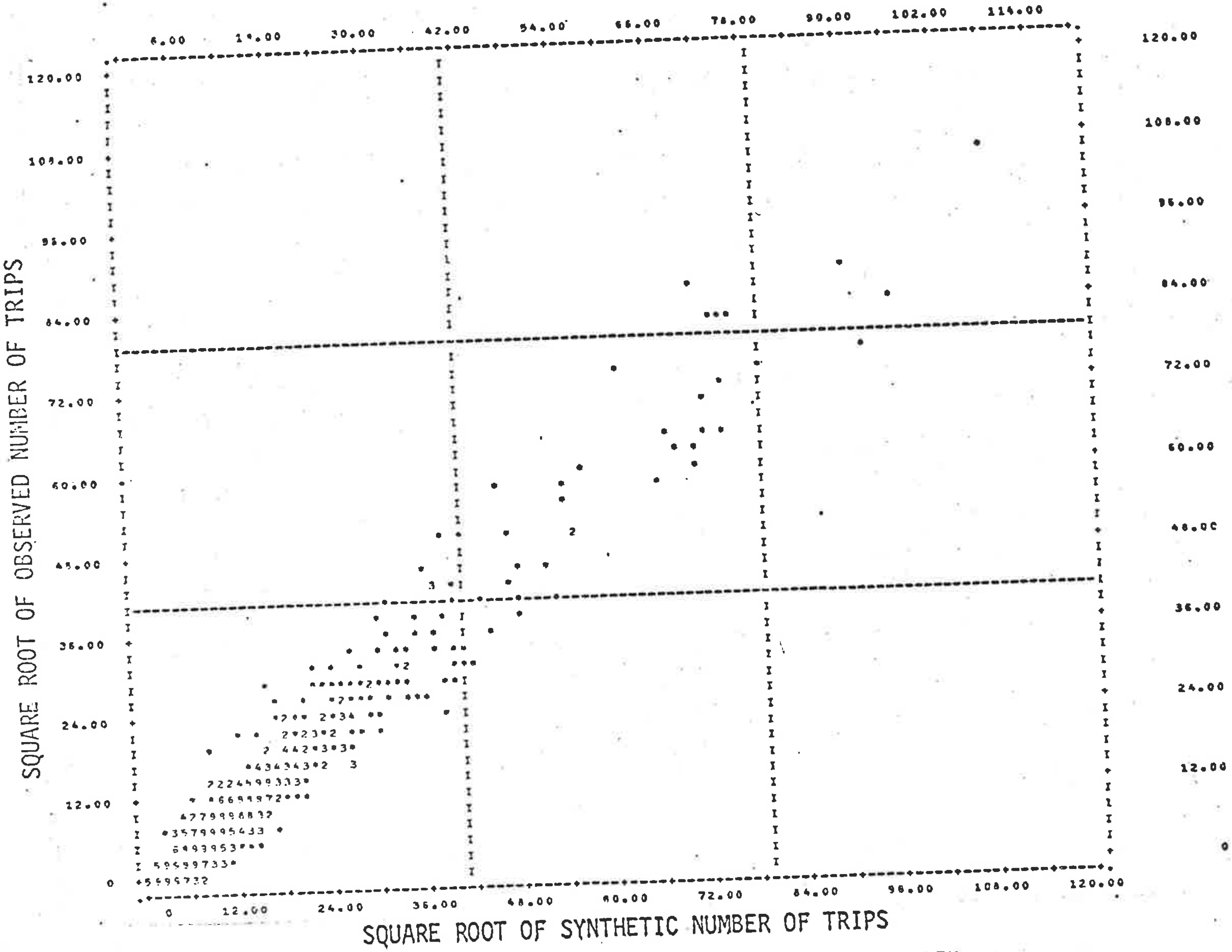

FIGURE 6.5 : ALL WORKERS-DATA SEPARATED BY SEX.

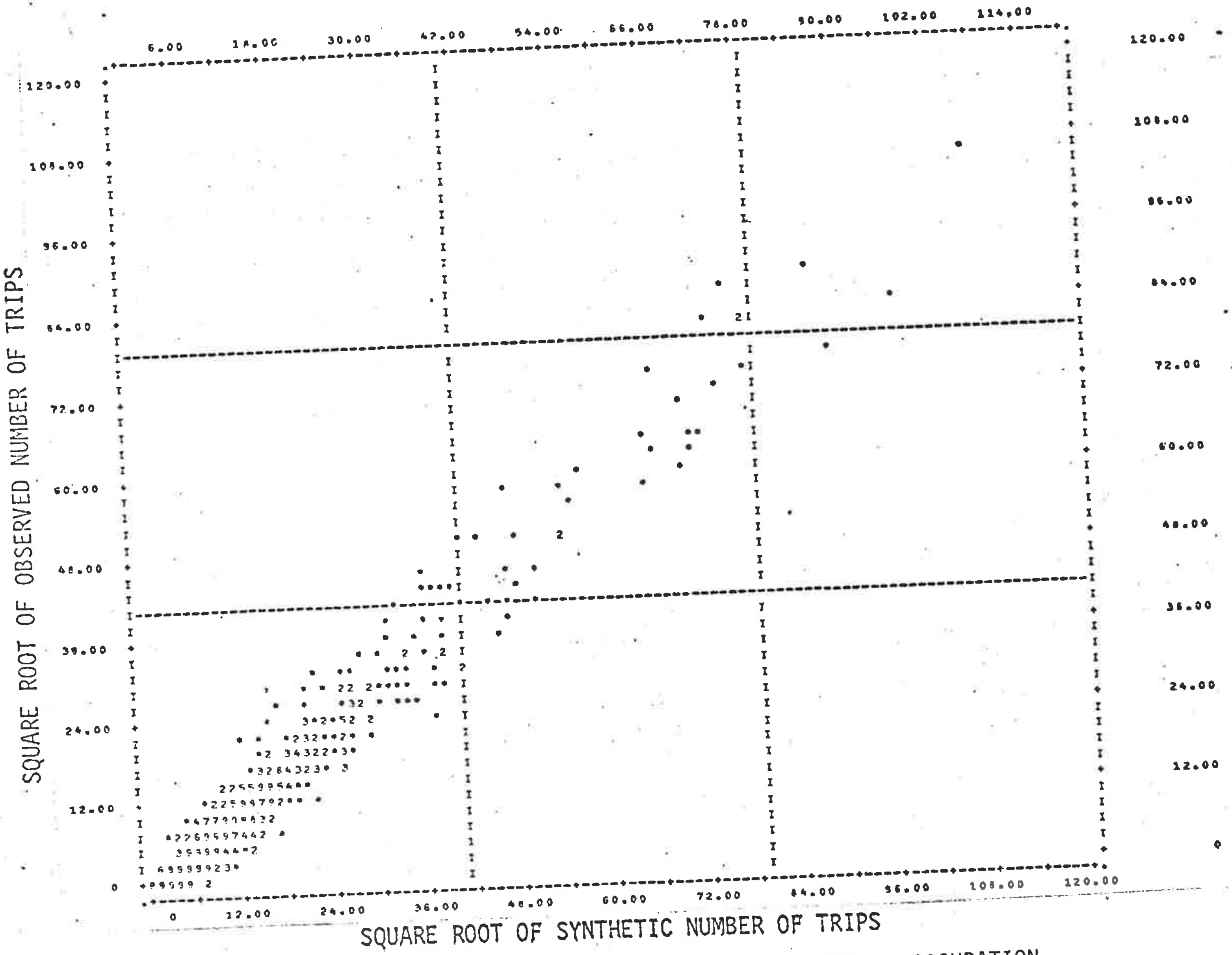

FIGURE 6.6: ALL WORKERS-DATA SEPARATED BY OCCUPATION

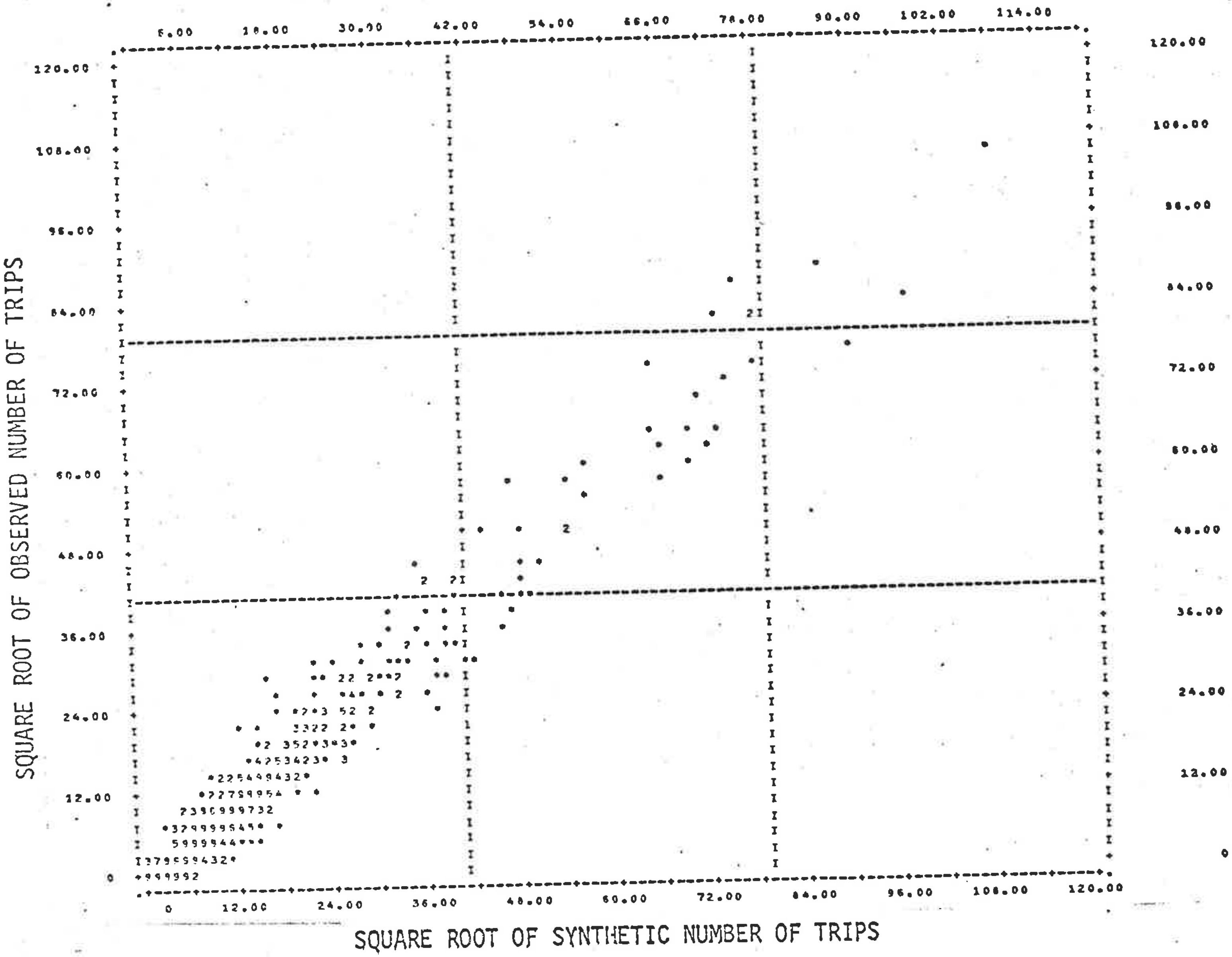

FIGURE 6.7: ALL WORKERS-DATA SEPARATED BY SEX AND OCCUPATION.

TABLE 6.8: STATISTICS OF CORRELATION FOR SQUARE ROOTS OF NUMBERS OF TRIPS FOR FOUR PREDICTIONS OF ALL TRIPS.

Level of disaggregation	Number of categories summed	R (1)	(1-R)	Intercept (A) (2)	Slope (B) (3)	Standard error of estimate (4)
None	1	.976	.024	-.84	1.016	3.00
By sex	2	.975	.025	-.29	.995	3.08
By occupation	8	.980	.020	-.36	1.000	2.77
By sex and occ.	16	.979	.021	-.13	.993	2.79

In all cases: $0 < \sqrt{Y} < 103$

Notes: (1) R is the coefficient of correlation.

(2) A is the intercept at $\sqrt{X}=0$ of the line of best fit.

(3) B is the slope of the line of best fit between $\sqrt{Y}$ and $\sqrt{X}$.

(4) The standard error of the estimate can be used to calculate confidence intervals for the predicted values $\sqrt{X}$ since the points are normally distributed about the line $\sqrt{Y} = \sqrt{X}$.

while disaggregation by occupation (±38%) or by sex and occupation (±40%) increases accuracy slightly from the original value of ±42%.

6.3 MAJOR MOVEMENTS

The accuracy of the four predictions in modelling the significant movements (more than 1000 trips) of section 5.4 was compared using the mean-percentage error. For each prediction the mean percentage errors in estimation of the significant intra-zonal, inter-zonal to CBD and inter-zonal non-CBD movements are given in Table 6.9. These values show that disaggregating data by occupation improved accuracy of estimation of inter-zonal movements but decreased that of intra-zonal movements, disaggregating data by sex decreased the accuracy of estimation of all three types of significant movement and disaggregating data by sex and occupation decreased the accuracy of estimation of intra-zonal movements but increased the accuracy for inter-zonal movements (both CBD and non-CBD).

Tables 6.10 - 6.12 which give the mean percentage errors for each of the four predictions of the 63 movements, show that in general disaggregating data by sex decreases accuracy of estimation slightly while disaggregating data by occupation or by sex and occupation increases the accuracy of estimation.

6.4 SUMMARY

This chapter has examined the accuracy of prediction achieved by the gravity model when applied to data disaggregated by sex and occupation.

Section 6.1 showed that the model is sensitive to changes in the observed distribution of trips (i.e. between categories). The parameters of the friction factor function varied between $1/\lambda = 5$ minutes

TABLE 6.9: ANALYSIS OF MEAN PERCENTAGE ERROR OF PREDICTION OF SIGNIFICANT MOVEMENTS (MORE THAN 1000 OBSERVED TRIPS).

Type of movement	Level of disaggregation of data			
	None	by sex	by occ	by sex & occ
Intra-zonal	20	27	21	24
to CBD	21	22	16	17
Inter-zonal (non-CBD)	26	26	25	25
All movements	23	25	21	22

TABLE 6.10: MAJOR INTRA-ZONAL MOVEMENTS (MORE THAN 1000 OBSERVED TRIPS).

Zone	Obs. trips	Level of disaggregation of data							
		None		By sex		By occ		By sex & occ	
		Pred trips	% diff.	Pred trips	% diff.	Pred trips	% diff.	Pred trips	% diff
1	3871	4953	+28	5001	+29	4850	+25	4405	+14
2	1258	1521	+21	1724	+37	1517	+21	1648	+31
3	2197	2159	-2	2363	+8	2203	0	2416	+10
4	1912	1430	-25	1473	-23	1382	-28	1603	-16
7	4032	4855	+20	5170	+28	4923	+22	4536	+13
8	7285	9016	+24	9305	+28	9435	+30	9704	+33
14	5951	8165	+37	8656	+45	8020	+35	8427	+42
16	3978	4437	+11	4751	+19	4344	+9	4114	+3
17	1103	1396	+27	1614	+46	1623	+47	1784	+62
18	3384	4059	+20	4569	+35	4196	+24	4504	+33
20	6814	5309	-22	5281	-22	5434	-20	5578	-18
23	4321	5306	+22	5673	+31	5289	+22	5509	+27
25	1851	2068	+12	2412	+30	2159	+17	2398	+30
27	2624	1534	-42	1680	-36	1609	-39	1730	-34
29	4928	4989	+1	5158	+5	4906	0	5117	+4
31	11167	11294	+1	11661	+4	11531	+3	12401	+11

TABLE 6.11: MAJOR MOVEMENTS TO THE CBD (MORE THAN 1000 OBSERVED TRIPS).

Origin Zone	Obs Trips	None: Pred trips	None: % diff.	By sex: Pred trips	By sex: % diff.	By occ: Pred trips	By occ: % diff.	By sex & occ: Pred trips	By sex & occ: % diff.
2	2772	1586	-43	1419	-49	1946	-30	1831	-34
3	5798	3971	-32	3677	-37	4340	-25	4181	-28
4	4460	5315	+19	5007	+12	5044	+13	4906	+10
7	1823	1698	-7	1479	-19	1672	-8	1485	-19
8	8146	8126	0	7902	-3	7677	-6	7470	-8
10	1928	1452	-25	1367	-29	1627	-16	1549	-20
11	2010	2170	+8	2121	+6	2340	+16	2307	+15
13	1236	1380	+12	1313	+6	1318	+7	1267	+3
14	7778	5267	-32	4801	-38	5848	-25	5480	-30
16	6928	5753	-17	5272	-24	6218	-10	5992	-14
18	1647	1382	-15	1128	-32	1329	-19	1175	-29
19	2104	2769	+32	2657	+26	2584	+23	2543	+21
20	1721	2806	+63	2729	+59	2485	+44	2370	+38
21	2673	3012	+13	2948	+10	2936	+10	2899	+8
22	1228	1566	+28	1515	+23	1471	+20	1442	+17
23	4281	4685	+9	4329	+1	4322	+1	4066	-5
25	3760	3351	-11	3025	-20	3280	-13	3090	-18
26	1005	1686	+68	1661	+65	1413	+41	1410	+40
27	5437	5607	+3	5436	0	5642	+4	5520	+2
28	1108	1091	-1	1066	-4	1144	+3	1135	+3
29	6719	5726	-15	5543	-18	6113	-9	5947	-11
31	5816	6311	+8	6089	+5	6253	+8	5870	+1

TABLE 6.12: MAJOR INTER-ZONAL MOVEMENTS (OTHER THAN TO CBD) (MORE THAN 1000 OBSERVED TRIPS).

Zones	Obs trips	Level of disaggregation of data							
		None		By sex		By occ		By sex & occ	
		Pred trips	% diff.	Pred trips	% diff.	Pred trips	% diff.	Pred trips	% diff.
7-23	2131	1256	-42	1219	-43	1258	-41	1268	-40
8-20	1382	1448	+5	1387	0	1454	+5	1430	+3
8-29	1170	682	-42	670	-43	729	-38	716	-39
8-31	3394	2077	-39	2029	-40	2139	-37	2110	-38
11-31	1006	1117	+11	1127	+12	1035	+3	1037	+3
14-16	1992	1366	-30	1397	-30	1240	-38	1354	-32
14-29	2744	3043	+11	3036	+11	2939	+7	2972	+8
16-14	1891	1341	-29	1463	-23	1257	-34	1263	-33
16-27	1105	1709	+55	1808	+64	1686	+53	1736	+57
16-29	1122	1104	-2	1113	-1	9993	-11	1007	-10
17-7	1603	1469	-8	1509	-6	1525	-5	1529	-5
17-23	1052	459	-56	453	-57	457	-57	446	-58
18-14	1643	914	-44	889	-46	973	-41	934	-43
20-31	3079	2852	-7	2945	-4	3002	-3	3143	+2
21-8	1227	1061	-13	1086	-11	1086	-11	1097	-11
23-7	1825	1820	0	1928	+6	2006	+10	2064	+13
23-8	2582	2165	-16	2180	-16	2172	-16	2262	-12
23-31	1721	990	-42	951	-45	1038	-40	1018	-41
24-8	1399	1225	-13	1235	-12	1237	-12	1238	-12
29-14	1163	1107	-5	1151	-1	1094	-6	1097	-6
21-31	1564	2362	+51	2346	+50	2208	+41	2187	+40
31-8	1389	1000	-28	1009	-27	965	-31	954	-31
31-12	1289	893	-31	868	-33	883	-31	892	-31
31-20	3439	2948	-14	2842	-17	2925	-15	2881	-16
31-27	1369	1972	+44	1985	+45	2055	+50	2063	+51

and $1/\lambda = 28$ minutes.

Section 6.1.2 examined the correlation between predicted and observed values on the basis of the square roots of numbers of trips. Proximity to the line-of-best-fit closely represented proximity to the line $\sqrt{Y} = \sqrt{X}$ in almost every category as the line-of-best-fit was within 2.5% of the line $\sqrt{Y} = \sqrt{X}$ in every category except three with small numbers of trips. For those categories with line-of-best-fit equal to $\sqrt{Y} = \sqrt{X}$ the coefficient of correlation varied between $R = 0.948$ and $R = 0.978$ and the standard error between 0.7 and 3.0.

The 95% confidence limits of prediction were typically ±16% for a predicted value of 900 trips. However the larger categories such as male craftsmen and all workers achieved less accuracy (±27% and ±42% respectively) at that value. The confidence limits become a smaller percentage of the central estimate as that estimate increases which indicates that the model is able to predict larger movements more satisfactorily than smaller movements.

Sections 6.2 and 6.3 examined the accuracy of the four total predictions obtained by summing the predictions from the separate categories. It was established that the line-of-best-fit between square roots of predicted and observed numbers of trips was very close to $\sqrt{Y} = \sqrt{X}$ for each of the predictions, and that the correlation coefficient was a legitimate statistic of goodness-of-fit.

The proximity to unity of the coefficient of correlation was shown to have increased by 16% as a result of separately modelling data for workers in different occupations, and to have decreased by 4% due to separately modelling male and female workers. Similarly the mean percentage error in "estimation of significant movements" went from 23% for a single application of the model to 25% for separate modelling of male and female workers, and to 21% for separate modelling of the different occupational categories.

The 95% confidence limits of prediction at X = 900 trips (i.e. the maximum error of prediction for 65% of trips) also indicated a slight decrease in accuracy due to disaggregation by sex (from ±42% to ±43%) and slight increases due to disaggregation by occupation (±38%) or by occupation and sex (±40%).

7. CONCLUSIONS

7.1 THE LITERATURE

The conventional process for analysis of transport was described in chapter 1. In this process the relation between travel and the factors that affect it is quantified using computer-based mathematical modelling.

From the literature reviewed in chapter 2 it was established that gravity models of various forms have been successful in providing that quantification in many cities throughout the world. The gravity model, of which Wilson (1967) provided a derivation, infers that movement between two zones is proportional to the sizes of the zones and inversely proportional to some function of their separation.

Investigation showed that the many different models discussed in chapter 2 were generally reduceable to that simple premise. However there have been many interesting variations to the basic model intended to increase the level of detail at which travel behaviour could be predicted.

For instance Edens (1970) used different functions of separation for zones of different accessibility, and showed that the function of separation used in any conventional gravity model was an area-wide average. Whilst the use of such a family of functions was beyond the scope of this study it was recognized that by using an area-wide average function some inaccuracy of prediction was likely to result, especially in outer zones where accessibilities are much lower than average. This and other variations to the basic model were rejected in the interest of maintaining simplicity.

7.2 DATA

Another cause of modelling inaccuracy was the choice of zones. As explained in chapter 4 the choice of zone system was restricted by the availability of data, the ability to handle large amounts of data, the travel time data available and the smallness of the numbers of trips. Beardwood and Kirby (1975) claimed that data is "compressible" within the gravity model i.e. that the level of zonal aggregation does not affect the accuracy of prediction. However their claim required that the travel-times be "suitably averaged".

By aggregating data to zones as large as those used in this study, the travel times used were forced to represent wider ranges of travel times, thus introducing inaccuracy into the modelling.

Beardwood and Kirby (1975) also claimed that data is "excludable" i.e. omitting all trips to or from a zone does not affect the predictions of the model. This implied that the treatment of a study area as a closed system involved no error. However most authors recognized that small errors result from the omission of all trips not completely contained within the study area.

In addition to being average values the travel-times used were not entirely appropriate for use with work-trips as the Bureau of Public Roads (1965) recommendation that off-peak times be used was followed in this study. Most journeys to work occur during the morning peak hour when congestion in some areas can severely increase some travel-times. However only off-peak travel-time data was available since the S.A. Highways Department uses a planning package which uses off-peak travel times and automatically allows for peak-hour congestion. While this lack of data is recognized it is difficult to estimate the error involved and the resulting lack of accuracy of the model.

Another inadequacy of the available data was the relative sizes of the Local Government Areas which were used as zones in this study.

The zones varied widely in spatial area (figure 4.1) and the size of resident workforce varied from 1200 in Col. Light Gardens to 28000 in Enfield (Table 4.4). Ideally zones for use in a predictive model should be similar in either area or population but this is not always possible in a developing centralized city such as Adelaide.

Similarly the division of data into occupational categories was very uneven with the male craftsmen category including 94000 workers and the female transport category including only 2000 workers. Ideally occupations should be grouped to give similar sized categories.

7.3 THE MODEL

Although the model used in this study was able to predict trip movements with reasonable accuracy, the calibration procedure was not as sensitive as it might have been.

The use of the trip length frequency distribution as a statistic to be matched is the main area of concern. It was apparent from the intermediate results of the calibration process (appendix C) that the calibration parameters converged quickly towards the final values, and that the several iterations required to match the trip length frequency distribution often caused only very small changes in the values of the parameters and in the individual predicted movements. The difficulty arises because of the large number of degrees of freedom involved in predicting the 961 movements of this study compared to the small number of degrees of freedom involved in matching the 25 intervals of the trip length frequency distributions. There are many trip distributions that have the same trip length frequency distribution given a fixed travel-time matrix.

Thus the calibration process does not generally force the predicted distribution much closer to the observed distribution once the basic shape of the deterrence function has been established, but conversely the process does establish the basic shape of the deterrence function very quickly.

To cause large changes to the predicted trip distribution it would be necessary to use a statistic with many more degrees of freedom such as a trip length frequency distribution with intervals of one-half minutes instead of two minutes. The use of intervals of one-minute was investigated but it was found that the trip length frequency distribution exhibited an unacceptable irregular "saw-tooth" shape due to the limited accuracy of the available data on travel times.

7.4 THE RESULTS

In chapter 5 it was shown that:

(i) Common statistics such as mean percentage error and root-mean -square-error give a misleading impression of goodness-of-fit;

(ii) Linear correlation and regression analyses, including confidence limits of prediction based on standard errors, gave a much more realistic assessment of accuracy; and

(iii) Graphical presentation was useful in demonstrating goodness-of-fit.

Considering all journeys to work, about 65% of all trips were involved in 63 movements containing more than 1000 trips. The mean percentage error in prediction of these movements was 23% but more importantly the 95% confidence limits on the prediction of these 63 movements was less than ±42% and this figure decreased rapidly as the value of the prediction increased (e.g. at $X = 5000$ trips the confidence range is ±23%).

It was concluded that since: (i) the accuracy of the travel times is probably no better than 12%; (ii) an area-wide average deterrence function was used; (iii) external trips were omitted; (iv) off-peak travel times were used to represent peak-hour trips; and (v) the size of the zones varied widely; the performance of the model is predicting 95% of movements to within fifteen times their square root is satisfactory.

Many of the significant errors in prediction occurred with movements to or from outer zones due probably to the mixture of urban and rural travel behaviour within the same zones.

In chapter 6 it was shown that the 95% confidence limits of prediction at $X = 900$ trips were within ±16% for almost every category of worker. Only the larger categories had wider confidence ranges. Hence it was concluded that there can be reasonable confidence in any prediction over about 900 trips from application of the model used in this study to any of the 27 categories of worker.

In section 6.3 it was shown that a small but significant increase in accuracy could be achieved by separate modelling of trips by workers in different occupations, but that separate modelling of male and female workers produced slightly less accurate predictions. The result of separating data by sex and occupation was to increase the accuracy slightly less than for separate modelling of the occupational categories.

The increase in accuracy from disaggregation of data by occupation was expected since workers in any one occupation were expected to behave more like each other than like any other workers. The only explanation offered for the decrease in accuracy due to disaggregation by sex is the interdependence of the two sexes due to marriage, cohabitation and the restriction of the freedom of choice of at least one spouse with regard to location of employment.

It was concluded that, for general planning purposes, the improvement in predictive accuracy from disaggregation of data by occupation is not worth the extra time and computing costs involved. The same may not be true of other socio-economic variables such as car ownership, income age etc. - there is scope for further research. However it is probable that the inherent errors discussed earlier masked the real effect of the additional variables.

When applied to the overall trip data the model achieved an accuracy of prediction sufficient for general planning purposes (±23% at 5000 trips). By paying slightly more attention to accuracy of input data (particularly travel-times) the accuracy of prediction obtainable with this model could probably be increased. There could be real confidence in the model as a planning tool. Expected changes in trip distribution over short time periods could be confidently predicted provided origin, destination and travel-time information was available for the design year.

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APPENDIX A: CLASSIFICATION OF OCCUPATIONS

(1) PROFESSIONAL, TECHNICAL AND RELATED WORKERS:

Architects, Engineers and Surveyors, Professional;

Chemists, Physicists, Geologists and Other Physical Scientists;

Biologists, Veterinarians, Agronomists and Related Scientists;

Medical Practitioners and Dentists;

Nurses, including Probationers or Trainees;

Professional Medical Workers, n.e.c.;

Teachers;

Clergy and Related Members of Religious Orders;

Law Professionals;

Artists, Entertainers, Writers and Related Workers;

Draftsmen and Technicians, n.e.c.;

Other Professional, Technical and Related Workers.

(2) ADMINISTRATIVE, EXECUTIVE AND MANAGERIAL WORKERS:

Administrative and Executive Officials, Government, n.e.c.;

Employers, Workers on Own Account, Status O, Directors, Managers, n.e.c..

(3) CLERICAL WORKERS:

Book-keepers and Cashiers;

Stenographers and Typists;

Other Clerical Workers.

(4) SALES WORKERS:

Insurance, Real Estate Salesmen, Auctioneers and Valuers;

Commercial Travellers and Manufacturers Agents;

Proprietors and Shopkeepers, Workers on Own Account, n.e.c.;

Status O, Retail and Wholesale Trade, Salesmen, Shop Assistants and Related Workers.

(5) FARMERS, FISHERMEN, HUNTERS, TIMBER GETTERS AND RELATED WORKERS:

Farmers and Farm Managers;

Farm Workers, including Farm Foremen;

Wool Classers;

Hunters and Trappers;

Fishermen and Related Workers;

Timber Getters and Other Forestry Workers.

(6) MINERS, QUARRYMEN AND RELATED WORKERS:

Miners, Mineral Prospectors and Quarrymen;

Well Drillers, Oil, Water and Related Workers;

Mineral Treaters.

(7) WORKERS IN TRANSPORT AND COMMUNICATION:

Deck and Engineer Officers, Ship, not Services;

Deck and Engine Room Hands, Ship and Boatmen, not Services;

Aircraft Pilots, Navigators and Flight Engineers, not Services;

Drivers and Firemen, Rail Transport;

Drivers, Road Transport;

Guards and Conductors, Railway;

Inspectors, Supervisors, Traffic Controllers and Despatchers, Transport;

Telephone, Telegraph and Related Telecommunication Operators;

Postmasters, Postmen and Messengers;

Workers in Transport and Communication, n.e.c..

(8) TRADESMEN, PRODUCTION-PROCESS WORKERS AND LABOURERS, N.E.C.:

Spinners, Weavers, Knitters, Dyers and Related Workers;

Tailors, Cutters, Furriers and Related Workers;

Leather Cutters, Lasters, Sewers (except Gloves and Garments) and Related Workers;

Furnacemen, Rollers, Drawers, Moulders and Related Metal Making and Treating Workers;

Precision Instrument Makers, Watchmakers, Jewellers and Related Workers;

Toolmakers, Metal Machinists, Mechanics, Plumbers and Related Metal Workers;

Electricians and Related Electrical and Electronic Workers;

Metal Workers, Metal and Electrical Production-Process Workers, n.e.c.;

Carpenters, Woodworking Machinists, Cabinetmakers and Related Workers, Painters and Decorators;

Bricklayers, Plasterers and Construction Workers, n.e.c.;

Compositors, Printing Machinists, Engravers, Bookbinders and Related Workers;

Potters, Kilnmen, Glass and Clay Formers and Related Workers;

Millers, Bakers, Butchers, Brewers and Related Food and Drink Workers;

Chemical, Sugar and Paper Production-Process Workers;

Tobacco Preparers and Tobacco Product Makers;

Paper Products, Rubber, Plastic and Production-Process Workers, n.e.c.;

Packers, Wrappers, Labellers,

Stationary Engine, Excavating and Lifting Equipment Operators;

Storemen and Freight Handlers;

Labourers, n.e.c.

(9) SERVICE, SPORT AND RECREATION WORKERS:

Fire Brigade, Police and Other Protective Service Workers;

Housekeepers, Cooks, Maids and Related Workers;

Waiters, Bartenders;

Caretakers, Cleaners, Buildings;

Barbers, Hairdressers and Beauticians;

Launderers, Dry Cleaners and Pressers;

Athletes, Sportsmen and Related Workers;

Photographers and Camera Operators;

Undertakers and Crematorium Workers;

Service, Sport, Recreation Workers, n.e.c.

(10) MEMBERS OF ARMED SERVICES:

Officers, Royal Australian Air Force;

Other Ranks, Royal Australian Air Force;

Officers, Australian Military Forces;

Other Ranks, Australian Military Forces;

Officers, Royal Australian Navy;

Other Ranks, Royal Australian Navy;

Officers, Overseas Forces in Australia;

Other Ranks, Overseas Forces in Australia.

(11) OCCUPATION INADEQUATELY DESCRIBED OR NOT STATED:

Occupation Inadequately Described or Not Stated: excluding Managerial Workers, "Other and Inadequately Described or Not Stated" code No. 119 Major Group 1.

APPENDIX B: STATISTICAL PROCEDURES

B.1 GOODNESS-OF-FIT STATISTICS.

Chi-squared is defined as:

$$\sum_i \sum_j \frac{(n_{ij} - m_{ij})^2}{n_{ij}} .$$

Mean percentage error is:

$$\frac{100}{N} \sum_i \sum_j \frac{|n_{ij} - m_{ij}|}{n_{ij}} .$$

Root-mean-square-error is:

$$\{\frac{1}{N} \sum_i \sum_j (n_{ij} - m_{ij})^2\}^{\frac{1}{2}}$$

where n_{ij} is the observed number of trips;

m_{ij} is the synthesized number of trips; and

N is the number of cells in the matrix.

(Source: Burington and May, 1970).

B.2 REGRESSION AND CORRELATION ANALYSIS.

A simple linear regression was used to fit a straight line to a series of data points in Section 5.3. The line was of the form:

$$Y = a + bX$$

and the formulae used to calculate a and b were:

$$b = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sum_{i=1}^{n} (X_i - \bar{X})^2}$$

where X_i = the ith observation of variable X (horizontal axis);

Y_i = the ith observation of variable Y (vertical axis);

N = number of observations;

$\bar{X}$ = mean of variable X; and

$\bar{Y}$ = mean of variable Y;

and a = $\bar{Y} - b\bar{X}$.

The Pearson product-moment correlation coefficient (r) was used to measure the strength of relationship between the two variables. In this case, the strength of relationship indicates both the goodness-of-fit of the linear regression line to the data and - when r is squared, the proportion of variance in one variable explained by the other.

The correlation coefficient varies between -1 and +1 with a coefficient of 0 indicating that there is no relation between the two variables; coefficients of +1 and -1 indicate perfect positive and negative correlation respectively.

Mathematically, r is defined as the ratio of covariation to square root of the product of the variation in X and the variation in Y, where X and Y symbolize the two variables. This corresponds to the formula:

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\left\{\left[\sum_{i=1}^{n} (X_i - \bar{X})^2\right]\left[\sum_{i=1}^{n} (Y_i - \bar{Y})^2\right]\right\}^{\frac{1}{2}}}$$

The standard error of the estimate is the standard deviation of the "residuals". Residuals are the errors made in predicting Y from X by the use of the regression equation. The formula for standard error of the estimate is:

$$Se = \left(\frac{\sum_{i=1}^{n} [Y_j \ (Y_i - a - bX_i \ )]}{n - 2} \right)^{\frac{1}{2}} \quad .$$

APPENDIX C: THE CALIBRATION PROGRAM

```
      PROGRAM BPRGM(TAPE4,INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
     ≠TAPE1,TAPE2,TAPE3,TAPE10)
C
C
C
C     THIS PROGRAM CALIBRATES THE GRAVITY MODEL TRIP DISTRIBUTION
C     PROCEDURE.
C     GIVEN TRIP END NUMBERS AND AN OBSERVED TRIP INTERCHANGE MATRIX,
C     PARAMETERS WILL BE CALCULATED WHICH MAXIMIZE THE GOODNESS-OF-FIT
C     OF THE SYNTHESIZED TRIP MATRIX TO THE OBSERVED.
C     THE PROGRAM WAS SPECIFICALLY DESIGNED FOR USE IN ADELAIDE WITH
C     31 LOCAL GOVERNMENT AREAS BUT MODIFICATIONS CAN EASILY BE MADE
C     TO OPERATE WITH ANOTHER NUMBER OF ZONES.
C          PROGRAMME WRITTEN, DEVELOPED AND TESTED BY
C
C                    T. W. HILL
C                    DEPT. OF CIVIL ENGINEERING
C                    UNIVERSITY OF ADELAIDE
C                    1977-8
C
C
C
      COMMON E(31,31),SS(31,31),PY(31),AY(31),FREQ(80),FF(80),FO(31,31),
     *D(80),FREQU(60),AYA(31),AYORIG(31),RR(31),AYAA(31)
      COMMON TT(31,31)
      DIMENSION OCC(9)
      COMMON RATIO(31,31),DIFF(31,31),OPT
C
C     OUTPUT OPTION    OPT=1 FOR MINIMUM OUTPUT
C                      OPT≠1 FOR FULL OUTPUT
C
      READ 16,OPT
   16 FORMAT(F3.0)
C
C     NUMBER OF ZONES
C
      NQ=31
      MINTIM=3
      MAXTIM=51
      INC=2
C
C
C     READ TRAVEL TIME MATRIX SS(I,J)
C
C
      REWIND 10
      DO 1 I=1,NQ
    1 READ (10,94) (SS(I,J),J=1,NQ)
   94 FORMAT(1H ,16F8.2)
      IF(OPT.EQ.1.) GO TO 97
      WRITE(6,95)
   95 FORMAT(1H1,*INTERZONAL TRAVEL TIME MATRIX SS(I,J)*)
      DO 96 I=1,NQ
      WRITE(6,94) (SS(I,J),J=1,NQ)
   96 CONTINUE
   97 CONTINUE
C
C
C     READ ACTUAL TRIP TABLE E(I,J) FOR CALIBRATION
C
C
      CALL READMAT(NQ,OCC)
      DO 647 I=1,NQ
      PY(I)=0.
      DO 645 J=1,NQ
      PY(I)=PY(I)+E(I,J)
  645 CONTINUE
  647 CONTINUE
      DO 640 J=1,NQ
      AY(J)=0.
      DO 642 I=1,NQ
      AY(J)=AY(J)+E(I,J)
  642 CONTINUE
      AYORIG(J)=AY(J)
  640 CONTINUE
      WRITE(6,641)
```

```
  641 FORMAT(1H0,////1X,*TRIP PRODUCTIONS OF ZONE I*)
      WRITE(6,643) (PY(I),I=1,NO)
  643 FORMAT(1H ,5X,*PY(I)*,3X,10F8.0)
      WRITE(6,645)
  645 FORMAT(1H0,*TRIP ATTRACTIONS OF ZONE J*)
      WRITE(6,644) (AY(J),J=1,NO)
  644 FORMAT(1H ,5X,*AY(J)*,3X,10F8.0)
C
C
C     CALCULATE ACTUAL AV TRIP LENGTH (DBAR) FROM E(I,J)
C
C
      CALL EDBAR(NO,COT,TRIPS,DBAR)
  920 CONTINUE
C
C     CALCULATE ACTUAL FREQUENCY TABLE
C
      WRITE(6,534)
  534 FORMAT(1H1,*ACTUAL FREQUENCY TABLE*)
      OPT1=0.
      CALLFRTBLE(NO,FREQ,SS,E,TRIPS,DBAR,MINTIM,MAXTIM,INC,OPT,OPT1)
C
C
      DO 100 I=1,MAXTIM
  100 FF(I)=1.
      WRITE(6,101)
  101 FORMAT(1H1,10X,*INITIAL TRAVEL TIME FACTORS*)
      WRITE(6,102) (FF(I),I=MINTIM,MAXTIM,INC)
  102 FORMAT(1H0,2X,15F8.0)
      PRINT 306,MINTIM,INC
      MM=0
      NN=0
  145 CONTINUE
C
C     CALCULATE TRAVEL TIME FACTORS FO(I,J)
C
      CALL          TTFACT (MINTIM,MAXTIM,INC,NO,FACTOR)
 1555 CONTINUE
      MM=MM+1
C
C
C     CALC TRIP TABLE TT(I,J) FROM KNOWN TRIP ENDS PY(I) AND AY(J)
C
C
      CALL TTDIST(NO)
C
C     CALCULATE AV TRIP LENGTH (SYNTHETIC) SBAR FROM TT(I,J)
C
      CALL MODAVL(NO,TOTT,TTRPP,SBAR)
      ERROR= ABS((DBAR-SBAR)/DBAR*100.)
      WRITE(6,420) ERROR
  420 FORMAT(1H0,*TRAVEL TIME ERROR*,F7.2,*  PER CENT*)
C
C     CALCULATE SYNTHETIC FREQ TABLE
C
      IF(OPT.EQ.1.) GO TO 536
      WRITE(6,535)
  535 FORMAT(1H1,*SYNTHETIC FREQUENCY TABLE*)
536   CONTINUE
      IF(OPT.EQ.1.) OPT1=1.
      CALL FRTBLE(NO,FREQU,SS,TT,TTRPP,SBAR,MINTIM,MAXTIM,INC,OPT,OPT1)
      OPT1=0.
C
C     COMPARE TRIP LENGTH FREQ. DISTRIBUTIONS AND MODIFY TRAVEL TIME
C              FACTORS FF IF NECESSARY
C
      NCOUNT=0
      DO 150 K=MINTIM,MAXTIM,INC
      DIF=ABS(FREQ(K)-FREQU(K))
      IF(DIF.LT.0.5) NCOUNT=NCOUNT+1
  150 CONTINUE
      MAXN=(MAXTIM-MINTIM)/INC+1
      PRINT 430,NCOUNT,MAXN
  430 FORMAT(1H0,///* THERE ARE*,I4,*  OUT OF*,I4,*  VALUES OF SYNTH FRE
     *QUENCY WITHIN 0.5 PER CENT OF ACTUAL FREQUENCY*)
      NS=(MAXTIM-MINTIM)*4/5/INC
```

```
      IF(NCOUNT.GT.NS.AND.ERROR.LE.3.) GO TO 146
      IF(MM.EQ.4) GO TO 146
C
C     MODIFY TRAVEL TIME FACTORS
C
      WRITE(6,654)
  654 FORMAT(1H1,*COMPARISON UNSATISFACTORY - MODIFY TRAVEL TIME FACTORS
     * AND REPEAT*,////)
      DO 200 K=MINTIM,MAXTIM,INC
      IF(FREQU(K).NE.0.) FF(K)=FF(K)*FREQ(K)/FREQU(K)
  200 CONTINUE
      WRITE(6,305) (FF(I),I=MINTIM,MAXTIM,INC)
  305 FORMAT(1H0,*MODIFIED TRAVEL TIME FACTORS*,(//4X,15F8.2))
      PRINT 306,MINTIM,INC
C
C     FIT FUNCTION TO MODIFIED TRAVEL TIME FACTORS
C
      CALL TAN(FF,MINTIM,MAXTIM,INC)
      WRITE(6,300) (FF(I),I=MINTIM,MAXTIM,INC)
 300  FORMAT(1H0,20X,
     **TRAVEL TIME FACTORS MODIFIED TO FIT THE CURVE*,(//4X,15F8.2))
      PRINT 306,MINTIM,INC
  306 FORMAT(*0(FIRST VALUE = 0-*,I3,* MINUTES , EACH SUCCESSIVE VALUE =
     C NEXT*,I3,* MINUTE INTERVAL)*)
      GO TO 145
  146 CONTINUE
C
C     CALCULATE SYNTHETIC COLUMN SUMS AND COMPARE TO ACTUAL AY VALUES
C
      CALL SOMA(NO)
      NAA=0
      DO 683 J=1,NO
      CRITAA=ABS(1-AYAA(J))
      IF(CRITAA.LE.0.10) NAA=NAA+1
  683 CONTINUE
      WRITE(6,687) NAA
  687 FORMAT(1H0,*THERE ARE*,I4,*  VALUES OF AYA(J) WITHIN 10 PER CENT O
     *F AYORIG(J)*)
      NAYTOL=0.8*NO
      NN=NN+1
      IF(NN.EQ.2.OR.NAA.GE.NAYTOL) GO TO 1999
C
C     MODIFY AY VALUES AND RESTART CALIBRATION
C
      WRITE(6,684)
  684 FORMAT(1H1,*COMPARISON UNSATISFACTORY - MODIFY ATTRACTIONS AND REP
     *EAT*,////)
      MM=0
      DO 688 J=1,NO
      AY(J)=AY(J)*AYORIG(J)/AYA(J)
  688 CONTINUE
      GO TO 1555

 1999 CONTINUE
      WRITE(6,685)
  685 FORMAT(1H0,*COMPARISON SATISFACTORY - CALIBRATION COMPLETE*)
C
C     MINIMUM OUTPUT OPTION
C
      IF(OPT.NE.1.) GO TO 700
      PRINT 710
 710  FORMAT(1H1,10X,*SYNTHETIC TRIP TABLE*,//)
      DO 720 I=1,NO
 720  PRINT 730,(TT(I,J),J=1,NO)
 730  FORMAT(1H ,16F8.0)
      PRINT 740,TOTT,TTRPP,SBAR
 740  FORMAT(1H0,10X,*TOTAL LENGTH OF TRAVEL*,5X,F12.0//
     +              11X,*TOTAL NUMBER OF TRIPS*,6X,F12.0//
     +              11X,*AV TRIP LENGTH SBAR*,7X,F10.3)
      PRINT 420,ERROR
      OPT=0
      PRINT 535
      CALL FRTBLE(NO,FREQU,SS,TT,TTRPP,SBAR,MINTIM,MAXTIM,INC,OPT,OPT1)
      PRINT 430,NCOUNT,MAXN
 700  CONTINUE
```

```
                CALL TESTMAT(NQ)
      C
      C         CALCULATE ACTUAL AND SYNTHETIC AVERAGE INTRA-ZONAL PERCENTAGE
      C
                TOTKF=TOTKG=0.
                DO 60 I=1,31
                TOTKF=TOTKF+TT(I,I)/PY(I)
      60        TOTKG=TOTKG+Z(I,I)/PY(I)
                TOTKG=TOTKG/31.*100.
                TOTKF=TOTKF/31.*100.
                PRINT 61,TOTKG,TOTKF
      61        FORMAT(/1H0,*ACTUAL AV. PER CENT*,
               +*INTRA-ZONAL IS*,F8.2,9X,*SYNTHETIC AV. PER CENT INTRA-ZONAL *
               +*IS*,F8.2)
                REWIND 4
                WRITE(4,997) OCC
      997       FORMAT(* SYNTHETIC TRIP TABLE FOR*,8A10)
                DO 1000 I=1,NQ
      1000      WRITE(4,998) (TT(I,J),J=1,NQ)
      998       FORMAT(1H ,15F8.0)
                ENDFILE 4
                STOP
                END
```

```
      SUBROUTINE READMAT(NQ,OCC)
      COMMON E(31,31),SS(31,31),PY(31),AY(31),FREQ(80),FF(80),FQ(31,31),
     *D(80),FREQU(80),AYA(31),AYORIG(31),RR(31),AYAA(31)
      COMMON TT(31,31)
      COMMON RATIO(31,31),DIFF(31,31),OPT
      DIMENSION OCC(8)
C
C     THERE ARE 11 OCCUPATION CATEGORIES
C              CATEGORY 12 COMPRISES CATEGORIES 5,6,10 AND 11
C              CATEGORY 13 IS THE TOTAL
C
      INTEGER POS(13),CAT,SEX
      DATA POS/1,2,3,4,0,0,5,6,7,0,0,8,9/
      REWIND 1
      REWIND 2
      REWIND 3
C
C        MALE=1      FEMALE=2      TOTAL=3
C
      READ(5,2) CAT,SEX
    2 FORMAT(2I2)
      NUM=(POS(CAT)-1)*125
      IF(NUM.EQ.0) GO TO 5
      DO 3 I=1,NUM
    3 READ(SEX,4) DUMMY
    4 FORMAT(A1)
    5 READ(SEX,205) OCC
  205 FORMAT(8A10)
      WRITE(6,201) OCC
  201 FORMAT(1H1,*ACTUAL TRIP TABLE FOR*,10X,8A10///)
  905 DO 906 I=1,NQ
C
C
C     READ ACTUAL TRIP TABLE AND TRIP PRODUCTIONS
C
C
      READ(SEX,907) (E(I,J),J=1,NQ)
  907 FORMAT(10F8.0)
      WRITE(6,908) (E(I,J),J=1,NQ)
  908 FORMAT(1H ,10F8.0)
  906 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EDBAR(NQ,COT,TRIPS,DBAR)
      COMMON E(31,31),SS(31,31),PY(31),AY(31),FREQ(80),FF(80),F0(31,31),
     *D(80),FREQU(80),AYA(31),AYORIG(31),RR(31),AYAA(31)
      COMMON TT(31,31)
      COMMON RATIO(31,31),DIFF(31,31),OPT
C
C
C     CALC AV ACTUAL TRIP LENGTH DBAR(MINUTES)
C
C
C     ACTUAL TOTAL LENGTH OF TRAVEL COT(MINS)
C     CALC ACTUAL TOTAL NO OF TRIPS - TRIPS
C
      COT=0.
      TRIPS=0.
      DO 910 I=1,NQ
      DO 910 J=1,NQ
      COT=COT+E(I,J)*SS(I,J)
      TRIPS= TRIPS+ E(I,J)
  910 CONTINUE
      WRITE(6,912) COT,TRIPS
  912 FORMAT(1H0,*TOT LENGTH OF TRAVEL TIME*,F12.0,20X,*TOT NO. OF TRIPS
     **,F12.0)
C
C     CALC ACTUAL AV TRIP LENGTH DBAR(MINS)
C
      DBAR = COT/TRIPS
      WRITE(6,915) DBAR
  915 FORMAT(1H0,5X,*AV ACTUAL TRIP LENGTH DBAR(MIN)*,3X,F10.2)
      RETURN
      END
```

```
      SUBROUTINE FRTBLE(NQ,TABLE,TIME,TTMTRX,TOT,AV,MINTIM,MAXTIM,INC,
     +OPT,OPT1)
      DIMENSION TABLE(80),TIME(31,31),TTMTRX(31,31)
      DIMENSION TAB(80)
      DIMENSION X(80),Y(80)
      IF(OPT.EQ.1) GO TO 680
      WRITE(6,615)
615   FORMAT(1H0,3X,*TIME INTERVAL     TRIPS    P/C *)
680   CONTINUE
C
C     CALCULATE TOTAL FREQUENCY DISTRIBUTION
C
      VAR=0.
      DO 600 K=1,80
      TABLE(K)=0.
  600 CONTINUE
      DO 612 J=1,NQ
      DO 611 I=1,NQ
      DO 609 K=MINTIM,MAXTIM,INC
      SK=K
      IF(TIME(I,J).LE.SK) GO TO 610
  609 CONTINUE
      TABLE(MAXTIM)=TABLE(MAXTIM)+TTMTRX(I,J)
      GO TO 611
  610 TABLE(K)=TABLE(K)+TTMTRX(I,J)
  611 CONTINUE
  612 CONTINUE
      DO 682 K=MINTIM,MAXTIM,INC
      TAB(K)=TABLE(K)
      TABLE(K)=TABLE(K)/TOT*100.
682   CONTINUE
C
C     PROCEED ONLY WHEN FULL OUTPUT REQUIRED, OTHERWISE RETURN
C
      IF(OPT1.EQ.1.) RETURN



C
C     CALCULATE FREQUENCY DISTRIBUTION OF TRIPS
C
      L=0
      DO 613 K=MINTIM,MAXTIM,INC
      WRITE(6,614) L,K,TAB(K),TABLE(K)
  614 FORMAT(1H0,I4,*   TO*,I4,*   MIN*,F8.0,F6.2)
      L=K
  613 CONTINUE
      PRINT 520,TOT,TOT*AV,AV
520   FORMAT(/1H0,*TRIPS          *,F14.0
     +          /1H0,*TRIP MINS    *,F14.0
     +          /1H0,*AV TRIP MIN*,F14.2)
C
C     CALCULATE STANDARD DEVIATION OF TRAVEL TIME
C
      FINC=INC
      DO 650 K=MINTIM,MAXTIM,INC
      FK=K
      VAR=VAR+TAB(K)*(FK-.5*FINC-AV)**2/(TOT-1.)
  650 CONTINUE
      SIGMA=SQRT(VAR)
      WRITE(6,651) VAR,SIGMA
  651 FORMAT(1H0,*SAMPLE VARIANCE*,F10.2/1H0,*STANDARD DEVIATION*,F7.2)
C
C     PLOT FREQUENCY TABLE
C
      LIMIT=(MAXTIM-1)/INC+1
      DO 317 JX=1,LIMIT
      IX=INC*JX-INC+1
      X(JX)=IX
      Y(JX)=TABLE(IX)
  317 CONTINUE
      CALL QIKPLT(X,Y,-LIMIT,1,23H*TRAVEL TIME (MINUTES)*,16H*TRIP FREQU
     CENCY*)
      RETURN
      END
```

```
          SUBROUTINE TTFACT (MINTIM,MAXTIM,INC,NO)
          COMMON F(31,31),SS(31,31),PY(31),AY(31),FREQ(80),FF(80),FQ(31,31),
         *D(80),FREQU(80),AYA(31),AYORIG(31),RR(31),AYAA(31)
          COMMON TT(31,31)
          COMMON RATIU(31,31),DIFF(31,31),OPT
C
C         CALCULATE TRAVEL TIME FACTORS FOR EACH ZONE PAIR
C                   FROM FACTOR VS. TIME CURVE
C
          DO 106 I=1,NO
          DO 104 J=1,NO
          DO 107 K=MINTIM,MAXTIM,INC
          SK=K
          IF(SS(I,J).GT.SK) GO TO 107
          FQ(I,J) = FF(K)
          GO TO 104
      107 CONTINUE
          FQ(I,J)=FF(MAXTIM)
      104 CONTINUE
      106 CONTINUE
C
          IF(OPT.EQ.1.) GO TO 109
          WRITE(6,103)
      103 FORMAT(1H0,10X,*TRAVEL TIME FACTORS BETWEEN ZONE PAIRS FQ(I,J)*)
          DO 108 I=1,NO
          WRITE(6,105) I,(FQ(I,J),J=1,NO)
      105 FORMAT(1H ,*FQ(*,I3,* ,J )*,15F8.2/4X,16F8.2)
      108 CONTINUE
      109 CONTINUE
          RETURN
          END
```

```
      SUBROUTINE TTDIST(NO)
      COMMON E(31,31),FS(31,31),PY(31),AY(31),FREQ(80),FF(80),FO(31,31),
     *D(80),FREQU(80),AYA(31),AYORIG(31),RR(31),AYAA(31)
      COMMON TT(31,31)
      COMMON RATIO(31,31),DIFF(31,31),OPT
C
C     OUTPUT OF ACCESSIBILITIES OPTION      OPT2=1 DO NOT PRINT
C                                           OPT2≠1 PRINT
C
      OPT2=1.
C
C
C     TRIP DISTRIBUTION AND CALCULATION OF ZONAL ACCESSIBILITIES
C
C
      IF(OPT2.EQ.1.) GO TO 1642
      WRITE(5,657)
  657 FORMAT(1H0,10X,*CALC ZONAL ACCESSIBILITIES*)
 1642 CONTINUE
C
C     CALC OF ZONAL ACCESSIBILITIES
C
      DO 654 J=1,NO
      RR(J)=0.
      DO 655 JA=1,NO
      RR(J)= RR(J)+ (AY(JA)*FQ(J,JA))
  655 CONTINUE
      IF(OPT2.EQ.1.) GO TO 654
      WRITE(6,656) RR(J)
  656 FORMAT(1H0,5X,10F10.0)
  654 CONTINUE
C
C     CALC OF TRIP DISTN TABLE(CALIB)
C
      IF(OPT.EQ.1.) GO TO 620
      WRITE(6,658)
  658 FORMAT(1H1,10X,*SYNTHETIC TRIP TABLE*,//)
  620 CONTINUE
      DO 659 I=1,NO
      DO 660 J=1,NO
      TT(I,J)=(PY(I)*AY(J)*FO(I,J))/RR(I)
  660 CONTINUE
      IF(OPT.EQ.1.) GO TO 659
      WRITE(6,661) (TT(I,J),J=1,NO)
  661 FORMAT(1H ,16F8.0)
  659 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MODAVL(NQ,TOTT,TTRPP,SBAR)
      COMMON E(31,31),SS(31,31),PY(31),AY(31),FREQ(80),FF(80),FO(31,31),
     *D(80),FREQU(80),AYA(31),AYORIG(31),RR(31),AYAA(31)
      COMMON TT(31,31)
      COMMON RATIO(31,31),DIFF(31,31),OPT
C
C     CALCULATE SYNTHETIC AV TRIP LENGTH SBAR (MIN),
C          TOTAL LENGTH OF TRAVEL TOTT(MIN)  AND
C          TOTAL NO OF TRIPS TTRPP.
C
      TOTT=0.
      TTRPP=0.
      DO 900 I=1,NQ
      DO 900 J=1,NQ
      TOTT=TOTT+TT(I,J)*SS(I,J)
      TTRPP= TTRPP + TT(I,J)
  900 CONTINUE
      SBAR = TOTT/TTRPP
      WRITE(6,905) TOTT,TTRPP,SBAR
  905 FORMAT(1H0,10X,*TOTAL LENGTH OF TRAVEL*,5X,F12.0//11X,*TOTAL NUMBE
     *R OF TRIPS*,6X,F12.0//11X,*AV. TRIP LENGTH SBAR*,7X,F10.3)
      RETURN
      END
```

```
      SUBROUTINE LSTSQS(Y,MINTIM,MAXTIM,INC)
      DIMENSIONY(80)
C
C     CALCULATE PARABOLA OF BEST FIT    Y = F(X)
C
      S0=S1=S2=S3=S4=T0=T1=T2=0.
      DO 1000 I=MINTIM,MAXTIM,INC
      DI=I
      DI=ALOG(DI)
      Y(I)=ALOG(Y(I))
      S0=S0+1
      S1=S1+ DI
      S2=S2+(DI)**2
      S3=S3+(DI)**3
      S4=S4+(DI)**4
      T0=T0+Y(I)
      T1=T1+Y(I)*DI
      T2=T2+Y(I)*DI*DI
 1000 CONTINUE
      C=((S1*S3-S1*S2)*(S1*T2-S2*T1)-(S1*S3-S2*S2)*(S0*T2-S2*T0))/((S0*
     CS3-S1*S2)*(S1*S4-S2*S3)-(S1*S3-S2*S2)*(S0*S4-S2*S2))
      B=((S1*T2-S2*T1)-C*(S4*S1-S3*S2))/(S3*S1-S2*S2)
      A=(T2-S4*C-S3*B)/S2
      DO 1002 I=MINTIM,MAXTIM,INC
      DI=I
      DI=ALOG(DI)
      Y(I)=EXP(A+B*DI +C*DI*DI)
 1002 CONTINUE
      WRITE(6,1001) A,B,C
 1001 FORMAT(1H0,30(1H*),*    PARAMETERS ARE A = *,F8.2,
     **     B = *,F8.2,*    C = *,F8.2,/1H0,20X,*WHERE FUNCTION IS LN(FF) =
     * A + B.LN(D) + C.LN(D).LN(D)*////)
      RETURN
      END
```

```
      SUBROUTINE TANNER(Y,MINTIM,MAXTIM,INC)
      DIMENSIONY(20)
      REAL N,LNC,LAMBDA
C
C     FIT TANNER CURVE TO DATA    Y = EXP(-LAMBDA*D)/D**N
C
      AA=AB=AC=AD=AE=AF=AG=AH=AI=0.
      DO 5 I=MINTIM,MAXTIM,INC
      IF(Y(I).LT.0.) Y(I)=.000001
      Y(I)=ALOG(Y(I))
      DI=I
      D=ALOG(DI)
      AA=AA+Y(I)*DI
      AB=AB+DI*DI
      AC=AC+DI*D
      AD=AD+Y(I)*D
      AE=AE+D*D
      AF=AF+1
      AG=AG+DI
      AH=AH+D
      AI=AI+Y(I)
    5 CONTINUE
      B1=AA*AE-AC*AD
      B2=AB*AE-AC*AC
      B3=AD*AG-AC*AH
      B4=AA*AH-AC*AI
      B5=AB*AH-AC*AG
      B6=AG*AH-AC*AF
      LAMBDA=(B3*B4-B1*B6)/(B2*B6-B3*B5)
      LNC=(B1+LAMBDA*B2)/B3
      N=(LNC*AG-AA-LAMBDA*AB)/AC
      C=EXP(LNC)
      PRINT 2, C,LAMBDA,N
    2 FORMAT(1H0,20(1H*),*TANNER PARAMETERS ARE  C=*,F6.2,* LAMBDA=*,
     +F6.4,*  N=*,F6.2/1H0,20X,*WHERE FUNCTION IS  FF = C.EXP(-LAMB*
     +*DA.D)/D*,3H**N////)
      DO 6 I=MINTIM,MAXTIM,INC
      DI=I
      Y(I)=C*EXP(-LAMBDA*DI)/DI**N
    6 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TAN(Y,MINTIM,MAXTIM,INC)
C
C     FIT MODIFIED TANNER CURVE TO DATA    Y = C*EXP(-LAMBDA*D)/D
C
      DIMENSIONY(80)
      A1=A2=A3=A4=A5=A6=A7=0
      MINT=MINTIM+INC
      DO 5 I=MINT,MAXTIM,INC
      IF(Y(I).LE.0.) Y(I)=.000001
      Y(I)=ALOG(Y(I))
      DI=I
      D=ALOG(DI)
      A1=A1+1
      A2=A2+DI
      A3=A3+Y(I)
      A4=A4+DI*DI
      A5=A5+ALOG(DI)
      A6=A6+DI*ALOG(DI)
      A7=A7+DI*Y(I)
    5 CONTINUE
      C=((A3+A5)*A4-(A7+A6)*A2)/(A1*A4-A2*A2)
      ALAM=(C*A1-A3-A5)/A2
      C=EXP(C)
      PRINT 2,C,ALAM
    2 FORMAT(1H0,3((1H*),*    CURVE OF BEST FIT IS    FF=*,F5.1,
     +        1H*,*EXP(-*,F6.3,1H*,*D)/D*////)
      DO 6 I=MINTIM,MAXTIM,INC
      DI=I
      Y(I)=C*EXP(-ALAM*DI)/DI
    6 CONTINUE
      RETURN
      END
```

```
                  SUBROUTINE SOMA(NO)
                  COMMON S(31,31),SS(31,31),PY(31),AY(31),FREQ(80),FF(80),FO(31,31),
                 *D(80),FREQU(80),AYA(31),AYORIG(31),RR(31),AYAA(31)
                  COMMON TT(31,31)
                  COMMON RATIO(31,31),DIFF(31,31),OPT
            C
            C     CALCULATE SYNTHETIC COLUMN TOTALS  AYA(J)
            C
                  DO 640 J=1,NO
                  AYA(J)=0.
                  DO 640 I=1,NO
                  AYA(J)=AYA(J)+TT(I,J)
            640   CONTINUE
                  WRITE(6,675)
              675 FORMAT(1H1,10X,*COMPARE MODEL AYA(J)  WITH ACTUAL AYORIG(J)*)
                  WRITE(6,676)
              676 FORMAT(1H0,11X,*J*,15X,*AYORIG(J)*,13X,*AY(J)*,14X,*AYA(J)*,11X,
                 **AYA(J)/AYORIG(J)*)
            C
            C     CALCULATE RATIOS SYNTHETIC/ACTUAL ATTRACTIONS  -   AYAA(J)
            C
                  DO 677 J=1,NO
                  AYAA(J)=AYA(J)/AYORIG(J)
                  WRITE(6,676) J,AYORIG(J),AY(J),AYA(J),AYAA(J)
              678 FORMAT(1H0,7X,I4,15X,F8.0,12X,F8.0,12X,F8.0,12X,F8.3)
              677 CONTINUE
                  RETURN
                  END
```

```
      SUBROUTINE TESTMAT(NQ)
      COMMON E(31,31),SS(31,31),PY(31),AY(31),FREQ(80),FF(80),FQ(31,31),
     *D(80),FREQU(80),AYA(31),AYORIG(31),RR(31),AYAA(31)
      COMMON TT(31,31)
      COMMON RATIO(31,31),DIFF(31,31),OPT
C
C     CALCULATE MEAN PERCENTAGE ERROR                 PE
C               ROOT-MEAN-SQUARE ERROR                RMS
C               RATIOS SYNTHETIC/ACTUAL               RATIO(I,J)
C               DIFFERENCES SYNTHETIC-ACTUAL          DIFF(I,J)
C
      PE=RMS=0.
      N=0
      PRINT 5
    5 FORMAT(1H1,*RATIO OF SYNTHETIC OVER ACTUAL*)
      DO 1 I=1,NQ
      DO 2 J=1,NQ
      RATIO(I,J)=TT(I,J)/(E(I,J)+.00001)
      DIFF(I,J)=TT(I,J)-E(I,J)
      DIF=ABS(E(I,J)-TT(I,J))
      IF(E(I,J).LT..000001)   GO TO 9
      PE=PE+DIF/E(I,J)
      N=N+1
    9 CONTINUE
      RMS=RMS+DIF**2
    2 CONTINUE
      PRINT 4,(RATIO(I,J),J=1,NQ)
    4 FORMAT(1H , 16F8.3 )
    1 CONTINUE
      PRINT 8
    8 FORMAT(1H1,*SYNTHETIC-ACTUAL*)
      DO 6 I=1,NQ
    6 PRINT 7,(DIFF(I,J),J=1,NQ)
    7 FORMAT(1H ,16F8.0)
      PE=PE/N*100.
      RMS=SQRT(RMS/NQ**2)
      PRINT 3,PE,RMS
    3 FORMAT(1H0,*COMPARISON STATISTICS BETWEEN OBSERVED AND SYNTHESIZED
     ≠ TRIP MATRICES*
     ≠ /1H0,*MEAN PERCENTAGE ERROR IS*,
     ≠F10.2,/1H0,*ROOT-MEAN-SQUARE ERROR IS*,F10.2)
      RETURN
      END
```

ACTUAL TRIP TABLE FOR TOTAL

3871.	10.	97.	14.	1.	0.	59.	220.	4.	5.	10.	76.	83.	132.	1.	96.
7.	4.	21.	97.	46.	28.	64.	2.	14.	119.	97.	38.	234.	0.	245.	
2772.	1256.	102.	8.	4.	1.	14.	121.	1.	373.	27.	104.	84.	939.	51.	378.
5.	92.	14.	118.	23.	44.	61.	3.	6.	111.	183.	27.	632.	4.	331.	
5798.	15.	2197.	183.	5.	11.	71.	381.	1.	28.	10.	196.	794.	250.	3.	312.
16.	21.	149.	190.	83.	208.	177.	18.	42.	171.	555.	82.	475.	1.	503.	
4450.	22.	672.	1912.	1.	46.	209.	716.	2.	13.	10.	247.	852.	260.	2.	161.
11.	8.	636.	163.	109.	343.	195.	23.	155.	226.	267.	84.	577.	2.	655.	
436.	15.	26.	4.	55.	0.	7.	30.	0.	8.	1.	22.	24.	146.	4.	192.
0.	2.	1.	10.	3.	7.	10.	2.	2.	28.	59.	5.	73.	0.	30.	
309.	4.	100.	41.	0.	436.	4.	42.	1.	0.	0.	11.	45.	10.	0.	21.
0.	2.	18.	5.	7.	16.	17.	55.	3.	15.	20.	8.	34.	0.	24.	
1823.	7.	55.	25.	1.	1.	4032.	968.	76.	2.	10.	142.	78.	38.	1.	53.
400.	2.	23.	164.	101.	28.	2131.	1.	75.	104.	59.	27.	219.	2.	470.	
8146.	32.	359.	186.	10.	9.	457.	7285.	15.	9.	30.	905.	539.	340.	6.	245.
29.	18.	244.	1382.	875.	212.	805.	6.	327.	580.	362.	324.	1170.	1.	3394.	
132.	0.	3.	0.	0.	0.	145.	98.	994.	0.	1.	7.	3.	2.	0.	8.
91.	0.	0.	13.	5.	1.	185.	0.	0.	13.	8.	5.	23.	0.	23.	
1928.	157.	52.	10.	6.	1.	17.	91.	2.	893.	32.	71.	62.	439.	5.	159.
3.	22.	10.	94.	17.	35.	40.	3.	6.	105.	143.	13.	611.	0.	296.	
2010.	28.	70.	14.	2.	1.	41.	183.	3.	62.	655.	165.	82.	157.	3.	90.
7.	11.	12.	403.	29.	19.	56.	1.	11.	208.	86.	18.	603.	0.	1006.	
805.	4.	26.	5.	0.	0.	78.	305.	0.	3.	5.	801.	39.	81.	1.	30.
0.	3.	6.	120.	40.	8.	27.	0.	4.	203.	33.	12.	223.	0.	672.	
1236.	4.	311.	57.	1.	5.	56.	143.	0.	7.	6.	58.	875.	87.	2.	73.
4.	4.	59.	41.	25.	91.	54.	1.	20.	64.	91.	19.	184.	1.	215.	
7778.	854.	328.	39.	33.	4.	86.	446.	1.	643.	56.	345.	275.	5951.	130.	1992.
5.	268.	42.	307.	94.	97.	122.	12.	24.	445.	807.	98.	2744.	8.	939.	
477.	31.	23.	2.	4.	0.	3.	40.	0.	16.	3.	24.	25.	297.	282.	198.
1.	105.	3.	19.	5.	6.	3.	12.	1.	35.	62.	3.	144.	15.	55.	
6928.	142.	537.	33.	106.	5.	51.	356.	3.	103.	20.	238.	330.	1891.	53.	3978.
11.	139.	50.	198.	106.	103.	147.	25.	23.	238.	1105.	88.	1122.	2.	612.	
721.	3.	20.	32.	0.	0.	1663.	498.	280.	0.	3.	76.	23.	25.	0.	56.
1103.	0.	14.	79.	44.	12.	1052.	0.	33.	35.	42.	10.	90.	0.	264.	
1647.	143.	67.	5.	7.	5.	8.	61.	1.	69.	14.	89.	60.	1643.	82.	817.
1.	3384.	13.	63.	18.	25.	21.	5.	9.	134.	296.	20.	616.	230.	229.	
2104.	8.	240.	242.	1.	8.	132.	373.	0.	8.	5.	113.	445.	150.	2.	77.
5.	9.	740.	76.	48.	253.	97.	6.	44.	96.	103.	54.	259.	0.	344.	
1721.	17.	83.	16.	0.	0.	188.	650.	1.	9.	40.	263.	59.	77.	4.	90.
1.	4.	6.	6814.	41.	18.	89.	1.	13.	173.	73.	20.	294.	1.	3079.	
2673.	6.	127.	25.	2.	1.	160.	1227.	1.	12.	8.	244.	117.	199.	2.	94.
14.	6.	35.	156.	544.	58.	205.	4.	39.	149.	118.	140.	250.	1.	521.	
1228.	6.	122.	62.	0.	2.	87.	159.	2.	4.	4.	58.	292.	94.	2.	70.
10.	10.	109.	46.	31.	509.	43.	5.	15.	52.	57.	47.	127.	0.	191.	
4291.	17.	141.	86.	3.	3.	1825.	2582.	31.	15.	15.	463.	244.	186.	2.	180.
120.	8.	89.	649.	312.	105.	4321.	9.	304.	256.	189.	109.	641.	1.	1721.	
993.	12.	147.	9.	3.	20.	3.	62.	0.	11.	0.	23.	49.	90.	5.	118.
3.	14.	6.	20.	11.	16.	70.	831.	8.	28.	105.	26.	91.	2.	71.	
3750.	8.	278.	226.	3.	4.	298.	1399.	8.	10.	19.	263.	350.	188.	0.	154.
25.	12.	163.	392.	188.	162.	580.	6.	1851.	209.	210.	166.	538.	0.	994.	
1005.	11.	38.	6.	4.	2.	95.	127.	0.	6.	19.	171.	48.	224.	3.	70.
3.	6.	5.	82.	19.	16.	27.	3.	10.	769.	63.	10.	642.	0.	459.	
5437.	50.	516.	53.	16.	4.	94.	367.	4.	46.	21.	193.	290.	865.	7.	772.
6.	33.	41.	139.	72.	94.	138.	12.	25.	256.	2624.	59.	941.	3.	526.	
1108.	1.	48.	13.	0.	0.	30.	230.	0.	4.	2.	50.	48.	35.	2.	30.
3.	5.	34.	45.	80.	39.	77.	3.	18.	71.	47.	279.	70.	3.	98.	
6719.	131.	238.	42.	9.	1.	98.	527.	1.	287.	126.	437.	268.	1163.	12.	453.
16.	58.	41.	444.	95.	74.	184.	5.	27.	834.	451.	69.	4928.	1.	1584.	
53.	8.	4.	0.	0.	1.	0.	4.	0.	1.	0.	1.	1.	15.	2.	10.
0.	64.	3.	7.	0.	0.	2.	1.	1.	5.	0.	3.	8.	549.	5.	
5818.	50.	200.	41.	3.	1.	542.	1389.	3.	47.	245.	1289.	204.	432.	11.	225.
14.	21.	35.	3439.	135.	57.	206.	4.	32.	724.	205.	65.	1369.	2.	11167.	

TRIP PRODUCTIONS OF ZONE I

PY(I)	5697.	7887.	12970.	13040.	1211.	1257.	11142.	28312.	1818.	5363.
PY(I)	6046.	3537.	3794.	24943.	1894.	18797.	6110.	9712.	6038.	13847.
PY(I)	7448.	3444.	18918.	2707.	12484.	3943.	13813.	2473.	19275.	765.
PY(I)	27873.									

TRIP ATTRACTIONS OF ZONE J

AY(J)	88156.	3093.	7384.	3370.	280.	572.	10487.	21103.	1435.	2870.
AY(J)	1357.	7165.	6094.	16326.	680.	11202.	1914.	4355.	2626.	15795.
AY(J)	3598.	2684.	11157.	1059.	3142.	6494.	8430.	1926.	19931.	829.
AY(J)	30703.									

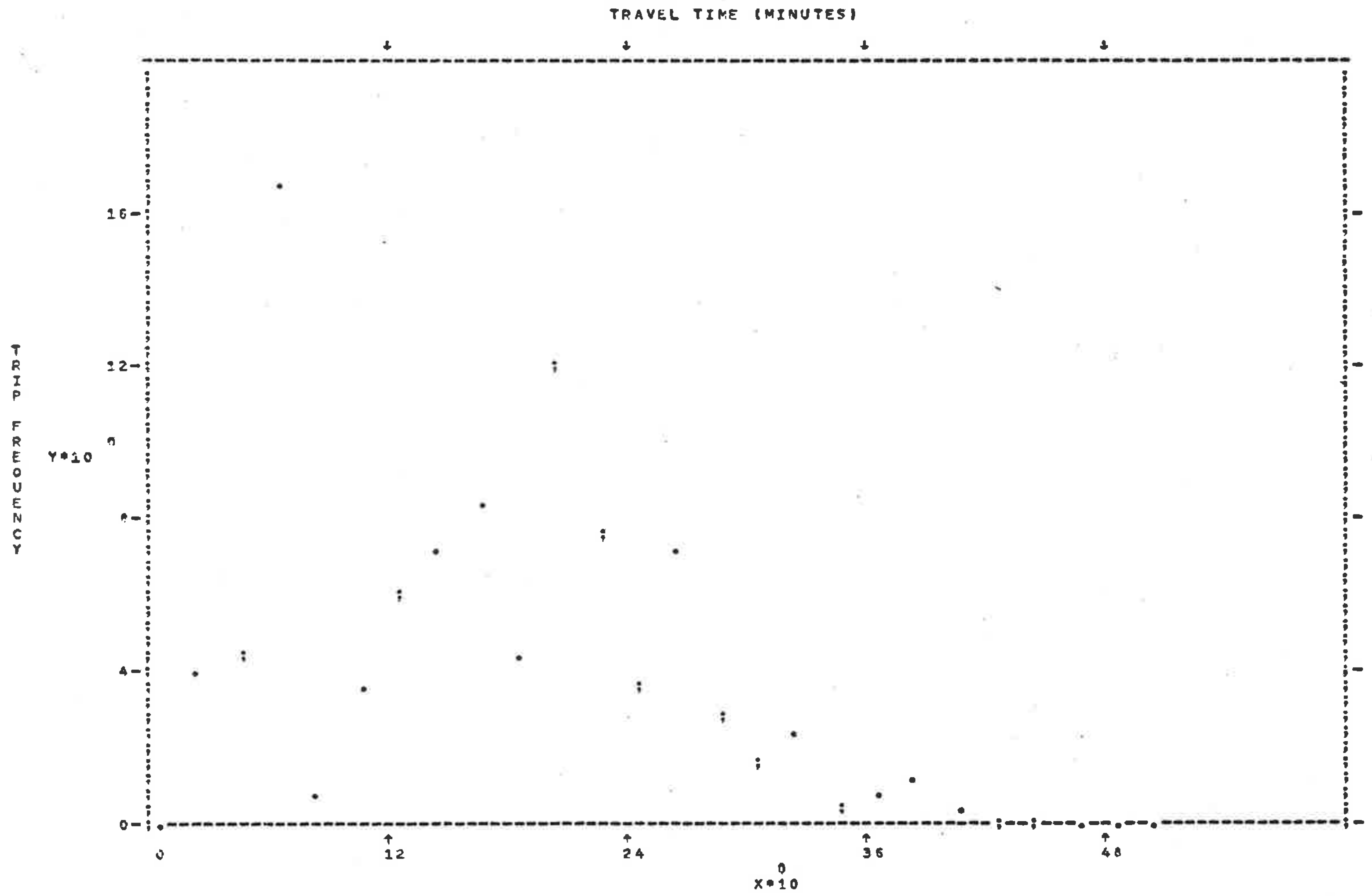
TOT LENGTH OF TRAVEL TIME 4912783. TOT NO. OF TRIPS 296639.

AV ACTUAL TRIP LENGTH DBAR(MIN) 16.56

ACTUAL FREQUENCY TABLE

0	TO	3	MIN	12127.	4.09
3	TO	5	MIN	14060.	4.74
5	TO	7	MIN	50101.	16.89
7	TO	9	MIN	2738.	.91
9	TO	11	MIN	11150.	3.76
11	TO	13	MIN	18942.	6.39
13	TO	15	MIN	21623.	7.29
15	TO	17	MIN	25090.	8.46
17	TO	19	MIN	13313.	4.49
19	TO	21	MIN	36776.	12.40
21	TO	23	MIN	23437.	7.90
23	TO	25	MIN	11431.	3.85
25	TO	27	MIN	21940.	7.40
27	TO	29	MIN	9373.	3.16
29	TO	31	MIN	5401.	1.82
31	TO	33	MIN	7334.	2.47
33	TO	35	MIN	2163.	.73
35	TO	37	MIN	2576.	.87
37	TO	39	MIN	3718.	1.25
39	TO	41	MIN	1220.	.41
41	TO	43	MIN	787.	.27
43	TO	45	MIN	649.	.22
45	TO	47	MIN	123.	.04
47	TO	49	MIN	307.	.10
49	TO	51	MIN	290.	.10

TRIPS	296639.
TRIP MINS	4912783.
AV TRIP MIN	16.56
SAMPLE VARIANCE	84.40
STANDARD DEVIATION	9.19


TRAVEL TIME (MINUTES)
TRIP FREQUENCY
Y*10
16
12
4
0
0
12
24
36
48
X*10

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          INITIAL TRAVEL TIME FACTORS
        1.      1.      1.      1.      1.      1.      1.      1.      1.      1.      1.      1.      1.      1.      1.
        1.      1.      1.      1.      1.      1.      1.      1.      1.      1.
(FIRST VALUE = 0-  3 MINUTES , EACH SUCCESSIVE VALUE = NEXT  2 MINUTE INTERVAL)
          TOTAL LENGTH OF TRAVEL          7254409.
          TOTAL NUMBER OF TRIPS            296639.
          AV. TRIP LENGTH SBAR            24.455
TRAVEL TIME ERROR  47.66  PER CENT


THERE ARE   3  OUT OF  25  VALUES OF SYNTH FREQUENCY WITHIN 0.5 PER CENT OF ACTUAL FREQUENCY
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COMPARISON UNSATISFACTORY - MODIFY TRAVEL TIME FACTORS AND REPEAT


MODIFIED TRAVEL TIME FACTORS
      22.38    5.00    4.87    2.09    2.94    1.94    1.19    1.27     .98     .87     .92     .50     .79     .61     .41

        .39     .37     .24     .35     .22     .19     .13     .10     .09     .06
(FIRST VALUE = 0-  3 MINUTES , EACH SUCCESSIVE VALUE = NEXT  2 MINUTE INTERVAL)
******************************   CURVE OF BEST FIT IS   FF= 42.4*EXP(-  .041*D)/D


                    TRAVEL TIME FACTORS MODIFIED TO FIT THE CURVE
      12.50    5.91    4.55    3.26    2.46    1.91    1.53    1.24    1.02     .85     .72     .61     .52     .45     .38

        .33     .29     .25     .22     .19     .17     .15     .13     .12     .10
(FIRST VALUE = 0-  3 MINUTES , EACH SUCCESSIVE VALUE = NEXT  2 MINUTE INTERVAL)
          TOTAL LENGTH OF TRAVEL          5071945.
          TOTAL NUMBER OF TRIPS            296639.
          AV. TRIP LENGTH SBAR            17.098
TRAVEL TIME ERROR   3.24  PER CENT


THERE ARE  19  OUT OF  25  VALUES OF SYNTH FREQUENCY WITHIN 0.5 PER CENT OF ACTUAL FREQUENCY
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COMPARISON UNSATISFACTORY - MODIFY TRAVEL TIME FACTORS AND REPEAT


MODIFIED TRAVEL TIME FACTORS
      14.16    7.76    4.23    2.23    2.49    1.87    1.37    1.22    1.04     .88     .79     .46     .62     .48     .33

       .30     .26     .18     .20     .16     .10     .09     .06     .05     .03
(FIRST VALUE = 0-  3 MINUTES , EACH SUCCESSIVE VALUE = NEXT  2 MINUTE INTERVAL)
******************************   CURVE OF BEST FIT IS   FF= 56.0*EXP(-  .058*D)/D


                    TRAVEL TIME FACTORS MODIFIED TO FIT THE CURVE
      15.67    8.37    5.32    3.68    2.68    2.02    1.55    1.22     .97     .78     .63     .52     .43     .35     .30

       .25     .21     .17     .15     .12     .11     .09     .08     .07     .06
(FIRST VALUE = 0-  3 MINUTES , EACH SUCCESSIVE VALUE = NEXT  2 MINUTE INTERVAL)
          TOTAL LENGTH OF TRAVEL         4653597.
          TOTAL NUMBER OF TRIPS           296639.
          AV. TRIP LENGTH SBAR           15.688
TRAVEL TIME ERROR   5.28  PER CENT


THERE ARE  15  OUT OF  25  VALUES OF SYNTH FREQUENCY WITHIN 0.5 PER CENT OF ACTUAL FREQUENCY
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COMPARISON UNSATISFACTORY - MODIFY TRAVEL TIME FACTORS AND REPEAT


MODIFIED TRAVEL TIME FACTORS
      13.42    6.12    4.77    2.21    2.40    1.83    1.37    1.19    1.03    .86    .75    .45    .60    .46    .32

        .29     .25     .17     .19     .15     .09     .08     .05     .05     .03
(FIRST VALUE = 0-  3 MINUTES , EACH SUCCESSIVE VALUE = NEXT  2 MINUTE INTERVAL)
******************************   CURVE OF BEST FIT IS   FF= 57.0*EXP(-  .061*D)/D


                    TRAVEL TIME FACTORS MODIFIED TO FIT THE CURVE
      15.83    9.42    5.33    3.67    2.66    1.99    1.53    1.20 .  .95    .76    .62    .50    .41    .34    .28

        .23     .20     .16     .14     .12     .10     .08     .07     .06     .05
(FIRST VALUE = 0-  3 MINUTES , EACH SUCCESSIVE VALUE = NEXT  2 MINUTE INTERVAL)
          TOTAL LENGTH OF TRAVEL          4605626.
          TOTAL NUMBER OF TRIPS            296639.
          AV. TRIP LENGTH SBAR            15.526
TRAVEL TIME ERROR   6.25  PER CENT


THERE ARE  15  OUT OF  25  VALUES OF SYNTH FREQUENCY WITHIN 0.5 PER CENT OF ACTUAL FREQUENCY
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COMPARE MODEL AYA(J) WITH ACTUAL AYORIG(J)

J	AYORIG(J)	AY(J)	AYA(J)	AYA(J)/AYORIG(J)
1	88156.	88156.	68147.	.773
2	3093.	3093.	4105.	1.327
3	7384.	7384.	7611.	1.031
4	3370.	3370.	3204.	.951
5	280.	280.	278.	.993
6	572.	572.	442.	.773
7	10467.	10467.	12011.	1.148
8	21100.	21100.	24632.	1.167
9	1435.	1435.	1051.	.733
10	2670.	2670.	2450.	.918
11	1397.	1397.	1029.	.737
12	7165.	7165.	6402.	.893
13	6694.	6694.	7071.	1.056
14	16326.	16326.	19514.	1.195
15	680.	680.	526.	.774
16	11202.	11202.	12347.	1.102
17	1914.	1914.	2516.	1.315
18	4358.	4358.	6514.	1.495
19	2626.	2626.	2925.	1.114
20	15795.	15795.	12277.	.777
21	3598.	3598.	4001.	1.112
22	2684.	2684.	3197.	1.191
23	11157.	11157.	12500.	1.120
24	1059.	1059.	1002.	.946
25	3142.	3142.	5397.	1.718
26	6494.	6494.	5866.	.903
27	8430.	8430.	12513.	1.484
28	1928.	1928.	1872.	.971
29	19931.	19931.	22437.	1.126
30	829.	829.	462.	.557
31	30703.	30703.	32337.	1.053

THERE ARE 9 VALUES OF AYA(J) WITHIN 10 PER CENT OF AYORIG(J)

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COMPARISON UNSATISFACTORY - MODIFY ATTRACTIONS AND REPEAT


          TOTAL LENGTH OF TRAVEL          4804725.
          TOTAL NUMBER OF TRIPS            296639.
          AV. TRIP LENGTH SBAR            16.197
TRAVEL TIME ERROR   2.20  PER CENT


THERE ARE  20  OUT OF  25  VALUES OF SYNTH FREQUENCY WITHIN 0.5 PER CENT OF ACTUAL FREQUENCY
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COMPARE MODEL AYA(J) WITH ACTUAL AYORIG(J)

J	AYORIG(J)	AY(J)	AYA(J)	AYA(J)/AYORIG(J)
1	88156.	114039.	86661.	.983
2	3093.	2330.	3258.	1.053
3	7384.	7164.	7401.	1.002
4	3370.	3544.	3310.	.982
5	280.	282.	287.	1.023
6	572.	740.	566.	.989
7	10467.	9121.	10913.	1.043
8	21100.	18074.	21143.	1.002
9	1435.	1959.	1416.	.987
10	2670.	2910.	2731.	1.023
11	1397.	1896.	1376.	.985
12	7165.	8019.	7085.	.989
13	6694.	6337.	6617.	.989
14	16325.	13659.	17039.	1.044
15	680.	879.	704.	1.035
16	11202.	10163.	11450.	1.022
17	1914.	1456.	2043.	1.067
18	4358.	2916.	5044.	1.157
19	2626.	2358.	2588.	.986
20	15795.	20322.	15145.	.959
21	3598.	3236.	3569.	.992
22	2684.	2253.	2636.	.982
23	11157.	9958.	11480.	1.029
24	1059.	1120.	1060.	1.001
25	3142.	1829.	3332.	1.060
26	6494.	7189.	6409.	.987
27	8430.	5679.	8485.	1.007
28	1928.	1986.	1912.	.992
29	19931.	17705.	20025.	1.005
30	829.	1488.	853.	1.029
31	30703.	29151.	30102.	.980

THERE ARE 30 VALUES OF AYA(J) WITHIN 10 PER CENT OF AYORIG(J)

COMPARISON SATISFACTORY - CALIBRATION COMPLETE

SYNTHETIC TRIP TABLE

4953.	4.	23.	11.	1.	3.	11.	71.	1.	8.	7.	50.	39.	29.	1.	32.
1.	2.	15.	53.	20.	18.	21.	4.	4.	57.	45.	12.	87.	0.	114.	
1596.	2521.	55.	14.	11.	4.	19.	103.	4.	319.	59.	112.	61.	1499.	43.	258.
3.	91.	13.	236.	26.	18.	29.	16.	6.	149.	144.	11.	693.	17.	740.	
3971.	31.	2159.	240.	10.	64.	85.	513.	8.	68.	36.	187.	954.	262.	14.	688.
8.	83.	204.	188.	139.	254.	132.	125.	43.	250.	855.	134.	762.	16.	454.	
5315.	17.	650.	1430.	5.	85.	234.	687.	17.	36.	34.	250.	575.	120.	7.	261.
22.	36.	475.	252.	185.	340.	177.	43.	166.	273.	265.	180.	377.	8.	517.	
385.	12.	24.	5.	25.	1.	10.	23.	1.	15.	5.	22.	21.	150.	4.	148.
0.	7.	5.	22.	6.	8.	6.	7.	1.	37.	83.	4.	116.	2.	54.	
555.	2.	70.	35.	1.	75.	29.	58.	2.	4.	3.	21.	62.	14.	1.	33.
3.	4.	23.	25.	16.	29.	15.	5.	7.	23.	34.	15.	38.	1.	52.	
1689.	8.	74.	76.	2.	23.	4855.	870.	190.	13.	14.	172.	66.	52.	3.	53.
245.	9.	42.	262.	126.	28.	1256.	7.	88.	106.	70.	52.	154.	5.	432.	
8126.	30.	337.	167.	5.	35.	650.	9016.	52.	53.	60.	899.	452.	210.	8.	223.
55.	16.	210.	1446.	606.	253.	1117.	30.	163.	512.	327.	285.	682.	7.	2077.	
249.	3.	11.	5.	1.	3.	311.	113.	690.	3.	2.	25.	10.	15.	1.	12.
65.	3.	5.	44.	17.	7.	91.	1.	11.	13.	9.	6.	24.	2.	64.	
1452.	157.	75.	15.	7.	4.	16.	50.	3.	393.	58.	102.	45.	691.	14.	159.
2.	25.	17.	101.	23.	19.	25.	14.	5.	62.	173.	14.	896.	5.	702.	
2170.	44.	61.	21.	4.	5.	26.	153.	2.	87.	253.	155.	65.	210.	6.	72.
2.	12.	20.	367.	33.	28.	34.	8.	8.	275.	87.	20.	678.	3.	1117.	
1270.	7.	27.	14.	1.	3.	29.	201.	3.	14.	13.	626.	45.	64.	1.	32.
3.	6.	13.	173.	36.	16.	46.	4.	7.	133.	50.	22.	252.	1.	415.	
1380.	5.	153.	43.	2.	11.	15.	139.	1.	8.	6.	62.	1014.	39.	2.	98.
1.	3.	63.	58.	39.	84.	34.	17.	11.	69.	115.	40.	90.	1.	148.	
5267.	695.	273.	46.	63.	14.	61.	333.	11.	651.	131.	451.	200.	8165.	118.	1366.
14.	249.	62.	265.	85.	71.	93.	77.	20.	614.	763.	52.	3043.	47.	1641.	
455.	57.	41.	7.	14.	2.	9.	36.	2.	37.	11.	23.	30.	333.	284.	158.
2.	56.	8.	25.	9.	11.	10.	8.	2.	29.	88.	5.	85.	10.	58.	
5753.	118.	703.	99.	61.	30.	62.	347.	8.	147.	44.	123.	493.	1341.	55.	4437.
6.	81.	147.	233.	90.	221.	95.	183.	92.	296.	1709.	46.	1114.	17.	560.	
351.	7.	42.	42.	1.	12.	1469.	450.	237.	9.	7.	95.	36.	69.	3.	31.
1396.	9.	23.	202.	27.	16.	469.	4.	46.	60.	40.	26.	69.	5.	243.	
1362.	156.	316.	51.	10.	15.	41.	95.	9.	87.	27.	165.	65.	914.	73.	303.
7.	4059.	17.	51.	24.	19.	45.	15.	8.	124.	170.	15.	641.	348.	420.	
2769.	7.	222.	191.	2.	23.	52.	348.	4.	17.	13.	100.	342.	65.	5.	157.
5.	5.	491.	96.	100.	168.	83.	27.	44.	111.	176.	60.	189.	2.	243.	
2906.	32.	56.	29.	3.	7.	126.	675.	9.	28.	71.	373.	87.	76.	3.	69.
12.	7.	27.	5309.	80.	31.	201.	9.	30.	268.	95.	33.	436.	4.	2852.	
3012.	10.	120.	59.	2.	12.	124.	1061.	10.	18.	17.	212.	167.	71.	3.	76.
4.	5.	80.	225.	601.	99.	209.	10.	31.	121.	119.	117.	240.	2.	610.	
1556.	4.	128.	63.	2.	13.	16.	194.	2.	9.	9.	55.	209.	34.	2.	109.
2.	3.	76.	51.	56.	320.	45.	32.	5.	61.	102.	65.	98.	1.	131.	
4695.	16.	165.	83.	3.	17.	1820.	2165.	61.	29.	26.	402.	215.	113.	4.	118.
111.	15.	97.	537.	307.	113.	5306.	15.	365.	188.	160.	122.	340.	8.	990.	
1031.	9.	170.	21.	4.	7.	11.	60.	1.	17.	6.	39.	115.	100.	4.	241.
1.	6.	34.	40.	16.	32.	16.	211.	7.	53.	179.	18.	160.	1.	37.	
3351.	14.	211.	302.	2.	33.	496.	1225.	39.	20.	22.	236.	278.	96.	4.	447.
43.	11.	202.	493.	176.	45.	1418.	27.	2068.	144.	114.	170.	217.	5.	586.	
1689.	11.	43.	17.	3.	4.	21.	133.	2.	10.	28.	155.	58.	100.	2.	49.
2.	6.	17.	149.	24.	21.	23.	5.	5.	585.	84.	16.	341.	3.	337.	
5607.	46.	612.	70.	24.	23.	57.	357.	4.	112.	37.	244.	406.	525.	21.	1197.
5.	32.	116.	221.	89.	144.	90.	86.	17.	353.	1534.	48.	1134.	5.	576.	
1091.	3.	69.	34.	1.	7.	30.	271.	2.	7.	6.	77.	101.	26.	1.	23.
2.	2.	38.	55.	69.	66.	69.	7.	17.	55.	35.	133.	71.	1.	177.	
5726.	117.	286.	53.	18.	13.	66.	394.	6.	337.	154.	650.	168.	1107.	11.	408.
5.	63.	63.	539.	105.	73.	103.	45.	18.	759.	599.	53.	4849.	13.	2362.	
89.	9.	18.	3.	1.	1.	6.	12.	1.	5.	2.	10.	4.	50.	4.	18.
1.	101.	2.	13.	2.	1.	7.	1.	1.	22.	7.	1.	38.	337.	27.	
6311.	104.	147.	60.	7.	15.	155.	1000.	14.	201.	211.	893.	231.	498.	6.	173.
15.	35.	71.	2948.	223.	82.	246.	23.	37.	616.	254.	110.	1972.	8.	11294.	

TOTAL LENGTH OF TRAVEL 4804725.

TOTAL NUMBER OF TRIPS 296539.

AV TRIP LENGTH SBAR 16.197

TRAVEL TIME ERROR 2.20 PER CENT

SYNTHETIC FREQUENCY TABLE

TIME INTERVAL				TRIPS	P/C
0	TO	3	MIN	11968.	4.03
3	TO	5	MIN	13691.	4.62
5	TO	7	MIN	52752.	17.76
7	TO	9	MIN	3575.	1.21
9	TO	11	MIN	11164.	3.76
11	TO	13	MIN	19570.	6.60
13	TO	15	MIN	24988.	8.42
15	TO	17	MIN	25798.	8.70
17	TO	19	MIN	13029.	4.39
19	TO	21	MIN	35770.	12.06
21	TO	23	MIN	22082.	7.44
23	TO	25	MIN	13493.	4.55
25	TO	27	MIN	18917.	6.38
27	TO	29	MIN	7308.	2.46
29	TO	31	MIN	4728.	1.59
31	TO	33	MIN	6235.	2.10
33	TO	35	MIN	1842.	.62
35	TO	37	MIN	2600.	.88
37	TO	39	MIN	3594.	1.21
39	TO	41	MIN	940.	.32
41	TO	43	MIN	896.	.30
43	TO	45	MIN	606.	.20
45	TO	47	MIN	166.	.06
47	TO	49	MIN	391.	.13
49	TO	51	MIN	534.	.18

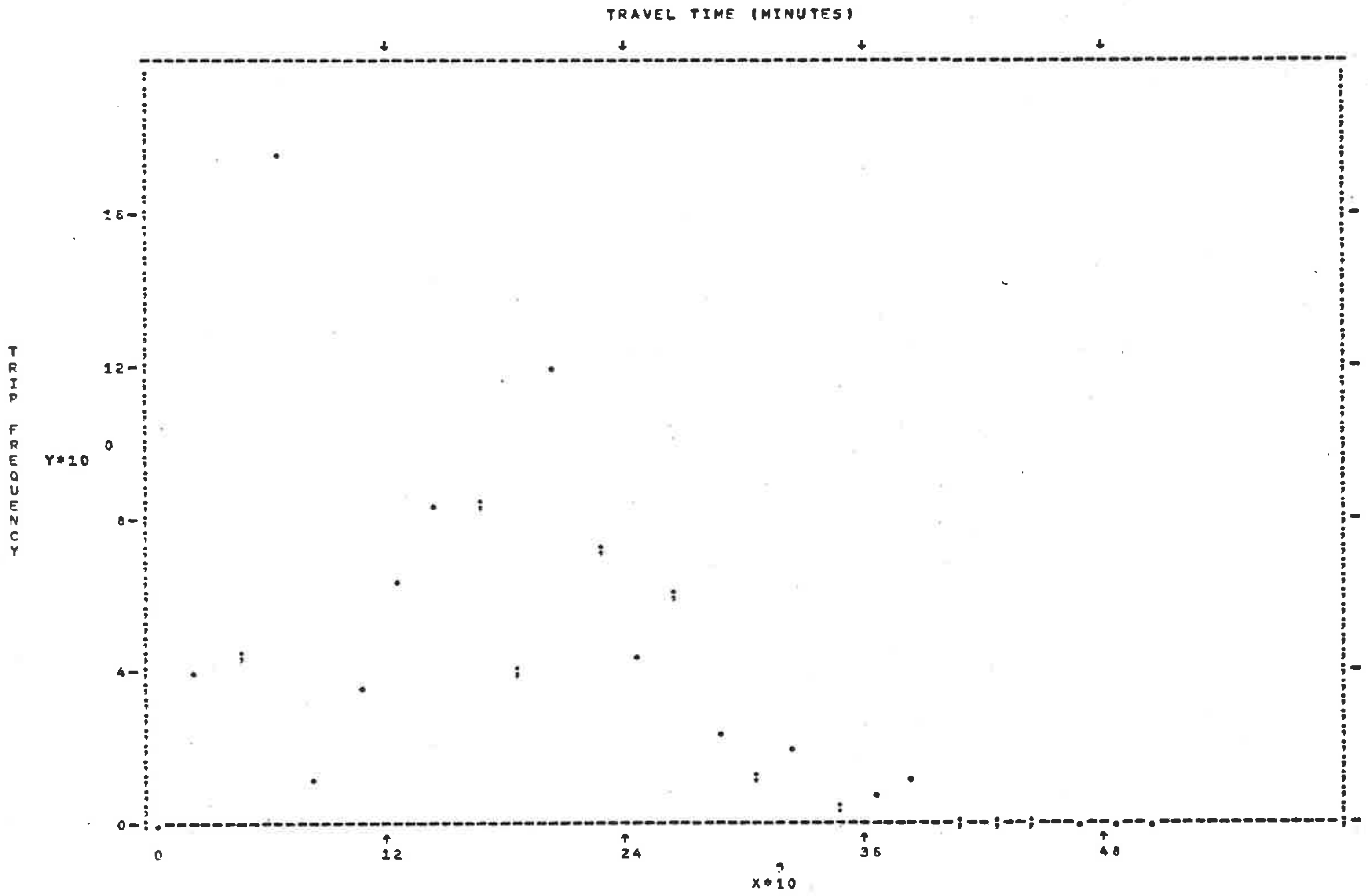
TRIPS 296639.

TRIP MINS 4804725.

AV TRIP MIN 16.20

SAMPLE VARIANCE 82.77

STANDARD DEVIATION 9.10



THERE ARE 20 OUT OF 25 VALUES OF SYNTH FREQUENCY WITHIN 0.5 PER CENT OF ACTUAL FREQUENCY

RATIO OF SYNTHETIC OVER ACTUAL

1.260	.408	.235	.804	.896	********	.187	.323	.248	1.507	.745	.652	.472	.220	.887	.329
.148	.518	.694	.542	.435	.536	.330	2.193	.277	.477	.463	.323	.371	********	.467	
.576	1.209	.678	2.390	2.759	3.544	1.369	.849	4.117	.856	2.203	1.079	.728	1.598	.851	.686
.612	.594	.957	1.998	1.135	.413	.474	5.225	1.044	1.340	.788	.413	1.096	4.315	2.235	
.685	1.625	.983	1.312	1.964	5.830	1.192	1.346	7.809	2.420	3.642	.953	1.201	1.049	4.663	2.207
.505	3.941	1.371	.992	1.678	1.222	.745	7.020	1.014	1.464	1.540	1.640	1.604	16.465	.923	
1.192	.787	.957	.748	5.000	1.866	1.122	.959	8.514	2.779	3.363	1.012	.674	.462	3.265	1.623
1.961	4.525	.747	1.548	1.710	.992	.801	1.850	1.070	1.209	.991	2.143	.654	3.969	.789	
.864	.609	.672	1.139	.446	********	1.359	.775	********	1.685	3.222	1.004	.692	1.024	.918	.773
********	3.293	5.326	2.162	2.010	1.087	.635	2.680	.493	1.441	1.406	.897	1.594	********	1.611	
1.797	.433	.644	.647	********	.172	7.320	1.361	2.055	********	********	1.920	1.360	1.433	********	1.554
********	2.164	1.264	5.068	2.250	1.797	.678	.099	2.401	1.539	1.725	1.901	1.131	********	2.187	
.926	1.073	1.259	2.926	3.488	23.479	1.204	.698	2.495	5.462	1.393	1.212	.642	1.301	2.632	1.007
.612	4.659	1.824	1.965	1.247	.995	.589	6.947	1.173	1.024	1.191	1.914	.708	2.398	.918	
.996	.940	.865	.890	.618	3.864	1.422	1.238	3.441	5.923	2.010	.994	.838	.617	1.346	.910
1.935	.906	.659	1.043	.921	1.192	1.387	4.918	.497	.915	.904	.879	.583	7.102	.612	
1.255	********	11.221	********	********	********	2.142	1.154	.694	********	2.149	3.510	3.309	7.738	********	1.439
.709	********	********	3.410	3.369	5.902	.492	********	********	1.021	1.112	1.217	1.025	********	2.764	
.753	.799	1.439	1.475	1.132	3.674	.959	.586	1.267	.440	1.801	1.438	.730	1.575	2.745	.998
.528	1.142	1.653	3.073	1.359	.555	.620	4.752	.759	.590	1.207	1.091	1.467	********	2.372	
1.090	1.884	.669	1.483	1.769	5.209	.646	.639	.832	1.406	.386	.925	.795	1.259	2.062	.795
.311	1.087	1.666	.960	1.149	1.466	.613	7.880	.682	1.324	1.017	1.135	1.125	********	1.110	
1.575	1.039	2.054	2.712	********	********	.369	.680	********	4.325	2.583	.764	1.150	.767	1.126	1.069
********	2.118	1.687	1.495	.901	1.993	1.721	********	1.750	.857	1.519	1.642	1.131	********	.618	
1.117	1.379	.620	.753	1.754	2.292	.270	.972	********	1.142	1.315	1.063	1.159	.447	1.040	1.336
.367	.656	1.075	1.410	1.566	.319	.633	17.335	.569	1.078	1.258	2.107	.488	.766	.688	
.677	.615	.832	1.184	1.313	3.405	1.095	.746	11.205	1.013	2.339	1.309	.728	1.372	.508	.686
2.714	.929	1.475	.863	.905	.733	.751	6.445	.839	1.379	.946	.532	1.109	5.872	1.748	
.353	1.835	1.786	3.544	1.093	********	3.159	.904	********	2.282	3.625	.939	1.210	1.122	1.006	.786
1.513	.537	2.626	1.305	1.826	1.792	3.449	.646	2.233	.819	1.421	1.567	.587	.686	1.060	
.730	.678	1.509	2.589	.590	6.087	1.218	.975	2.728	1.425	2.167	.938	1.494	.709	1.034	1.115
.553	.584	2.941	1.159	.900	2.147	.645	7.323	4.012	.992	1.546	.520	.984	8.403	.914	
1.320	2.397	1.637	3.498	********	********	.917	.904	.845	********	2.292	1.250	1.298	2.747	********	.560
1.265	********	1.672	2.553	.614	1.320	.438	********	1.381	1.714	.951	2.815	.989	********	.321	
.729	1.090	4.717	10.213	1.458	3.048	5.110	1.175	8.779	1.259	1.953	1.855	1.079	.556	.894	.371
6.525	1.199	1.325	1.446	1.313	.777	2.125	3.228	.911	.923	.823	.725	1.040	1.513	1.835	
1.316	1.085	.927	.790	2.353	2.673	.394	.933	********	2.075	2.611	.868	.768	.432	1.461	2.036
.968	.546	.544	1.270	2.184	.663	.857	4.531	1.009	1.155	1.712	1.487	.695	********	.707	
1.531	1.692	.694	1.761	********	********	.676	1.035	9.427	3.102	1.769	1.420	1.482	1.011	.645	.763
11.708	1.822	3.385	.773	1.942	1.727	2.259	9.005	2.343	1.951	1.295	1.653	1.482	3.719	.926	
1.127	1.676	.947	2.380	1.056	12.424	.774	.865	10.121	1.505	2.152	.868	1.431	.647	1.336	.810
.316	.890	2.276	1.442	.630	1.709	1.017	2.542	.787	.810	1.008	.833	.962	1.673	1.172	
1.275	.681	1.050	1.022	********	6.617	.184	1.220	1.210	2.214	2.132	.943	.714	.367	.922	1.558
.152	.256	.712	1.114	1.866	.628	1.041	2.404	.308	1.178	1.782	1.390	.769	********	.666	
1.094	.366	1.150	.965	1.092	5.780	.997	.638	2.607	1.904	1.743	.869	.882	.610	2.240	.656
.923	1.858	1.091	1.269	.965	1.077	1.228	1.715	1.201	.658	.846	1.122	.541	7.585	.573	
1.141	.783	1.125	2.347	1.337	.334	3.543	.574	********	1.576	********	1.704	2.353	1.109	.709	2.041
.345	.406	5.579	1.979	1.438	2.003	.815	.253	.922	1.877	1.709	.690	1.756	.734	1.372	
.832	1.726	.787	1.341	.655	8.131	1.663	.876	4.919	2.036	1.168	.833	.796	.509	********	2.900
1.711	.884	1.237	1.257	.935	.279	2.445	4.524	1.117	.691	.543	1.023	.385	********	.589	
1.660	1.027	1.121	2.854	.647	1.794	.217	1.047	********	1.591	1.477	.904	1.211	.448	.554	.704
.645	.919	3.467	1.822	1.252	1.292	.835	1.810	.497	.760	1.334	1.821	.532	********	.735	
1.031	.971	.993	1.321	1.565	5.637	.564	.973	1.108	2.431	1.784	1.266	1.399	.607	3.066	1.551
.905	.836	2.827	1.593	1.369	1.535	.652	7.959	.661	1.381	.585	.822	1.205	1.562	1.095	
.984	2.565	1.427	2.607	********	********	.599	.961	********	1.635	3.117	1.534	2.103	.730	.408	.761
.908	.387	1.105	1.224	.850	1.694	.636	2.268	.972	.768	.734	.478	1.013	.202	1.808	
.852	.893	1.212	1.236	1.985	13.292	.679	.747	6.205	1.172	1.219	1.467	.628	.952	.937	.903
.400	1.134	1.526	1.215	1.109	.991	.560	9.014	.588	.910	1.329	.764	1.012	12.903	1.510	
1.678	1.708	4.562	********	********	.946	********	2.999	********	5.221	********	10.244	4.206	3.336	1.942	1.824
********	1.203	.522	1.927	********	********	3.305	1.211	1.214	4.384	********	.439	4.725	.559	5.349	
1.085	2.087	.733	1.472	2.321	15.147	.287	.720	4.560	4.274	.862	.093	1.133	1.154	.570	.769
1.042	1.656	2.015	.857	1.655	1.442	1.194	5.729	1.170	.865	1.240	1.690	1.441	3.812	1.011	

SYNTHETIC-ACTUAL

1082.	-6.	-74.	-3.	-0.	3.	-48.	-149.	-3.	3.	-3.	-26.	-44.	-103.	-0.	-66.
-6.	-2.	-6.	-44.	-26.	-10.	-43.	2.	-10.	-82.	-52.	-25.	-147.	0.	-131.	
-1176.	253.	-33.	8.	7.	3.	5.	-18.	3.	-54.	32.	8.	-23.	560.	-8.	-118.
-2.	-1.	-1.	116.	3.	-26.	-32.	13.	0.	36.	-33.	-16.	61.	13.	409.	
-1827.	12.	-38.	57.	5.	53.	14.	132.	7.	40.	26.	-9.	160.	12.	11.	376.
-6.	62.	55.	-2.	56.	46.	-45.	108.	1.	79.	300.	52.	287.	15.	-39.	
855.	-5.	-22.	-482.	4.	40.	25.	-29.	15.	23.	24.	3.	-277.	-140.	5.	100.
11.	28.	-161.	89.	77.	-3.	-19.	20.	11.	47.	-2.	96.	-200.	6.	-138.	
-51.	-3.	-12.	1.	-30.	1.	3.	-7.	1.	6.	4.	0.	-3.	4.	-0.	-44.
0.	5.	4.	12.	3.	1.	-4.	5.	-1.	11.	24.	-1.	43.	2.	24.	
245.	-2.	-38.	-8.	1.	-361.	25.	16.	1.	4.	3.	10.	17.	4.	1.	12.
3.	2.	5.	20.	9.	13.	-2.	-50.	4.	8.	14.	7.	4.	1.	28.	
-134.	1.	15.	50.	2.	22.	823.	-98.	114.	11.	4.	30.	-12.	14.	2.	0.
-155.	7.	19.	175.	25.	-0.	-875.	6.	13.	2.	11.	25.	-64.	3.	-38.	
-20.	-2.	-52.	-19.	-4.	26.	193.	1731.	37.	44.	30.	-6.	-87.	-130.	2.	-22.
27.	-2.	-34.	66.	-69.	41.	312.	24.	-164.	-48.	-35.	-39.	-488.	6.	-1317.	
57.	3.	10.	9.	1.	3.	166.	15.	-304.	3.	1.	18.	7.	13.	1.	4.
-26.	3.	5.	31.	12.	6.	-94.	1.	11.	0.	1.	1.	1.	2.	41.	
-478.	-40.	23.	5.	1.	3.	-1.	-1.	1.	-500.	26.	31.	-17.	252.	9.	-0.
-1.	3.	7.	7.	6.	-16.	-15.	11.	-1.	-43.	30.	1.	285.	5.	436.	
160.	16.	-9.	7.	2.	4.	-15.	-30.	-1.	25.	-402.	-12.	-17.	43.	3.	-18.
-8.	1.	8.	-16.	4.	9.	-22.	7.	-3.	67.	1.	2.	75.	3.	111.	
484.	3.	1.	9.	1.	3.	-49.	-104.	3.	11.	6.	-173.	6.	-17.	0.	2.
3.	3.	5.	59.	-4.	8.	19.	4.	3.	-70.	17.	10.	29.	1.	-257.	
144.	2.	-118.	-14.	1.	6.	-41.	-4.	1.	1.	2.	4.	139.	-48.	0.	25.
-3.	-1.	4.	17.	14.	-7.	-20.	16.	-9.	5.	24.	21.	-94.	-0.	-67.	
-2511.	-156.	-55.	7.	30.	10.	5.	-113.	10.	8.	75.	106.	-75.	2214.	-12.	-626.
9.	-19.	20.	-42.	-9.	-26.	-29.	65.	-4.	159.	-44.	-46.	299.	39.	702.	
-22.	26.	16.	5.	0.	2.	6.	-4.	2.	21.	8.	-1.	5.	36.	2.	-40.
1.	-43.	5.	6.	4.	5.	7.	-4.	1.	-6.	26.	2.	-59.	-5.	3.	
-1175.	-24.	166.	66.	-45.	25.	11.	-9.	5.	44.	24.	-15.	163.	-550.	2.	459.
-5.	-58.	97.	32.	-10.	118.	-52.	158.	59.	-2.	604.	-42.	-16.	15.	-52.	
230.	4.	17.	30.	1.	13.	-134.	-48.	-43.	9.	4.	19.	9.	44.	3.	-25.
293.	9.	9.	123.	-17.	4.	-593.	4.	13.	25.	-7.	18.	-1.	5.	-21.	
-265.	13.	245.	46.	5.	10.	33.	14.	8.	18.	13.	76.	5.	-729.	-9.	-514.
6.	675.	4.	28.	6.	-6.	24.	11.	-1.	-10.	-36.	-5.	25.	118.	191.	
665.	1.	-18.	-51.	1.	15.	-80.	-25.	4.	9.	8.	-13.	-103.	-35.	1.	60.
-0.	-4.	-338.	20.	54.	-85.	-14.	21.	0.	15.	73.	26.	-79.	2.	-101.	
1085.	15.	-25.	13.	3.	7.	-62.	25.	8.	19.	31.	110.	28.	1.	-1.	-21.
11.	3.	19.	-1505.	39.	13.	112.	8.	17.	35.	22.	13.	142.	3.	-227.	
339.	4.	-7.	34.	0.	11.	-36.	-166.	9.	6.	9.	-32.	50.	-38.	1.	-18.
-10.	-1.	45.	69.	-343.	41.	4.	6.	-8.	-28.	1.	-22.	-10.	1.	89.	
338.	-2.	6.	1.	2.	21.	-71.	35.	0.	5.	5.	-3.	-83.	-60.	-0.	39.
-8.	-7.	-31.	5.	27.	-189.	2.	7.	-10.	9.	45.	18.	-29.	1.	-60.	
404.	-1.	27.	-3.	0.	14.	-5.	-417.	39.	14.	11.	-61.	-29.	-73.	2.	-62.
-9.	7.	5.	188.	-5.	8.	985.	6.	61.	-88.	-29.	13.	-295.	7.	-731.	
128.	-3.	23.	12.	1.	-13.	6.	-2.	1.	6.	6.	16.	66.	10.	-1.	123.
-2.	-8.	28.	20.	5.	16.	-4.	-620.	-1.	25.	74.	-8.	69.	-1.	26.	
-409.	6.	-67.	77.	-1.	29.	198.	-174.	31.	10.	3.	-47.	-72.	-92.	4.	293.
18.	-1.	39.	101.	-12.	-117.	838.	21.	217.	-55.	-96.	4.	-331.	5.	-408.	
583.	0.	5.	11.	-1.	2.	-74.	6.	2.	4.	9.	-16.	10.	-124.	-1.	-21.
-1.	-0.	12.	67.	6.	5.	-4.	2.	-5.	-184.	21.	8.	-301.	3.	-122.	
170.	-4.	-4.	17.	8.	19.	-41.	-10.	0.	56.	16.	51.	116.	-340.	14.	425.
-1.	-6.	75.	82.	27.	50.	-45.	84.	-8.	97.	-1090.	-11.	193.	2.	50.	
-17.	1.	21.	21.	1.	7.	-0.	-9.	2.	3.	4.	27.	53.	-9.	-1.	-7.
-0.	-3.	4.	10.	-11.	27.	-28.	4.	-1.	-16.	-12.	-146.	1.	-2.	79.	
-593.	-14.	50.	11.	9.	12.	-22.	-133.	5.	45.	28.	213.	-100.	-56.	-1.	-44.
[illegible]	7.	22.	85.	10.	-1.	-81.	40.	-11.	-75.	148.	-16.	61.	12.	798.	
36.	4.	14.	3.	1.	-0.	6.	8.	1.	4.	2.	9.	3.	35.	2.	8.
1.	17.	-1.	6.	2.	1.	5.	0.	0.	17.	7.	-2.	30.	-242.	22.	
498.	54.	-53.	19.	4.	14.	-387.	-389.	11.	194.	-34.	-396.	27.	66.	-5.	-52.
1.	14.	36.	-491.	88.	25.	40.	19.	5.	-98.	49.	45.	603.	6.	127.	

COMPARISON STATISTICS BETWEEN OBSERVED AND SYNTHESIZED TRIP MATRICES

MEAN PERCENTAGE ERROR IS 100.10

ROOT-MEAN-SQUARE ERROR IS 221.90

ACTUAL AV. PER CENTINTRA-ZONAL IS 25.86 SYNTHETIC AV. PER CENT INTRA-ZONAL IS 22.57