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Evaluation of accessibility of urban transportation networks

Nanda N Srinivasan

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**EVALUATION OF ACCESSIBILITY OF URBAN
TRANSPORTATION NETWORKS**

by

Nanda Srinivasan

**A thesis submitted in partial fulfillment
of the requirements for the degree of**

Master of Science

in

Civil Engineering

**Department of Civil and Environmental Engineering
University of Nevada, Las Vegas
August 1997**

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ABSTRACT

This thesis examines accessibility of urban networks to serve the transportation needs of a community. The term accessibility is dealt with qualitatively and quantitatively, giving it a form and structure readily adaptable for implementation by metropolitan planning organizations. Accessibility has been defined from the point of view of the network. This definition helps in interfacing the network with the traditional travel demand models. A methodology was enunciated to develop accessibility indices for urban areas and implemented by means of automated software. The trip generation stage in the traditional urban transportation planning process (UTPP) is used along with a geographic information system (GIS) based approach in order to develop a program that evaluates accessibility measures and presents them in a graphical manner. The indices are expected to aid transportation planners, managers of public agencies and decision makers to make the best use of available resources in making changes to the transportation system and also help compare the system accessibility both within the system and across various systems in a region. The methodology has been implemented and an alternatives analysis performed for the Las Vegas Metropolitan area. The implementation scheme utilizes the spatial analysis capabilities of GIS and interfaces with the UTPP. A suite of programs are developed in the GIS environment to automate the process to a simple menu driven system. Twenty two indices have been defined and analyzed for the study area. These include five indices each for

trip production and attraction parameters namely home-based work, home based school, home based shop, home based other and aggregate accessibility indices. Similarly, a combined model incorporating both the production and attraction models (consisting of six indices) and a demographic model (consisting of five indices) are also developed and analyzed.

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ACKNOWLEDGEMENTS

I express my sincere thanks and appreciation to my advisor Dr. Shashi Sathisan for his support, encouragement and advice through out the course of my graduate study. Special thanks to Dr. Mohammed Kaseko for his comments and advice received from time to time both for my thesis and regular course work. I am thankful to Dr. Edward Neumann for reviewing my thesis and helping me understand important concepts in Transportation engineering. I also thank Dr. Ranel Erickson for reviewing my thesis and for agreeing to be the graduate faculty representative. I am grateful to the Department of Civil and Environmental Engineering for the financial support I received through out the course of my graduate study and the Transportation Research Center, UNLV for the use of all the facilities. I would also like to express my gratitude to Robert Putreski who taught me the basics of GIS and supported me through out my programming effort.

I also express my profound thanks to my family and friends for their constant motivation and support.

CHAPTER 1

INTRODUCTION

Traffic congestion has lately become one of the most undesirable aspects of urban living in the United States. The volume of vehicles using the transportation network in many metropolitan areas has increased tremendously without a corresponding increase in capacity. Urban travel is estimated to be increasing at the rate of 4 percent per year with the construction of new facilities being expected to accommodate less than a quarter of the additional demand. The 37 largest metropolitan areas in the United States have been reported to suffer 1.2 billion vehicle hours of delay (NCHRP, 1991). The economic losses for the United States in 1994 due to congestion was estimated at \$100 billion which is about 5 percent of the GNP (IVHS America 1995). Consequently, travel times to work have suffered a considerable delay.

In conjunction with increased traffic flow, transportation professionals and public administrators of today have to contend with an increase in public concern on aspects of living such as automobile sources of pollution (air and noise) and related problems. Budgetary problems and unavailability of land resources for enhancing system capacity constitute other sets of constraints. However, many metropolitan areas in the United States are addressing the need to enhance the system capacity using a variety of techniques

including building / modifying the network elements and employing intelligent transportation system initiatives. Changes to system capacity require considerable analyses primarily because they are highly resource intensive. Secondly, such changes take time (typically months to years) to materialize which requires a proper planning and implementation schedule. Once the change has been implemented, it is difficult to reverse because of the high cost involved.

Some of the questions that transportation professionals, elected officials and public administrators are required to answer include where to build, when to build and what to build in order that the system as a whole makes places and people more easily accessible without compromising with a plethora of other issues / constraints such as air quality and other pollution considerations. The problem of congestion itself has its roots in accessibility and mobility. In this era expansion of highway capacity has become all the more difficult. The choice of where to build given the budgetary and land use problems has therefore to be addressed in a very sensitive manner.

1.1 Motivation

Transportation planning researchers have historically tried to exploit the inherent interdependence of transportation and land use in order that a fully integrated systems approach predicting user behavior and transport facility is developed. A key issue faced by planners and public administrators is optimal allocation of resources in such a manner that travel demand is addressed both effectively and efficiently. Broadly, this issue has been addressed by two means: Building new facilities ,use of Travel Demand Management (TDM) strategies and traffic management strategies.

Building new facilities approach focuses on building strategic enhancements to the transportation system. The TDM strategies focus on reducing the demand for in a spatial and temporal manner so that fewer vehicles are on the system during peak periods while traffic management strategies aim at reducing trip times. In this thesis, the effort is focussed on the approaches to identify areas where system enhancement is needed. The primary idea of the research is to develop a decision support tool for comparing alternatives given a set of constraints.

The basic function of any transportation facility is to provide accessibility and mobility to the end user. Accessibility in general terms refers to the capability of being reached and mobility refers to the ease with which a movement can take place. Both these terms are fundamental to any systems approach and in order to describe the state of a transportation system, it is necessary to quantify them.

One of the most important considerations in instituting changes to a transportation system is the enhancement of accessibility. Transportation investments have therefore to be made keeping in mind that people and places have to be made more accessible. Transportation planning researchers have generally addressed the problem of estimating accessibility either in terms of people or places. Thus accessibility has been traditionally tackled in terms of identifying the proximity of a location to other locations, people and services. The proximity itself is measured in terms of travel time, travel distance or a generalized travel cost function. Transportation demand models have also used some measure of accessibility in order to estimate the trips that can theoretically be made between two locations based on some relative attractiveness measures. Thus, it can be seen that

accessibility measures are required to describe both the present state of a network and for the institution of changes.

1.2 Objective and Scope of Work

"Accessibility" is a common term used frequently in explaining spatial variations of various phenomena. The degree of accessibility is generally talked about in terms of location of facilities. It is quite difficult, on the contrary, to define the term for operational purposes.

Gould states:

"Accessibility ... is a slippery notion... one of those common terms that everyone uses until faced with the problem of defining and measuring it" (Gould, 1969).

Ingram defines accessibility as:

"... the inherent characteristic (or advantage) of a place with respect to overcoming some sort of spatially operating source of friction (for example time and/or distance)" (Ingram, 1971).

This thesis aims to develop some measures of accessibility in the context of a metropolitan area. A methodology is developed to identify accessibility from the perspective of the transportation network itself. An automated tool is also developed in order to apply the methodology across various networks within a metropolitan area or to compare networks in different metropolitan areas. Methodologies have also been incorporated in order to use the measures developed as means to support policy formulation, design and planning of enhancements to the transportation network. The trip generation stage in the sequential urban travel demand forecasting model has been used along with a Geographic Information Systems (GIS) based approach in order to develop a program that evaluates accessibility measures and presents them in a graphical manner. An illustrative case study has also been performed for the Las Vegas Metropolitan Valley area.

This region has experienced tremendous growth in the last few years. The metropolitan area is billed as the entertainment capital of the world and receives an estimated 29 million visitors annually. There has also been a rapid growth in the resident population which was 1.075 million in 1996. This is expected to grow further to about 2 million by 2020 (CCDCP, 1997). Employment levels are projected to grow by 100 percent in the next 20 years. There is, therefore, considerable strain on the existing transportation facilities. In 1995, the total person trips in the valley exceeded four million. The total vehicle miles of travel was at 18 million vehicle miles which resulted in the use of 58% of the total roadway daily capacity (RTC, 1995). In this research, freeway accessibility to all the areas in the valley has been quantified and analyzed.

1.3 Outline of Thesis

A review of literature is presented in Chapter 2. The focus of the review is the traditional measures of accessibility. Chapter 3 describes the methodological considerations of the study. Implementation of the methodology is considered in a generic manner in Chapter 4. Illustrations of the method are also presented therein. Chapter 5 presents a case study where in the methodology developed is applied to the Las Vegas Valley area freeway system. A summary of the research conclusions and recommendations are presented in Chapter 6.

CHAPTER 2

LITERATURE SURVEY

Accessibility measures have been sought to be developed by transportation professionals from time to time in order to address specific questions such as land use planning, urban infrastructure planning etc,. The objective of this research is to identify the various ways in which accessibility measures have been formulated and the methods by which these measures have been used in urban transportation planning. Some of the pertinent research methodologies are cited in this chapter in a chronological manner starting with the early methods such as the Hansen index to some of the more recently used procedures. A summary of the review is also presented at the end of the chapter.

2.1 Discussion

Hansen (1959) gives the fundamental formulation of accessibility. Defining accessibility as the intensity of possibility of interaction, the author proceeds to give an operational definition that: "Accessibility at point 1 to a particular type of activity at area 2 (say employment) is directly proportional to the size of the activity at area 2 (Number of jobs) and inversely proportional to some function of the distance separating point 1 and area 2." Data from Washington, D.C., were collected for empirical examinations of the relationships between residential development and accessibility. Accessibility was calculated

for employment, population and shopping opportunities for 70 areas in the Washington metropolitan area. The residential development ratio (i.e., the ratio of the developed land to the total land in the build out scenario) was calculated and examined to reveal its variance with accessibility. This paper fundamentally defined accessibility. The definition is still widely in use today.

Garrison (1960) investigated the connectivity of the interstate system in the fifties. He evaluated connectivity of a point to various other points in the network and used this measure to develop another measure called dispersion which was defined according to a distance-based access measure. Using this procedure, he performed a comparative study for various cities. The whole network was described by a graphical presentation and concepts from the theory of graphs were employed extensively to develop a relative measure based on activity location. The author opines that this method is relatively simple, but it is not useful for decision making in terms of whether a particular link should be added or not to a system as such empirical statements are outside the usual content of graph theory.

Ingram (1971) has presented a conceptual and operational definition for accessibility in terms of relative and integral accessibilities. These are further developed in terms of distance measures such as straight line (or Euclidean) distance and rectangular (or Manhattan) distance. These definitions are applied to Hamilton, Ontario. It is recommended that a measure based on normal, or Gaussian curve is the most suitable form for determining integral accessibility. Relative accessibility measures the degree to which two places on the same surface are connected.

Baxter and Lenzi (1974) attempted a measurement of relative accessibility in terms of physical separation (based on the transportation network) between the zones of a study

area. A network for the town of Reading in Berkshire was loaded, divided into study areas and analyzed for shortest distance between the centroids. From a matrix containing the shortest distance, a measure of relative accessibility was then derived.

Dalvi and Martin (1976) investigated the employment of accessibility measure to London. It used a Hansen-type measure explained by the equation 2.1.

$$Ac_i = \frac{\sum_{j=1}^n W_j e^{-\beta c_{ij}}}{\sum_{j=1}^n W_j} \quad \text{.....(2.1)}$$

where

W_j = Measure of attractiveness of zone j.

Ac_i = Accessibility of zone I to opportunities in zones $j= 1, \dots, n$.

c_{ij} = Cost of travel from zone i to j.

The accessibility was defined for choice attractiveness variables (such as population, employment etc,.). The sensitivity of this measure was then analyzed. The database used for the study was the London Travel Survey of 1962. The parameter was travel cost function and the basic spatial unit of analysis was the 406 zones chosen for analysis. The accessibility pattern was found to be highly sensitive to the choice of the attractor variable. The accessibility index point also proved quite sensitive to the effect of zonal configuration and disaggregation.

Black and Conroy (1977) have evaluated the accessibility of the Sydney metropolitan area in terms of employment opportunities within a specific travel time. A new accessibility index was defined as the area under the curve representing the cumulative

number of opportunities passed in a given travel time t . Accessibility is therefore measured as follows:

$$\text{Accessibility} = Pr_t (t - \bar{t}) \quad \dots (2.2)$$

where

Pr_t = Proportion of activities that have been passed up to time t

t = Specific time ordinate

$\bar{t}$ = Mean travel time to these activities

A measure of residents' accessibility to various modes of travel was then computed. The relationship between residents' accessibility and travel behavior to these opportunities was then investigated. Based on this formulation, a computer-based method to quantify the relationships were presented which were found to be consistent with graphical interpretations of accessibility. The methodology is stated to have three broad areas of application.

1. To monitor changes in accessibility as locations of activities alter.
2. Identify suburbs in the city with low accessibility.
3. Evaluate social implications of alternative plans for land use and transport.

Pirie (1978) reviewed all accessibility measures starting from Ingram to cumulative opportunity measures developed in the 70s. The paper proposed a time-space measure modified to reflect that accessibility is always created and that accessibility can be measured in terms of opportunity costs. It is felt that the two basic assumptions involved in the measure of accessibility i.e, that all origins are known and that all nodes are potential destinations severely restrict the inferences that can be made by use of the measures. The author states:

"Time-space measures of accessibility would be a useful antidote to the more popular measures only if they did not define accessibility with such finality."

Morris *et al* (1978) reviewed accessibility measures in terms of their applications.

It is stated that the measures help in the following three applications.

1. System evaluation to monitor changes in the urban system irrespective of whether such changes are planned or unplanned.
2. Travel Demand Modeling as input variables in modeling travel choice situations.
3. Urban Development Models in order to model urban form.

It can be seen that the first two applications directly concern the transportation planner/engineer, administrators or elected officials.

Domanski (1979) used spatial accessibility and costs as measures to represent spatial equity and economic efficiency. The author makes a hypothesis that higher spatial equity does not always mean lower economic efficiency. The application of accessibility as a tool in analyzing socioeconomic inequalities is discussed in this paper.

Bach (1981) investigated the effect of changing the level of spatial disaggregation of sets of data on the accessibility measures. It was also intended to investigate whether the method of measuring the distances affects the final results of accessibility and access opportunities. A related third question involved investigation of a correlation between distances measured in different ways such as travel time by car and Euclidean distances. It was felt that if such a correlation existed, then it would be possible to analyze the accessibility based on the most easily obtained measure.

Three experiments were conducted by Bach. The first "investigated the influence exerted by types of distance measures on location patterns of supply points." The second

investigated the effect of levels of disaggregation. The third concentrated on correlation between different types of distance measures. Data were obtained for the cities of Kleve and Dortmund in Germany. The area was divided into "sub-areas of statistical subareas", "statistical subareas", "statistical areas" and "administrative districts". For example, the Dortmund city comprising of an area of 108 sq. miles (62,000 inhabitants) was divided into 286 sub areas representing the lowest level of aggregation. At the second level of aggregation, the 286 sub areas were reduced to 171 statistical subareas. In the third and fourth aggregation, these were reduced to 62 and 12 zones/areas, respectively. Four different distance measures were used: (1) Euclidean distance, (2) Street network distances, (3) Public transit distances obtained by applying the shortest-path problem and (4) Public transit network distances.

The results indicated that:

1. Distance measures other than travel times by car result in different optimal locations of infrastructure facilities.
2. Different distance measures will result in different optimal locations for a system of infrastructure facilities.
3. Level of aggregation exerts a strong influence on the optimal location patterns as well as on the values of the location criteria.
4. There exists a high correlation between Euclidean distances and network distances except public transit distances.

Current *et al* (1987) presented the median shortest path problem (MSPP). This would help to generate "non-inferior solutions which explicitly demonstrate the tradeoffs

between network cost and network accessibility." The MSPP could help in assessing the location of new highways etc., in a network.

Hanson and Schwab (1987) studied accessibility from the perspective of whether an individual's accessibility to activity sites had any discernable impact on the person's travel pattern. It questioned the strength of the fundamental accessibility-travel link. A household travel survey was conducted in a town in Sweden (Uppsala). The adult members of the household were asked to keep a diary on all the out-of-home movements for thirty five consecutive days. The survey also had information pertaining to individual and household characteristics and location and type of all local service establishments. The measure of accessibility used was based on Pirie (1978). This cumulative accessibility index is quite sensitive to small-scale changes in the individual's travel activity pattern. The travel-accessibility relationship was then examined after controlling for a number of other variables known to affect travel. Five aspects of travel were examined: mode use, discretionary travel, trip complexity, travel for work and size of activity space. The result showed that the strongest relationship was encountered between accessibility and mode choice. It was found that people with many opportunities close to home make a higher proportion of their stops with non-motorized modes. Accessibility was found to have a relatively little impact on overall discretionary trip frequency. Insignificant associations were revealed for trip complexity while some evidence was found that accessibility around home and work affects the timing and location of trip making. The average distance from points to the centroid (size of activity space) was found to be significantly related to work-based accessibility measure. The paper concludes that the travel-accessibility measure is not as strong as conventionally portrayed. Where the relationship was found to be statistically significant, it was weak.

Linneker and Spence (1991) examined the changes in accessibility due to the construction of M-25, an orbital expressway around London. This facility was constructed over a period of 11 years at a cost of around £1 billion. The objective of the research was to examine the effect of construction of this facility on general accessibility. It should be noted that the whole of Britain was chosen as the geographical entity affected by the road, more emphasis being placed on South east part of Britain. The South East was divided into 129 areas and the rest of Britain into 50. The study then employed a Hansen type of accessibility index in order to measure the accessibility of each of these geographic entities in terms of their market potential. The Hansen concept is that smaller and more distant markets offer lower potential. The index is therefore “a measure of the relative impedance of a given area from the markets and input sources which the areas could actually or potentially supply or be supplied from.” This is similar to the concept employed in the gravity model trip distribution step of the traditional four step urban travel demand forecasting process.

$$MP_i = \sum_j \frac{Po_j}{C_{ij}^a} \quad \dots(2.3)$$

where

MP_i = Market potential of zone i

Po_j = A measure of mass or market potential in a zone j

C_{ij} = A measure of impedance or transport costs from i to j

a = An exponent, often assumed equal to 1

Time and distance data with and without the M-25 were obtained for cars and heavy commercial vehicles. A generalized transport cost estimated on the basis of suggestions from the Department of Environment's Mathematical Advisory unit was used. Accessibility changes due to the orbital motor way were then presented in a tabular form.

Coopers & Lybrand (1991) in their objective to develop development location equations for the Las Vegas Metropolitan area valley defined four indices based on population, employment, non-hotel employment and income. They based it on the average density of population, employment or income within a specific distance of a given point.

Arentze *et al* (1992) assert that accessibility to shopping facilities, traditionally defined as the ease with which these facilities can be reached, should be modified to reflect the distances between each of the individual facilities. It is stated that the method fits well with the Geographic Information System (GIS) environment. It asserts that the shortcoming of the traditional measures is that the users tend to combine different purposes in a single trip and this combination of trip purposes has to be accounted for. The accessibility is therefore defined as the lowest possible travel costs that have to be made to purchase a complete set of consumer goods. The number of trips is a function of:

- (1) Frequency with which the purchases of different goods need to be made; and
- (2) Degree of combining purchases of different goods.

The paper developed an optimization model for the problem. An associated computer model was then developed and linked to TRANSCAD (Caliper Corporation, 1996), a GIS software. The measure was then applied to Maastricht in Netherlands. The result showed a difference in access measures for single purpose and multi purpose trips. It is concluded that

the multi purpose accessibility measure is more sensitive to the actual location of shops vis-a-vis each other as compared to the single purpose accessibility measure.

Gould *et al* (1993) discuss the implementation of a national motor way accessibility model using two accessibility indicators called the absolute accessibility indicator (AAI) and relative accessibility indicator (RAI). The measures involved the determination of impedances in terms of route (arc) and node impedances. These impedances were determined in terms of travel time, infrastructure, traffic and origin nation of the arcs (due to the fact that crossing national boundaries involve time overlays). These were then implemented using the arc-macro language (AML) in ARC/INFO a Geographic Information System (GIS) program (ESRI 1993a). The following implementation stages were outlined (figure 2.1).

A. Data entry phase: This involved digitizing 8 layers of spatial data. The motor way consisted of 450 nodes and 650 arcs.

Each of the arcs were represented in terms of:

1. Origin and destination node.
2. Official name of the motor way.
3. Motor way type in 1992/2007.
4. Length of the arc.
5. Maximum speed in 1992/2007.
6. Driving time.
7. Median daily volume.
8. Percentage of heavy vehicles.
9. Traffic coefficient based on driver familiarity of the routes.

10. Infrastructure coefficient based on motor way type such as toll roads, country roads etc.,

11. Impedance in 1992/2007 which was based on the traffic coefficient, infrastructure coefficient and a nationality coefficient (a penalty for arcs emanating from neighboring Portugal).

B. Accessibility Indicator Calculation.

For the calculation of accessibility, the network module of ARC/INFO was run to calculate optimal routes. Given this, the distance between each origin and destination node was stored as an ASCII file. Euclidean distance between each origin and destination was then used to calculate the real impedances. The above two were merged using the JOIN command.

Figure 2.1: Scheme of RAI model implementation within ARC/INFO

C. Map Generation:

The iso-accessibility regions were calculated in the form of a contour map. The process is described in figure 2.1.

Bruce *et al* (1993) described a procedure to develop an indicator of the overall accessibility level of an area consolidating the individual accessibility measures suggested by Ingram (1971). Travel time was chosen as an accessibility indicator. This measure was then tested for its sensitivity and applied to the eight counties of the Philadelphia metropolitan area for comparison purposes. These were consolidated to obtain an overall index for the region as a whole and compared with those developed for sixty other metropolitan areas. Impact of the overall index on the employment opportunities in an area was observed to be significant. It was also observed that this relatively simple overall index measure captures the access level of local areas well too.

Mackiewicz and Ratajczak (1994) defined a new index for topological accessibility index for transportation network vertices (such as towns and cities on a freeway network) based on a time-space convergence presented by Janelle, 1969 (figure 2.2). The concept is that demand for accessibility is a time-space convergence problem as travel itself is based on temporal and spatial constraints in the system. With increased time-space interaction, a need for technological innovation arises to balance the system to equilibrium. This in turn fuels a new demand for resources. The process is illustrated in figure 2.2.

The definition of accessibility mathematically speaking was based on the Principal Eigenvector Method (PEM). A portion of an interstate highway system was analyzed using this definition as well as other definitions based on mathematical procedures such as sum of power series method (SPSM) and Linear equation system. It was found that the PEM

"allowed formulation of the comprehensive classification of vertices in the network in aspect increasing or decreasing their accessibility."

Figure 2.2: A process of reorganization in response to transportation improvements (Adapted from Janelle, 1969)

Davidson (1994) examined the relationship between accessibility and urban density both conceptually and experimentally. The basic concept of the Hansen index was used. A relationship of the following type was investigated:

$$\text{Accessibility} = f(\text{land-use intensity})$$

The accessibility measure itself was based on the following:

1. Available modes of travel.
2. Intra zonal accessibility: A function of generalized cost.
3. Total accessibility: Sum of inter and Intra zonal accessibilities by mode.
4. Impedance function which accounts for inter zonal accessibility: A function of the generalized cost.
5. Activity measure: Size of the activity.

Then using a gravity model type formulation, the accessibility measure was derived.

The density measure was developed to reflect the intensity of land-use. The centrality of an activity was defined in terms of a power impedance function. Detailed analysis of London and Brisbane were then conducted in order to calibrate an accessibility-density relationship. It was hypothesized that for each value of accessibility measure there is an equilibrium density and areas in cities tend to move toward that equilibrium. It was felt that this notion would lead to improved plans for assessing transportation projects.

Johnston (1996) presented the findings of a study of bus services and their relationship to the settlement pattern with regard to the spheres of urban influence and accessibility of one place to another. The index was based on a point system which is enumerated as follows.

Table 2.1: Point system to calculate accessibilities (Adapted from Johnston, 1996)

Characteristic	Definition	Points
Travel Time to Work	1. A service arriving in town before 8 am daily	2
	2. A service arriving in town before 9 am daily	1
Travel to Entertainment	1. A daily bus leaving town after 9.30 pm	2
	2. A bus leaving town after 9.30 pm on less than 6 days/week	1
Travel to shopping	For any journey to town and back with a stay of one hour	1
A Sunday Service		1
Length of the Journey	Less than 30 minutes	3
	30-60 minutes	2
	More than an hour	1

Using this accessibility index it was shown that the correlation between accessibility and average village size was weak. It was concluded that distribution of accessibility over the

study area being irregular, where the village indices of accessibility are highest, the influence of non-urban settlement pattern on their size is minimum.

The urban settlement area and distribution of the inter-urban bus routes were found to have an exerting influence on the index of accessibility. With this index of accessibility, the villages were ranked according to weekly bus service availability and analyzed for urban influence.

2.2 Summary

It can be seen that through the years several attempts have been made to define, quantify and measure accessibility. All of them have some common underlying criteria in that most of them used size, location and type of activity along with some travel impedance between activities as the basis of the definition of accessibility. The trip distribution stage in the traditional urban transportation planning process was deemed to be the most defining entity. Access measures were developed to quantify the proportion of travel between traffic analysis zones, given some demographic criteria and trip productions and attractions. The models did not address the trip generation stage itself, in other words, the models which replicate travel demand itself have been largely ignored. Moreover, most of the concepts developed were extremely complicated to apply to large networks easily and efficiently. Very few of the models had any associated graphical interface for easy visual interpretation of the index.

It can therefore be seen that there is a need to redefine accessibility keeping in view the following criteria:

1. The measure should be easy to interpret, analyze and apply to large urban networks.

2. It should be sufficiently broad-based so that it can be used as a tool to evaluate the transportation needs within an urban area as well as serve as a tool for comparison between different urban areas.
3. It must be easy to automate the process of generating the index and present the results graphically.

It can also be seen from the discussion that except in very few cases, there has been little effort spent in developing accessibility as one primary input in to a decision support system for the transportation planner. A definition based on the criteria laid out would aid as a vital decision support tool for efficient, equitable and optimal allocation of resources to change the capacity (supply characteristic) of the transportation network.

CHAPTER 3

Methodology

The literature review revealed the various methods by which accessibility was conceptualized. This chapter concentrates on the development of a methodology that addresses the concerns sited. A new approach to quantify accessibility is attempted. The concept has been fitted into the whole scheme of urban transportation planning methods in order to depict its utility. Applications of the measure developed in performing alternatives analyses have also been presented.

3.1 Theoretical Considerations

Traditionally accessibility has been defined for a particular base unit, usually the traffic analysis zone, so as to reflect a measure of the overall attractiveness of the zone. The main components include travel time and cost incurred to achieve the objective of overcoming the geographical friction of distance in order to reach the zone from various other zones. From the summary of the literature survey, it can be seen that trip generation is one important step in the Urban Transportation Planning (UTP) process that is directly affected by accessibility.

In this thesis, accessibility of a transportation network is sought to be measured from the point of view of the network. Thus the accessibility of the network is approached from

the angle of its utility i.e., the ability of the network in terms of its functional classes to cater to various factors influencing trip generation such as population, employment etc.,. Approached in this manner, accessibility can be defined as spatial distribution of some characteristic in a fixed area around a network.

3.2 Framework and network considerations

Accessibility should be a measure of the ease with which the objective of mobility can be met. This is achieved by measuring the proximity of the trip origins or ends to the road network itself. For example, the proximity of a residential area to a road network would help indicate the utility of the network and therefore yield the accessibility of the area. A road network in a metropolitan area basically serves the demand for travel -both in terms of passengers and cargo. Examples of the needs of travel demand for passenger travel include:

1. Connect a fixed area such as a residential area to places of employment such as the CBD.
2. Connect work places to other important work places.
3. Connect a residential area to schools and colleges.
4. Connect residential areas to wholesale and retail establishments.
5. Connect residential areas to places of tourism and recreation.

A definition of accessibility should take the above factors into consideration in order to be an efficient and effective analytical tool. The network in an urban area would consist of a large number of links. It is essential to select key links for which the accessibility is to be described. This subset should consist of the links that are crucial for mobility. In any urban network, the links that serve to move people and resources can be classified a number of

ways. The categorization of an urban network to functional classes is a mechanism that could be adopted for the development of a methodology to evaluate accessibility. The functional classes of urban road network adopted for this research are freeways/expressways, primary arterials, secondary arterials, collectors and distributors. From a mobility perspective, the key classes of concern are the freeways/expressways, primary arterials and secondary arterials. Thus, the methodology developed in this research will focus on these classes. It may however be extended to include the other classes as well. Once the sub-network is delineated and coded in terms of functional class and capacity, each link may be extracted and analyzed in order to obtain a measure of its effectiveness. Alternately, all the links may be considered together in order to assess their collective accessibility.

3.2.1 Definition

The first factor considered in the definition is the functional classification of the road network system. The accessibility of a link in the network is then determined on the basis of how long it would take a user to reach any node on that link. The next input is the travel demand characteristic. For the purposes of a broad definition, consider a link (say) i in a study area which has (say) n travel demand factors such as population, employment etc.,

Mathematically, the accessibility measure for this link can be stated as:

$$Accessibility\ Index = \frac{1}{n} \sum_{j=1}^n \left(\frac{u(l,k)}{U(k)} \right) \quad \dots (3.1)$$

where:

$u(l,k)$ =Spatial Distribution of trip generator variable k such as household size, income etc., around a fixed distance from link l .

$U(k)$ = Study area total of the variable k .

Thus, the number of people living within, say, a three minute driving distance from a given freeway ramp can be defined as the primary population service area for the given ramp. This number along with the corresponding regional estimates such as the number of people living in a development district can be used to define a ratio depicting the percentage of people primarily benefitting from the existence of the ramp. The concept can be extended to include sub-indices for various demographic characteristics of a study area. A mean of all these characteristics would then yield a measure of the overall accessibility of the ramp as described by equation 3.1. Instead of evaluating for a single link, it is more advantageous if a whole functional class of links were assessed for their combined accessibility. Thus, equation 3.1 can be modified so that $u(l,k)$ would now be a measure of the spatial distribution of trip generator variable k around a fixed distance from all links l belonging to a common functional class such as freeways, primary arterials etc,. This definition is developed in a complete manner in section 3.6.

The choice of the demographic characteristics itself can be based on the trip generation model as suggested in the literature survey. The indices could be expressed at the base level of analysis using the Traffic Analysis Zones. The sub-indices could then be used to construct an overall index which at one stroke can capture the utility and efficacy of the whole network.

It is expected that the definition would help in assessing the effectiveness of the various functional classes in a given network. A complete construction of various indices

would help in identifying areas that need special attention. The goal of this thesis is to develop an index which will reveal the overall effectiveness of changes to the transportation network for a system modification such as adding a link, enhancing the capacity of a link etc.,

It can be seen that the definition also renders it possible for use across various networks. This would allow comparison across various metropolitan transportation systems. For example the overall accessibility index of an urban area such as Las Vegas can be compared with other urban areas.

The methodology developed herein is applicable not just to road networks, but can be extended to include transit, rail, waterways, pipelines, automated people movers and air transportation network accessibilities too.

3.3 Distance Measures

The ease with which a given network of arterials and freeways may be accessed depends largely on the spatial distribution of the population and the way the network itself is structured. Thus, for a given arterial, the spatial distribution of the effective service area is dictated by the extent of secondary streets that feed into the arterial. In order to define the "outreach" of a link, it becomes imperative to measure the distance (or sphere of influence) on the network based on some criteria. These distance measures can be broadly classified into three categories (figure 3.1).

1. A fixed "Euclidean distance".
2. Manhattan distance.
3. Network Distance.

1. Euclidean distance

The Euclidean distance is the shortest distance between two points in the network. The trajectory obtained as a crow flies between two points is called the Euclidean distance.

In order to obtain a sphere of influence for any link in the network, this method would prescribe drawing a buffer around it at a fixed distance. This distance could be based on the maximum possible distance from the link at which the service population finds it desirable for use. The primary advantage of this method is that it is comparatively very simple and can be employed easily. However, this method is bound to present a crude approximation as the presence of secondary streets and other arterials around the link is not considered at all. Secondly, drawing a buffer at a fixed distance does not reflect the real travel times which are needed order to reach the link under consideration. This would imply the requirement of actual speeds of travel on the secondary streets. Thus, this measure is recommended only when there is lack of data pertaining to the secondary streets.

Figure 3.1: Distance Measures

2. Manhattan Distance

The Manhattan distance is defined as the sum of the distances traversed on two mutually perpendicular lines passing through the given points. This distance generally represents the maximum possible distance that the two points can actually be separated in terms of field conditions. This distance would be the same as the network distance in the case of a rectangular grid network. In other cases, the distance computed by this process is generally an overestimation. Thus, a measure computed on the basis of this distance would generally underestimate the accessibility.

3. Network distance

The Network distance method involves allocation of distances based on the actual network. Here, the actual distance traversed by the user in order to reach the link is employed.

A maximum tolerance is then input in order to define the service area.

The actual distance measure could itself be based on:

A. Travel distance measures.

B. Travel time measures.

A. Travel distance measures

In the travel distance measures method, a maximum tolerance distance is applied from each node on the link under consideration and the outreach area is thus defined. The assumptions involved are:

- i. The speed of travel is constant along all secondary streets and connecting arterials.
- ii. The actual volume of traffic on the secondary connectors has no influence on the travel time.

These assumptions make the method approximate. However, this is a much better approximation when compared to just buffering based on a fixed distance as it at least takes the actual network to consideration. This method is recommended under the following data restrictions:

- a. Lack of data such as posted speeds of travel along the secondary connectors and
- b. Lack of data such as number of lanes and capacity of the secondary connectors.

B. Travel time measures

The best measure in order to delineate service area is by demarcating the actual distance that a vehicle can travel a given "tolerance time" along the network order to reach the link under restrictions namely:

- i. The actual speed of travel along the secondary connectors.
- ii. The waiting time at intersections etc.,

The waiting time at intersections itself is highly stochastic in nature and the measurement of average wait times would involve lengthy calculations. Alternately, in order to determine the wait times, a relationship between the volume to capacity ratios and the average intersection delay may be used to determine the total travel time per link. The procedure suggested in the Highway Capacity Manual (TRB, 1994) is widely used in order to develop an estimate of the intersection delay. The approach used here combines a variety of factors such as intersection geometry, traffic flows and signal design in order to estimate the average stopped delay. Several researchers have attempted to develop intersection functions based primarily on the volume to capacity flows (v/c ratios). One such approach developed by Akcelik (1988) is described in section 3.4. Thus the actual average travel

speeds can be used in conjunction with travel time and delay in order to measure the service area. In general, the speed used could be based on:

- a. Posted speed of travel along the secondary streets. This would yield a "optimistic estimate" for the service area.
- b. A percentage of posted speed limit (such as 80% of the posted speed limit). This would yield a "pessimistic measure" of the service area.
- c. Actual speeds based on volume of flow. This can be obtained through running the four step Urban Transportation Planning Process and obtaining the volume of flow on the major streets. The Bureau of Public Roads (BPR) equation for the travel speed can then be employed in order to determine the congested speed. Instead of travel distances, the whole network can now be described terms of travel time. Thus intersection delays will also be accounted based on the number of intersections in the link and the type of intersection control. Then, using a cutoff or "tolerance time" of three minutes, the boundary of the service area can be defined.

3.4 Urban Transportation Planning Process

The Urban Transportation Planning Process (UTPP) is a formalized planning methodology designed to provide guidelines and priorities. A general framework representing the whole gamut of the transportation planning process is described in the flowchart illustrated in Figure 3.2 (Meyer, 1984).

An integral part of the urban transportation planning process is the four step travel demand forecasting process which together help to quantify travel demand for the network an urban area. These steps are briefly enumerated next.

Figure 3.2: Overview of the Urban Transportation Planning Process
 (Source: Meyer and Miller, 1984, Chapter 1)

In order that urban demand for travel be quantified in a compact and analytically feasible manner, it is imperative to work at an aggregate level of trip making as opposed to modeling individual trips. This aggregation should reflect a common pattern of trip making. The urban area is divided into base units of homogenous "transportation demand" characteristics called the traffic analysis zones (TAZs).

The common trip making characteristics that can be used to develop these TAZs include achieving homogeneous socio-economic characteristics for each zone's population, minimizing intra-zonal trips, recognizing physical, social, political / economic, historical and census boundaries, maintaining contiguous boundaries and avoiding zones within other zones (donuts).

The transportation network is of primary consideration delineating the boundaries for the zones. Once the TAZs have been defined, a four step process consisting of trip generation, trip distribution, mode split and traffic assignment is applied in order to obtain the traffic flows on the links of the network.

3.4.1 Trip generation

Trip generation is a process by which the number of trips originating or ending at a particular zone is quantified on the basis of socioeconomic characteristics of the zone. Trips are classified as productions or attractions based on their origin and destination purpose. The trips are classified as Home-Based Work, Non-Home Based and Home-Based Other. The most common methods of trip generation are cross-classification methods and multiple linear regression methods.

The production and attraction models are developed separately based on trip classification. The variables used typically for modeling trip production include household size, number of households, auto ownership, number of workers per household, household income, residential density and distance of the zone from the central business district (CBD). Trip attraction variables are typically selected from zonal employment levels, zonal floor space, type and density of land use and accessibility to work force.

The final output this process is a production and attraction table for the traffic analysis zones a network.

3.4.2 Trip Distribution

In this step, an estimate is made as to where the trips produced at each zone will go and how they will be divided terms of all other zones the area. Thus the flow of trips T_{ij} from each production zone i to every attraction zone j is estimated. The most widely used model used to accomplish trip distribution is the gravity model. The primary philosophy here is the Newton's law of gravitation. The trips made between two zones are assumed to be directly proportional to the trip production the origin zone and trip attraction of the destination zone compared to all the other zones the area, and inversely proportional to the impedance or friction between the two zones. This impedance is usually defined terms of travel time, cost of travel or a combination of the two labeled as the generalized cost function.

Mathematically the model can be stated as shown the following equation:

$$T_{ij} = P_i \frac{A_j F_{ij} K_{ij}}{\sum_{k=1}^n A_k F_{ik} K_{ik}} \quad \dots (3.2)$$

where

i = Origin Zone

j = Destination Zone

T_{ij} = Number of trips produced zone i and attracted to zone j

P_i = Total trips produced from zone i

A_j = Total trips attracted to zone j

F_{ij} = Friction factor for interchange ij

K_{ij} = Socio-economic adjustment factor for interchange ij

n = number of zones the study area

The total number of trips from an origin to each destination zone must be equal to the total trips P_i produced by the zone i , ie.,

$$\sum_{j=1}^n T_{ij} = P_i \quad \dots (3.3)$$

Similarly the sum of trips attracted to a TAZ from all origins must equal the total trips A_j attracted to the TAZ j , ie.,

$$\sum_{i=1}^n T_{ij} = A_j \quad \dots (3.4)$$

The trip interchange or Production-Attraction matrix obtained from this step is illustrated in table 3.1. The table would yield the distribution of person trips the study area. But, the transportation demand needs to be quantified in terms of the number of vehicles that use the network. The modal split or mode choice models help in achieving this objective by using the alternatives available to the trip maker.

Table 3.1: Trip Interchange Matrix

		TO							
		1	2	...	j	...	i	...	
FROM	1								
	2								
	...								
	i				T_i				P_i
	...								
	n								
					A_i				$\Sigma A_j = \Sigma P_i$

3.4.3 Modal Split

The mode split is an aspect of demand analysis that determines the number of trips between zones made by different modes of transportation available. The important steps involved are development of mode share percentages, application of these percentages to derive person trips by various modes of travel and use of vehicle occupancy rates to determine the vehicle trip tables by each mode type.

An important aspect of these mode choice models is the assumption that the probability of using various modes of equal attractiveness is the same. It is assumed that modal choice is affected by factors such as travel time, cost, accessibility, comfort, convenience and safety of the mode the scenario of competing modes.

A number of mode choice models have been researched recent times. Generally, these are divided to aggregate and dis-aggregate mode choice models. The aggregate models use trips ends and mode split matrices to develop a trip-interchange modal-split. The disaggregate models are probabilistic nature and are based on the theory of utility and disutility. Usually, mode split is performed after the trip distribution stage (e.g. the Las Vegas valley TRANPLAN model).

3.4.4 Traffic Assignment

The final step of the UTPP is called the traffic assignment process. Traffic volumes on each of the links the system is determined using an algorithmic approach which is based on the principle that as more and more vehicles use a particular link, it becomes more and more undesirable for further traffic. Some of these approaches include the "all or nothing" assignment, incremental assignment and the equilibrium assignment techniques.

An iterative approach is used to identify the expected volumes on various links. This is based on the assumption that the actual expected speeds of travel can be determined by the equation 3.5 called the Bureau of Public Roads equation (Papacostas, 1987).

$$S_v = S_f \frac{1}{1 + 0.15 (v/c)^4} \quad \dots(3.5)$$

where

S_v = Travel speed corresponding to a volume of traffic of v

S_f = Free flow speed

v = Volume of traffic on the link

c = Capacity of the link

Using S_v as the "equilibrium speed", the impedances for various links can now be coded in terms of travel time rather than distance. Further, in order to make the travel times more realistic, intersection delays may be computed on the basis of the v/c ratio at the intersection. The approach would involve calculation of the average delay per intersection in each link as a first step. The approach described by Ackcelic (1993) is one of the several research attempts that can be adopted. This approach is described next.

The delay per intersection consists of two components as described by equation 3.6.

$$d = d_1 + d_2 \quad \dots(3.6)$$

where

d = average vehicle delay

d_1 = Non-random delay term (delay due to signal cycle effects calculated assuming non-random arrivals at the average flow rate)

d_2 = Overflow delay term which includes the effect of non-random vehicles as well as the effect of any oversaturation flows.

The non-random component is estimated according to arrival characteristics and signal characteristics. The delay is expressed mathematically by equation 3.7

$$\begin{aligned}
 d_1 &= \frac{0.5C (1-h)^2}{1-hx} \quad \text{for } x \leq 1.0 \\
 &= 0.5(C-g) \quad \text{for } x > 1.0
 \end{aligned}
 \quad \dots(3.7)$$

where

h = green time / cycle length ratio

g = green time per cycle

x = volume to capacity ratio

The overflow delay component can be estimated by equation 3.8 (Ackcelic, 1993).

$$d_2 = 900Ti \left[(x-1) + \sqrt{(x-1)^2 + \frac{8k_c(x-x_0)}{cTi}} \right] \quad \text{for } x > x_0 \text{ (zero otherwise)} \dots(3.8)$$

where

Ti = Duration of flow period in hours

x_0 = Degree of saturation below which the overflow term is zero

k_c = A variable parameter derived by calibrating the steady-state expression

c = capacity in vehicles per hour

Once the individual delay for the average intersection is computed the total intersection delay per link can then be calculated by summing up across the intersections in the link.

The above technique for estimation of the service area is logically speaking the best possible procedure, but it can be applied only if the whole of the network is modeled the in computer model adopted. For example, the TRANPLAN (The travel demand forecasting

model) in the Las Vegas valley models using only 10,000 links and 2,500 nodes whereas the actual number of links is much more at 45,000 links and 20,000 nodes (BRW Inc, 1991). Secondly, the procedure is time consuming and difficult to automate. In order that there is a consistency the whole procedure, it is suggested that a percentage of the posted speed limits (based on the average v/c ratios) be taken order to construct the travel impedance in the network. This would help in simplifying the procedure enormously while not compromising the nature of index construction.

3.5 Methods for defining the service area boundary

Once an impedance measure is adopted, a fixed parameter is first needed to buffer the link under consideration in order to assess its accessibility. The buffer represents the limit of the “accessible” portion for a given threshold (upper limit) of travel time or travel distance or travel cost. The question that needs to be addressed in this stage is from which point on the link can one start to measure the impedances. In the case of major and minor arterials, the access could be at any node (intersection of secondary link with the arterial) on the link. In the case of freeways and other access controlled roads, the access ramps are indicators of freeway access/egress. These points themselves need to be buffered as opposed to buffering the whole of the link. This is because of the fact that access to the freeway is not dependent on the Euclidean distance from it, but the network distance at which the nearest on-ramp or off-ramp is available.

Limiting the distance measure (in this case travel time) to a fixed number (say 3 minutes), a buffer zone can be created for each link. This selection of time should be based on the tolerance of the motorist or alternately on the basis of policy formulation. This would

yield end points on the secondary street network until which the arterial is accessible within the set limit of travel time.

The next step is to extract the trip generation characteristics such as the number of people, employment characteristics etc., in the accessible area. This would necessitate development of a relationship between the accessible sub-network created above with the demographic characteristics of that area. Amongst the databases which quantify the spatial distribution of demographic and socio-economic data is the planning variables database for the purposes of transportation planning maintained by the metropolitan planning organizations (MPOs) or transportation planning agencies (RTC, 1996). This database spatially references the TAZs to the land use in each of the TAZs. Since the development of the TAZs itself is based on transportation planning considerations, it is proposed that the TAZ coverage be spatially referenced with the street centerline map for the study area. This is referred to in spatial reference systems as an overlay of coverages. The extraction of the concerned demographic variables can now be achieved in three methods as described below:

3.5.1 The Arc Length Method

In the arc length method, the accessible arcs are determined based on their proximity (in terms of travel time) to the ingress/egress points of the sub-network (by functional class) under consideration. The network of these arcs are assumed to represent the accessible region and are together termed as the accessible sub-network.

The length of arcs lying in each TAZ for the whole of the accessible sub-network is estimated. The ratio of the sum of the lengths of these arcs to the sum total of all the arcs

the whole network lying in that TAZ is then calculated as shown in equation 3.9. This is termed as the fundamental ratio. This method is therefore termed as the Arc Length Method.

$$r_i = \left[\frac{\sum_{j=1}^n l_j}{\sum_{j=1}^n L_j} \right] \quad \text{.....(3.9)}$$

where

r_i = Fundamental ratio for TAZ i.

l_j = Length of the accessible portion of arc j.

L_j = Total Length of arc j.

n = Total number of arcs the TAZ.

This ratio is then used to extract other demographic variables and assess them for their accessibility. An assumption is made that the demographic variables are distributed in a TAZ in proportion to the length of the road network the TAZ.

Figure 3.3: The Arc Length Method

This method is relatively easy and is eminently suited for application and automation through computer programs and commercial software available. The disadvantage is that an arc lying on the TAZ boundary may be incorrectly allocated to only one of the TAZs. This problem can however be worked around by tagging a label to all the accessible streets and by using this label to correctly allocate the arcs to the TAZs.

3.5.2 The Buffer method

In the buffer method, a buffer zone is drawn around the accessible sub-network to obtain a zone of accessibility at a fixed distance (say 200 ft) as shown figure 3.4. This zone is now spatially referenced with the TAZ in order to obtain a ratio of areas. These ratios are termed as the fundamental ratios.

Mathematically these can be calculated as follows:

$$r_i = \frac{\sum_{j=1}^m a_j}{A_i} \quad \text{.....(3.10)}$$

where:

r_i = Fundamental ratio for TAZ i

a_j = Buffered area of the accessible portion of arc j

A_j = Total Area of TAZ j

m = Total number of arcs the TAZ

The fundamental ratios can be used to extract accessible demographic characteristics based on the assumption that they are uniformly distributed within each TAZ.

The buffer method can help solve some of the problems associated with the Arc length method. But, even this case problems arise such as what if there is a big gated community adjacent to the arc boundary with the ingress and egress points not present along the arc boundary. It may not be accessible to the arterial and therefore cannot be considered in the computation. This method requires very detailed information and is therefore not suited for a macroscopic planning measure. It is also a computationally inefficient and time consuming method.

3.5.3 Hull Polygon Method

In the Hull Polygon method (Figure 3.5), a smooth polygon is drawn enveloping the end points of the accessible sub-network. This method is termed as the Hull Polygon

Figure 3.5: The Hull Polygon Method

Method. The ratio of the area of this polygon lying a TAZ to the total area of the TAZ is then calculated for all the TAZs involved. This ratio is then used to isolate demographic characteristics. This method is illustrated figure 3.5. This process yields the most optimistic measure of the service area. It is computationally easier method when compared to the buffer method, but it does not have any major advantages over the second method. The method is also highly approximate and should be used with care as it tends to grossly overestimate the accessible area.

The Arc length method involving the use of arc lengths is the recommended method in view of its simplicity, ease of interpretation and utility to the transportation planner.

The allocation and buffering process can be done for a single link or a combination of them. In each case, the measure would yield a measure of relative accessibility. The whole network can also be buffered order to obtain a composite index. In the case of one link it could yield a comparison of the utility of that link vis-a-vis all other links the network. In case the whole network were buffered, the measure could help in evaluating alternatives within a region or for comparisons across other regions.

3.6 Index Construction

The first step index construction is to identify the variables that correctly estimate accessibility. The most common ways to classify accessibility include population, auto-ownership, household size and income characteristics in the classification of residential accessibility and type of employment and location of jobs in assessing employment accessibility. Another way of looking at accessibility is in terms of trip origins and destinations. It can be seen that the trip generation characteristics across the study area are

usually studied in terms of multiple regression analysis or cross classification studies. These inputs are directly input into the trip generation module of the 4 step UTP process.

Based on the evaluation from the literature survey it was determined that the trip generation measures could be used advantageously to define accessibility of various traffic analysis zones. It is proposed that the same characteristics that are applied across the TAZs be applied to the service areas created for each link in the network. The assumptions herein are:

1. The trip generation characteristics are uniform for each demographic characteristic within the TAZ.
2. The trips accessible to the network in a TAZ is directly proportional to the ratio of sums of the lengths of accessible network arcs and the total length of all arcs in the TAZ.

The structure of the accessibility index is therefore subdivided in terms of residential accessibility index and employment accessibility index. Each of these main categories can be sub-divided in terms of the variables that describe trip productions and trip attractions (Destinations) respectively. For illustration purposes, a six component accessibility index can be considered as shown Figure 3.6.

The accessibility index is structured in terms of three residential and three employment sub-indices. The choice of the variables here is chosen keeping in view the Las Vegas Metropolitan area. Trip productions are basically dependent on household income, household size and auto ownership. These have therefore been chosen as the variables for the production sub-model. Work trip attractions are basically a function of the employment types in the area. Key employment classifications used for the purpose of predicting trip attractions include hotel, retail and office employment.

Figure 3.6: Structure of Composite Accessibility

These variables have therefore been considered in this illustration. The combined accessibility index can be described as some combination of the residential and employment indices.

Mathematically, the procedure can be stated as:

Residential accessibility (R) = f (Household size, Income, Auto-ownership)

Employment Accessibility (E) = f (Hotel, Retail, Office employment)(3.12)

Accessibility Index (A) = aR + bE

where

a,b are coefficients based on the relative weights to be given to the individual indices.

Since trip productions and attractions balance each other, the coefficients a and b can be made equal. Consequently, the overall index can be described as a mean of the component indices.

3.6.1 Residential Accessibility

For trip productions, one can construct an index based on the categories listed for production. For the purposes of illustration, let the following equation represent the trip productions for a particular TAZ.

Trip Productions = k + a * HHS + b * HHI + c * AUTO(3.13)

where

k = Constant

HHS = Average Household Size

HHI = Average Household Income

AUTO = Average Auto-ownership per household.

a,b,c = Regression Coefficients.

The index for residential accessibility can then be defined in terms of three descriptor variables namely household size, household income and auto-ownership. Each of these indices can be defined as follows:

1. Household size index

The number of households with household size belonging to various categories such as one person households, two person households etc., lying within each accessible region is estimated by TAZ by the use of the ratios developed. Thus, the fundamental ratio r_i developed after the definition of the accessible region can now be used to extract the accessible persons by category. The trip generation model is then used to generate accessible trips by TAZ. The accessible trips per TAZ is then divided by the sum of all accessible trips in the whole valley to obtain individual access index for each TAZ. Mathematically, the index for a TAZ can be stated as follows:

$$A_i^{HHS} = \frac{r_i * a_{HHS} * HHS_i}{\sum_{i=1}^n [a_{HHS} * HHS_i + a_{HHI} * HHI_i + a_{AUTO} * AUTO_i]} \quad \dots(3.14)$$

where

A_i^{HHS} = Household Size Accessibility index for TAZ i

a_{HHS} = Regression Coefficient (trip rate for HHS)

a_{HHI} = Regression Coefficient (trip rate for HHI)

a_{AUTO} = Regression Coefficient (trip rate for AUTO)

HHS_i = Average Household size for TAZ i

HHI_i = Average Household Income for TAZ i

$AUTO_i$ = Average Automobile ownership for TAZ i

n = Total number of TAZs the study area

r_i = Fundamental ratio

The sum of all the individual access indices for all the TAZs would yield the region wide access index for the variable. Mathematically, this can be stated as:

$$A^{HHS} = \frac{\sum_{i=1}^n [r_i * a_{HHS} * HHS_i]}{\sum_{i=1}^n [a_{HHS} * HHS_i + a_{HHI} * HHI_i + a_{AUTO} * AUTO_i]} \quad \dots(3.15)$$

where

A^{HHS} = Household Size Accessibility index for the study area.

2. Household Income Index

The number of households with incomes various categories (such as \$15,000 per annum, \$15,000-20,000 per annum etc.,) lying in each accessible region is calculated by TAZ.

A scheme similar to the one used for quantifying the Household Size Index can then be used to quantify the region wide index. Equation 3.16 gives the mathematical definition.

$$A^{HHI} = \frac{\sum_{i=1}^n [r_i * a_{HHI} * HHI_i]}{\sum_{i=1}^n [a_{HHS} * HHS_i + a_{HHI} * HHI_i + a_{AUTO} * AUTO_i]} \quad \dots(3.16)$$

where

A^{HHI} = Household Income Accessibility index for the study area.

3. Auto-ownership index

The number of households with auto ownership belonging to categories (such as 0,1,2, 3+) are determined. A scheme similar (equation 3.17) to the one used for quantifying the Household Size Index can then be used to quantify the region wide index.

$$A^{AUTO} = \frac{\sum_{i=1}^n [r_i * a_{AUTO} * AUTO_i]}{\sum_{i=1}^n [a_{HHS} * HHS_i + a_{HHI} * HHI_i + a_{AUTO} * AUTO_i]} \quad \dots(3.17)$$

Where

A^{AUTO} = Auto-ownership index for the study area.

Residential Accessibility Index

The residential accessibility index can then be constructed as a mean of the three indices. This would help in keeping the index in the same relative dimension as the sub-indices thus helping in a comparative study among the indices.

Mathematically, the index can be stated as follows.

$$RAI = 1/3 (A^{HHS} + A^{HHI} + A^{AUTO}) \quad \dots(3.18)$$

where

RAI = Residential accessibility index for the study area

A^{HHS} = Household size accessibility index for the study area

A^{HHI} = Household income accessibility index for the study area

A^{AUTO} = Auto-ownership accessibility index for the study area

3.6.2 Employment Accessibility

These indices can be created using a procedure similar to the residential indices, but by considering trip attractions as the basis. Thus, the three employment based indices can be described as follows.

Hotel Employment Index

The number of hotels lying within the accessible region are extracted in terms of their employment characteristic. This is input in the trip generation trip attraction sub model to determine the number of accessible hotel trips by TAZ. By using a similar procedure as described in the household size index, an index can now be constructed.

$$A^{hotel} = \frac{\sum_{i=1}^n [r_i * a_{hotel} * hotel_i]}{\sum_{i=1}^n [a_{hotel} * hotel_i + a_{retail} * retail_i + a_{office} * office_i]} \quad \dots(3.18)$$

where:

A^{hotel} = Hotel employment accessibility index

Retail Employment Index

The number of retail shops within the accessible region are determined either in terms of office space or employment characteristics depending up on the trip attraction model for the study area. These are then used to construct the retail employment index.

$$A^{retail} = \frac{\sum_{i=1}^n [r_i * a_{retail} * retail_i]}{\sum_{i=1}^n [a_{hotel} * hotel_i + a_{retail} * retail_i + a_{office} * office_i]} \quad \dots(3.19)$$

where

A^{retail} = Retail employment accessibility index

Office Employment Index

The number of employees or office space can be used to determine the number of office trips attracted by the accessible region. The data can be used to calculate the index.

$$A^{\text{office}} = \frac{\sum_{i=1}^n [r_i * a_{\text{office}} * \text{office}_i]}{\sum_{i=1}^n [a_{\text{hotel}} * \text{hotel}_i + a_{\text{retail}} * \text{retail}_i + a_{\text{office}} * \text{office}_i]} \quad \dots(3.18)$$

where:

A^{office} = Office employment accessibility index

Employment Accessibility Index

The mean of the three indices defined is termed as the employment accessibility index.

$$EAI = 1/3 (A^{\text{hotel}} + A^{\text{retail}} + A^{\text{office}}) \quad \dots(3.21)$$

Network Utility Index

A third index which utilizes only the fundamental ratios (r_i) is termed as the network index. It can be seen that this index is network dependent as it is defined considering the ratios of the length of arcs in the accessible region to the lengths of arcs in the whole study area. This index would represent the state of the urban network and its spatial distribution.

3.6.3 Construction of the combined index of accessibility

It can be seen that the residential access index depicts trip productions and employment access index depicts trip attractions. Considering that trip productions and

attractions through out the study area should be close to each other, a cumulative index can be constructed giving equal weighage to the two of them. Thus a combined access index can now be constructed as follows:

$$CAI = \frac{1}{2} \{ RAI + EAI \} \quad \text{.....(3.22)}$$

where

CAI = Combined Accessibility Index, RAI = Residential Accessibility Index and

EAI = Employment Accessibility Index

The structure of the definition renders it an easy tool to measure the access. The final index is a number ranging from 0 to 1. A value of 1 represents absolute accessibility for all the people in all zones. Instead of 1, the index may be normalized to a base number such as 1000 to represent the absolute maximum of accessibility. The closer the index for a particular link is to this number, the better is its accessibility. Thus equation 3.22 may be modified to be:

$$CAI = \frac{1}{2} (EAI + RAI) * 1000 \quad \text{.....(3.23)}$$

The index can be calculated for an isolated link, a group of links or the whole network. It can be assembled across the various functional classes of the roads and averaged to obtain a cumulative index for the network. Figure 3.7 illustrates the whole procedure for index construction through a flowchart.

3.7 Employment of Accessibility indices in Alternatives Analysis

A primary field of application of accessibility indices is in the selection of an alternative amongst a set of technically feasible alternatives. Under the present guidelines of the Intermodal Surface Transportation Efficiency Act (ISTEA) (TRB, 1992), any

Figure 3.7: Computation of Accessibility Indices

metropolitan planning organization has to undertake a four step approval process before implementing any planned changes to the network namely: social acceptance, environmental clearance, economic and technical feasibility. The use of accessibility indices can help in providing an additional support tool for the whole decision making process. One such process is depicted figure 3.8. The process starts with the computation of the base network accessibility indices. Planned improvements are then input as alternatives which imply network changes. These are now used to calculate the new accessibility indices for the changed scenario. The new indices can be compared with the old indices to assess the changes. The process can be repeated for various alternatives in order to arrive at the best alternative.

It can be seen that this procedure calculates the index using the traditional UTP model and interfacing it with changes to the network. Thus in the first stage, the base center line is coded in terms of impedances associated with the arcs of the network. The impedances are calculated from the traffic volumes in each arc. The traffic volumes per arc are outputs from the four step transportation planning process. The accessibility model is now run to determine the base accessibility index. Changes to the network result in changed traffic flows (demands) which are captured by the four step planning process and changed accessible ridership potential is captured by the increased accessible network (supply) resulting in new accessibility indices. A summary of the whole process describing each stage of the methodology is illustrated in figure 3.9.

A second application of the index is in the assessment of future accessibility indices considering the changes demographic and socio-economic variables. Generally, the trip generation procedure remains the same for a base year and forecast year the UTP process.

Figure 3.8: Use of Accessibility Indices in Alternative Analysis

Figure 3.9: Overview of Computation Process

Therefore, some of the index construction variables such as the regression coefficients do not change in the forecast year. If network changes are considered, these along with the projected demographic data are input the four step UTP process. In a vibrant economy, the volumes projected are generally bound to increase due projected change of demographic variables. These might cause a change in the speed of travel. But the changed speed due to this volume change could be offset by the change in impedance due to the additional of new facilities if road congestion were to be reduced in the target year. Thus the objective of the planner is to balance the increased flow with congestion in such a manner that some equilibrium is achieved between increased flow (demand for facility) and the supply.

Accessibility index values would provide a key to understanding the state of equilibrium as they have been constructed using both the supply and demand characteristics of the network. Since the accessibility index has been constructed taking into cognizance the trip productions and attractions, the forecast year index yields a measure of the trip making capacities of the service area. At the same time, since arc impedances are used defining the accessibility region for the trip productions and attractions, the accessible trips are adversely impacted. Therefore the index is also a direct measure of the state of functionality of the network.

A third application of the indices is in finding the environmental impact of planned changes. Since the accessibility values correlate with the trip making behavior, the total number of trip produced or attracted can be determined directly from the accessibility model. Using the final link volumes obtained the four step UTPP process, the total and hence the average Vehicle Miles of Travel (VMT) per trip can be obtained. The average speed of travel and the total VMT per vehicle along with the change the number of trips can be used to

model additional burden or ease on the environment due to the planned changes. The procedure above is suggested for further study and development.

CHAPTER 4

IMPLEMENTATION

This chapter considers an implementation strategy for the procedure developed and presented in the methodology. The implementation scheme is meant to be applied to any metropolitan area provided the data specifications are available. Illustration of the Las Vegas study area databases are provided in order to explain the process. The later part of the chapter deals with the application of the implementation scheme to the Las Vegas study area. An alternatives analysis for selection of a freeway ramp is performed at the end of the chapter.

4.1 Data Requirements

The primary requirement is the availability of the base year street network coverage. This database should reference the street network to a coordinate system with attributes. The coordinates themselves are used in order to describe the position of the link on a coverage called the “arc” coverage. The table is hence called the arc attribute table. This is illustrated in table 4.1 An example of a network database is the street centerline coverage developed by the GIS Management Office (GISMO) of Clark county. The coordinates are referenced to a cover called the street center line arc coverage. Figure 4.1 illustrates the coverage.

Figure 4.1 : Las Vegas Valley: Street-Center Line Network

Table 4.1: Street Center Line Arc Attribute Table

Street center line ID	Street Name	Coordinate Information	Posted Speed	Length of arc	Travel Time
(1)	(2)	(3)	(4)	(5)	(6) = (5)/ (4)

Since the street center lines are defined in terms of arcs and nodes and since each street has a number of links, each street will be coded a number of times- once for each link. Each link in turn has a “from” node and a “to” node. The nodes will be coded separately in a file called the Node Attribute Table. The information contained there would be referenced terms of nodes, node Ids and coordinates.

The second requirement would be a functional classification for the streets. This could exist either as an attribute in the street centerline database that references the street name by sections as a functional class or as a separate coverage. Thus the “arc Ids” can be used to reference the classification terms of various categories such as freeways, major and minor arterials and collectors. This attribute can be queried and only those arcs that belong to a functional class can be selected. As an example, the Las Vegas study area has been classified by the local metropolitan planning organization, the Regional Transportation Commission (RTC) in terms of Freeways and expressways, Major and Minor arterials and Collectors. Figure 4.2 illustrates the top three functional classes for the study area ie., freeways, primary and secondary arterials in 1995.

Figure 4.2: Las Vegas Valley: Streets by Functional Class (1995)

4.2 Sources for demographic data

The essential pre-requisite for any successful planning tool is the availability of accurate data. Data are required to analyze and demarcate traffic analysis zones, create trip generation models for the base units, develop mode choice models and project future demand for travel. Principal sources of data include the U.S. Bureau of the Census data called Census Transportation Planning Package Data (CTPP) (Rasas and Sathisan, 1995). Other important transportation databases include the databases developed from time to time by local metropolitan planning organizations, local planning agencies, local departments of public works or roads and state Departments of Transportation.

CTPP Data

The CTPP is a collection of data available for all major urban centers of the United States. The data provides aggregated information on many aspects of transportation planning such as population, income, auto-ownership, household and worker characteristics, mobility constraints, journey to work characteristics, employment characteristics etc., (Rasas and Sathisan, 1995). The CTPP data cannot be disaggregated, but can be combined to perform a variety of analyses. This data set is available only for 1990.

Local Sources of data

The local metropolitan agencies prepare a database updating it from time to time specifically for the purposes of transportation planning. These data are used to augment the decennial CTPP data so as make the data current and accurate. The local sources essentially contain more detailed data for the study area and are more useful for future projections as they are updated periodically as compared to the census data which are collected on a decennial basis. For a large and fast growing metropolitan area, it is very important that data

be as current as possible because the growth factor may cause incorrect projections. For example, the Las Vegas metropolitan area has grown tremendously terms of demographic characteristics recent years. Thus, the CTPP data collected 1990 shows the population at only 650,000 whereas the current population 1996 is 1.075 million. This is the reason the local metropolitan planning organization called the Regional Transportation Commission of Clark County, developed a database called Planning Variables database which contains estimates and projections developed from demographic, economic and land use information (Coopers and Lybrand, 1996). The database lists the TAZs for the valley along with estimates of variables such as population, dwelling units (occupied and total), household size, income, employment data, average income etc.,

Once a data source is chosen, the next step is to analyze how the demographic variables are distributed spatially over the study area. Specifically, the problem would involve extraction of the accessible population terms of their trip generation characteristics.

4.3 Network Selection

The first step would be to extract the sub-network for which accessibility is required to be measured. This sub-network should be extracted in terms of access points to the roads. The roads themselves may be classified into:

1. Freeways and expressways.
2. Primary Arterials.
3. Secondary Arterials.
4. Collectors.

In case of links that have at grade intersections, the position of intersections themselves could be used as access points. But in the case of freeways and expressways with the access being controlled, it is necessary to extract ramp positions along the freeways and use these as access/egress points depending up on the direction of the ramp. A ramp that allows movement onto the freeway is therefore required to be coded as a "RAMP FROM TO" (i.e., a ramp that allows movement from a particular street to a particular freeway or vice-versa) depending up on directionality. As an example, a ramp that allows movement from US 95 to a street such as Cheyenne would be coded as "Ramp US 95 Cheyenne" in the street centerline database. This delineation is important in order to distinguish accessibilities to and from an access-controlled link.

4.4 Creation of Impedance Network

Once the links for which accessibilities are desired are selected and coded into the street centerline in terms of the access points, the street center line coverage is prepared in terms of impedances. This requires travel time along all the links in the network, which in turn necessitates the estimated speed of travel. The first step is to run the local regional travel demand model in order to arrive at the link flows. These can then be used along with the capacities the Bureau of Public Roads (BPR) equation in order to define speeds along the various arcs. It is not expected that a regional model would take all the links the street center line database for modeling purposes. For those streets which are not covered by the model, the average volume to capacity ratio can be selected and used along with the posted speed limits the BPR equation.

A "to-impedance" and a "from-impedance" attribute are added to the street centerline database and defined in terms of travel time for the segment of the arc depending up on the directionality of travel the arc allows. In case of one-way streets, the from-impedance or to-impedance item can be coded as an arbitrarily high number so as to ensure no movement along the direction intended (i.e., opposite to the one-way travel direction). At the end of this step, the street centerline arc attribute table should look like table 4.2.

Table 4.2: Street Centerline Database after creating impedances

Street center line ID	Functional class & name	Coordinate Information	Posted Speed	Length of arc	Congestion (v/c ratio)	Estimated speeds	From impedance item (time)	To impedance item (time)
(1)	(2)	(3)	(4)	(5)	(6)	(7) $\text{fn}((6), (5))$	(8) $(5) \times (7)$	(9) $(5) / (7)$

4.5 Allocation and creation of accessible sub-network

The third step involves allocation of arcs to the selected access points based on a maximum travel time desired to evaluate accessibility, say 3 minutes. This would result creation of a "to-access sub-network" and a "from-access" sub-network of arcs. The process involves identification of those arcs that lie within the prescribed impedance value from the given access point. Each point is processed separately and added up in order to arrive at the combined access of all the points. As an example the from-access cover for the Las Vegas study area for the freeways in the valley were computed and developed as the coverage illustrated figure 4.3.

The next step is to determine the accessible region for overlay on the TAZs. This can be achieved in any of the three ways as mentioned in the methodology. The Arc length method is a good tool for the transportation planner as it allows a comparison of trips generated vis-a-vis the arcs that are accessible. Figures 4.4 through 4.6 illustrate the three methods for the freeway accessible corridors the Las Vegas Valley. The overlay is easily achieved in a GIS environment as an intersection of the accessible cover and the TAZ cover. At the end of this step, a table containing the fundamental ratios (r_i) for each TAZ i can be computed based on the length of accessible arcs as shown equation 3.9.

4.6 Construction of accessibility indices

The final step is to arrive at accessibility indicators based on the distribution of the trips by purpose for each zone in the study area. Based on the to and from accessible regions, the number of trip origins that are accessible to the network and the number of trip destinations that are accessible to the network are computed for each zone by trip purpose. The accessibility index has been defined as the ratio of accessible values for a variable of interest to the total value for the same variable in the whole study area. The variables themselves should be based on the trip generation model for the study area as this would help indicate accessible trips and therefore help in the extraction of only the relevant demographic and socio-economic variables. The trip generation model could be in terms of a regression model, trip rate or a cross classification scheme. In any of the cases, the same model can be used to express the number of accessible trips in terms of production and attraction models.

Figure 4.3: Las Vegas Valley: Freeway Accessibility: Accessible Streets

Figure 4.4: Las Vegas Valley: Freeway Accessibility By Arc Method

Figure 4.5: Las Vegas Valley: Freeway Accessibility By Buffer Method

Figure 4.6: Las Vegas Valley: Freeway Accessibility By Hull Polygon Method

For purposes of illustration, assume that the following regression model were employed for trip generation:

Trip Productions Model:

$$T(P)_{ij} = \sum_{k=1}^m [a_{ki} X_{kj}] \quad \dots(4.1)$$

and

Trip Attractions Model:

$$T(A)_{ij} = \sum_{k=1}^n [b_{ki} X_{kj}] \quad \dots(4.2)$$

Where:

$T(P)_{ij}$ = Trip productions for TAZ j by trip purpose i = 1,2,...l.

$T(A)_{ij}$ = Trip attractions for TAZ j by trip purpose i.

i = Trip Purpose such as home based work, home based other and non-home based.

j = TAZ number (j = 1,2,3...n)

k = Subscript of relevant demographic or socio-economic variables for TAZ j (k = 1,2,...m)

X_{kj} = Measure of Relevant demographic or socio-economic variable k for TAZ j

a_{ki}, b_{ki} = Trip making characteristics associated with each demographic variable k for trip purpose i.

The accessibility index for each TAZ should take in to account all the key variables used in the trip generation model. Thus, the contributions of individual production and attraction models for each of the demographic or socio-economic factor, k, need to be

summed together to determine the index for the TAZ. These are normalized with respect to valley wide totals in order to obtain a valley wide indicator. Thus the accessibility indices for the various trip purposes for a TAZ can be defined on the basis of equation 3.14 as follows:

$$A(P)_{ij} = \frac{\sum_{k=1}^m [r_j a_{ki} X_{kj}]}{\sum_{i=1}^l \sum_{j=1}^n \sum_{k=1}^m [a_{ki} X_{kj}]} \quad \text{.....(4.3)}$$

where:

$A(P)_{ij}$ = Production Accessibility index for TAZ j for trip purpose I.

r_j = Fundamental ratio for TAZ j.

l = Total number of trip purposes.

i = Trip Purpose such as home based work, home based other and non-home based.

j = TAZ no.

k = Relevant demographic or socio--economic variables for TAZ j

X_{kj} = Measure of Relevant demographic or socio--economic variable k for TAZ j

a_{ki}, b_{ki} = Trip making characteristics associated with each demographic variable k for trip purpose i.

The accessibility index for a trip purpose for all TAZs is a function of the individual accessibilities of each TAZ in terms of all the demographic or socio-economic factors.

Thus, the accessibility for each trip purpose can be expressed as follows.

$$A(P)_i = \frac{\sum_{j=1}^n \sum_{k=1}^m [r_j a_{ki} X_{kj}]}{\sum_{i=1}^l \sum_{j=1}^n \sum_{k=1}^m [a_{ki} X_{kj}]} \quad \text{.....(4.4)}$$

Where

$A(P)_i$ = Accessibility index for trip purpose i for the study area

and the combined accessibility index for all trip purposes for all TAZs can be expressed as shown in equation 4.5. This is the study area wide indicator of accessibility for trip productions.

$$A(P) = \frac{\sum_{i=1}^l \sum_{j=1}^n \sum_{k=1}^m [r_j a_{ki} X_{kj}]}{\sum_{i=1}^l \sum_{j=1}^n \sum_{k=1}^m [a_{ki} X_{kj}]} \quad \dots(4.5)$$

where:

$A(P)$ = Combined accessibility index for all trip productions in the study area

A similar scheme can be adopted for trip attractions indices. The only difference would be that the measures X_{kj} would be different and the coefficients the equations would now be b_{kj} . The mean of the productions and attractions indices can be used as the study area accessibility index as discussed in the methodology.

The choice of what the trips are to be normalized against is left to the discretion of the user. These sub-indices are added up by zone to obtain an overall production and attraction indicator for the zone. Alternately, they can be added up by purpose in order to obtain aggregate indicators by purpose. The case study illustrates this process completely.

4.7 Computer Models

The automation of the computation of the indices identified can be accomplished by using a GIS interface along with computer models for the four step transportation planning process. Several computer models are available to assist travel demand forecasting such as

EMME2 (Intro Consultants Inc., 1996), MINUTP (COMSIS, 1996) and TRANPLAN (UAG, 1995).

A Geographical Information System (GIS) references spatial data to attributes. This is a very powerful tool which can be used for a plethora of transportation planning applications. The following sections deal with a UTPP computer model called TRANPLAN and a GIS commercial software called ARC/INFO. These two specific tools have been selected for discussion as TRANPLAN is the planning tool and TRANPLAN is the GIS software adopted by the local metropolitan planning organization the Las Vegas area.

4.7. 1 TRANPLAN

TRANPLAN comprises of a comprehensive suite of transportation planning computer programs encompassing forecasting capabilities for both highway and transit systems. The software itself is based on the 4 step Urban Transportation Planning Process. It is structured as a dynamic tool comprising of 40 modules. These include network creation, trip distribution, trip generation, modal choice models, traffic assignment, reporting and printing the results. It is available for use on many hardware platforms. The data needed for running the model include:

1. Transportation Network.
2. A defined base unit called the Traffic Analysis Zone along with its centroid.
3. A calibrated Trip Generation model for productions and attractions and
4. Friction factors and growth factors for trip distribution process.

The whole process is summarized figure 4.7. The first step is to build the network. This is done through the BUILD HIGHWAY NETWORK module.

Figure 4.7: Overview of the TRANPLAN Process

The TRIP GENERATION module can then be used to estimate the number of trips by trip purpose terms of production and attraction models for all the TAZs. This is usually accomplished by considering trips generated or attracted as a function of socioeconomic and demographic variables in consonance with the locational and land use characteristics of a zone.

The output is a table containing productions and attractions for the various TAZs. The TRIP DISTRIBUTION module then distributes these trips between various origin and destination zones based on the relative attractiveness of travel. The gravity model is employed here. Next a logit mode choice model is used to separate person trips to various alternative modes. Finally the TRAFFIC ASSIGNMENT model is used to assign the modal trips to various links.

4.7.2 Geographic Information Systems (ARC/INFO)

A GIS is an organized collection of computer hardware, software, geographic data and personnel data designed to capture, store, update, manipulate, analyze and display all forms of geographically referenced information efficiently and effectively (ESRI, 1993a). It is combination of information databases and spatial databases with abilities for manipulation of both databases simultaneously and display of results in such a way that would help identify spatial relationships. The database concept is central to a GIS and it is the main difference between a GIS and any other mapping system which can produce only a graphic output (Burli, 1995).

ARC/INFO is an automated set of GIS software. The chief modules of the program that are relevant to this thesis include ARC, ARCEDIT, ARCPLOT, INFO and NETWORK.

Each module has its own functions. The ARC handles spatial referencing of data whilst the INFO handles the feature information database and relates it to other features.

Geographic data are referenced in terms of three primitive types: points, arcs and polygons. Spatial relationships between these features are used to describe the topology. The three main topological considerations of ARC/INFO are (ESRI, 1993a):

1. Arcs connect to each other at nodes (connectivity).
2. Arcs that connect to surround an area define a polygon (area definition).
3. Arcs have direction and left and right sides (contiguity).

These considerations help in building a coverage terms of coordinates. Every feature of this coverage is referenced in terms of a user ID which can be used to relate to other features in a INFO database.

Various coverages may be overlaid on one another in order to perform analysis. These overlaps are defined in terms of Boolean operators such as intersection, union and identity. This ability to relate to various spatial databases is what makes the GIS a very powerful analytical tool.

There is also a provision to program using a macro called as ARC Macro Language (AML). This is an interpretative language with programming capabilities and a set of tools suited to perform modeling. The AML is an elegant programming option to create menus for user interface, automated database access and display of information. The AML can be used extensively to tailor the needs of a process in such a way that information is obtained efficiently and effectively.

4.8 Case Study and Analysis

The Las Vegas Valley area was used for an illustrative case study in order to demonstrate the creation of the accessibility indices. This case study illustrates some of the applications of the tool developed the thesis. This chapter illustrates the development of the indices and elucidates the whole process as applied to a metropolitan area.

4.8.1 Data Sources

For this study, the data were obtained from various sources. The travel demand forecasting model (TRANPLAN), the planning variables database report (RTC, 1996), variables used in TRANPLAN, specifically the trip generation sub-routine were obtained from the Regional Transportation Commission (RTC). The street center line coverage was obtained from the Clark County GIS Management Office. A GIS coverage depicting the posted speeds was obtained from the Clark County Department of Public Works, Traffic Management Division. In addition the TAZ system developed by the RTC 1990 was also used. This system consists of 749 zones including ten external zones.

A functional classification of the road network was developed in the GIS environment for the purposes of the project based on the Regional Transportation Commission's TRANPLAN functional classes. These broadly include 4 classes: Freeways and Expressways, Principal arterials, Minor arterials and Collectors. The GIS coverage was developed only for freeways, principal and minor arterials for the purposes of the case study.

4.8.2 Assumptions

The highway network model developed in TRANPLAN and the street center line coverage developed by GISMO being developed by different entities do not conform with

one another completely. This is because TRANPLAN is modeled using straight lines to represent arcs whereas the street centerline is a precise database which accurately depicts the position/shape of the street centerline. In order to import the TRANPLAN loaded file into the street centerline, a lengthy conflation procedure is required wherein the whole highway network is rebuilt in terms of the street centerline coordinates. The problem was compounded by the lack of vertices in TRANPLAN. Therefore, for simplicity, the adoption of the TRANPLAN predicted volume of flows was discarded and only the posted speeds developed by the Clark County Department of Public Works, Traffic Management Division was used. However, this database covers only 104 major streets across the valley and the coverage is partial. A frequency test was conducted in order to obtain the average speed per segment and extended to the entire streets case of partial coverage of the street. The minor streets which were not coded in this coverage include local collectors and access streets. These were coded with a default posted speed of 20 mph. This is less than the typical posted speed limit of 25 mph, but since many of the collector streets have restrictions imposed due to road conditions, school zones, starts and stops due to stop signs etc., the 20 mph speed limit was considered appropriate.

The program was also made to include a user defined volume to capacity (v/c) ratio order to reduce errors when using the BPR equation. The default is set at 80% of the posted speed limit. When input into the BPR equation, this would imply a volume to capacity ratio of 0.707. This value is reasonably close to the v/c ratios found in most metropolitan areas.

4.8.3 Program Inputs

A computer code was developed in order to allow the user to identify the facility for analysis by prompting a list of the streets by functional class. Freeways were chosen for analysis. The specific facilities used were the I-15, I-215, US-95 and the Summerlin Parkway. The program then performed the analysis using a default speed of 80% of the posted speed limits and developed the accessible sub-network as described in the implementation strategy. The maximum impedance time was set arbitrarily to three minutes. At this point the analysis was continued in terms of defining the accessible region in terms of arc lengths themselves. An overlay was performed with the TAZs order to determine the accessible arcs per TAZ. Figure 4.4 shows the accessible arcs for all TAZs and figure 3.3 illustrates the procedure. The ratios of the accessible arcs to the total of all arcs in the TAZ were then obtained. These ratios were used by the final module of the program along with the trip generation sub-routine of the TRANPLAN model as described in the implementation scheme.

4.8.4 Definition of Indices

The trip generation sub-module of the TRANPLAN process is TAZ specific. The RTC uses a dis-aggregate household trip rate cross classification model for modeling trip generation. Cross classification is a model which utilizes rates to describe household trip making depending on household size, income and trip purpose. The entire process is achieved through an automated spreadsheet. The basic model assumes that trips per income category are linearly related. The following equation illustrates the basic model.

$$\text{Trips Per capita per day} = 0.007 \times \text{Income per annum (thousands)} + 2.76 \quad \dots (4.6)$$

The trip purposes are five number. They are Home Based Work trips (HBW), Home Based School Trips (HBSc), Home Based Shop Trips(HBSh), Home Based Other (HBO)

and Non-Home Based Trips (NHB). The methodology proposed involves computation of relevant demographic variables and computing accessible trips proportion to total trips. Since the scheme used the study area is a cross classification scheme, the final trips computed by TAZ by purpose can directly be used as an input. These can be quantified into three measures:

1. Production Model

The production model consists of 5 trip purpose derived indices namely:

- a. Home Based Work Productions Index.
- b. Home Based School Productions Index.
- c. Home Based Shop Productions Index.
- d. Home Based Other Productions Index.
- e. Non Home Based Productions Index.

All the five trip purposes can be aggregated to an Aggregate Trip Productions Index.

Thus a total of six production indices have been defined.

2. Attraction Model

Similar to the production model, the attraction model consists of 5 trip purpose derived indices namely:

- a. Home Based Work Attractions Index.
- b. Home Based School Attractions Index.
- c. Home Based Shop Attractions Index.
- d. Home Based Other Attractions Index.
- e. Non Home Based Attractions Index.

All the five indices can be combined to define a sixth Aggregate Trip Attractions Index.

3. Combined Model

The production and attraction indices by purpose can be averaged to find the aggregate index. Thus, each of the six indices that have been defined can be averaged for both the production and attraction models to obtain a combined measure. These measures are enumerated below:

- a. Aggregate Home Based Work Trips Index.
- b. Aggregate Home Based School Trips Index.
- c. Aggregate Home Based Shop Trips Index.
- d. Aggregate Home Based Other Trips Index.
- e. Aggregate Non-Home Based Trips Index.
- f. Combined Accessibility Index.

Since the trip generation model is a cross classification model, additional auxiliary indices were also defined order to help understand trip making characteristics better. These are grouped in to five indices under the heading of demographic sub-indices. These are enumerated as follows.

- a. Population Accessibility Index.
- b. Hotel/Casino Accessibility Index.
- c. Shop Accessibility Index.
- d. Office Accessibility Index.
- e. School Accessibility Index.

Thus 23 indices are defined based. A normalization of these indices would help in relative quantification of the index so that it can be used as a tool for comparison between various TAZs. In the case study two normalization methods were used. In one method, the

variables were normalized with respect to valley wide totals and in the other method, the variables were normalized to facility specific totals. Thus a total of 46 indices were defined for the valley. An additional network accessibility index describing the mean ratios that were obtained was also defined. It must be noted here that the type of normalization has only a scaling effect on the index. Hence the nature of the index will remain the same whatever be the method chosen by the user. In the case study, the variables were normalized against valley specific totals by purpose.

In the case of the trip generation model for the Las Vegas valley, the Non-Home Based trip productions are the same by TAZ as the Non-Home Based Trip attractions and therefore the number of indices was brought down to 22 from a possible 24.

Figures 4.8 to 4.29 describe the top TAZs by percentile group for freeway accessibility for the study area. Tables 4.3 to 4.24 describe the top 40 TAZs by accessibility index values. The accessibility has been normalized to a scale of 1000. Since there are about 750 TAZs in the study area, the average accessibility in the ideal case when all the TAZs were equally accessible would be 1.33 ($1000/750$). This number could be used for comparison of TAZ access.

The figures reveal distribution of accessible TAZs in terms of the degree of accessibility. Figure 4.8 depicts the distribution of home based work productions index. It can be seen that the most accessible regions in this case lie along the resort corridor - the area of concentration of the casinos. Quite a number of TAZs show up in the map which implies that the accessibility is fairly distributed amongst the TAZs. Table 4.3 relates the top 40 TAZs with their Home Based Work Productions accessibility indices. It can be seen that the top 10 TAZs account for a total of 110. This means that out of every 1000 home based work

trips produced in the valley, these TAZs account for 110 accessible trips. Considering equally distributed accessibility of 1.33, these TAZs are 8 times more accessible than the average TAZ. The normalization number (1000) is a measure of the total of all home based work trips in the valley. A separate query revealed that 604 of the 1000 trips are accessible to the freeway within a three minute driving distance and a total of 320 TAZs were in the accessible region. Thus more than one sixth of all the accessible home based work trips are accounted by the top ten TAZs (i.e., 3 percent of accessible TAZs).

Figure 4.9 shows the distribution of TAZs by home based school productions index. The measure of the total number of accessible home based school trips is 602 and the total number of TAZs in the accessible region 309. Table 4.4 reveals that in this case it can be seen that the top 5 TAZs themselves account for 70 accessible trips. This is a relatively high number, but school accessibilities are dependent upon the location of the schools. Thus, figure 4.4 reveals a markedly high concentration of accessibility.

Figure 4.10 and table 4.5 together describe the home based shop productions index. It can be seen that the distribution is similar to school accessibilities, since the shop index is also highly location dependent. Figure 4.11 and table 4.6 taken together describe the home based other productions index. The distribution is similar to the home based shop index.

Figure 4.12 and table 4.7 describe the aggregate trip productions index. This index captures freeway accessibility to all trip productions. The total measure of accessible trips for all TAZs was found to be 607 with a total of 365 TAZs lying in the accessible region. Again, it can be seen that the top 5 TAZs sum up to 50 in terms of the accessibility index. This implies that out of every 1000 productions, 607 are accessible to the freeway system within a travel time of three minutes and of these 607 trips, 50 i.e., more than 8% are

contributed by just 1.3% (5/365) of 365 TAZs lying in the accessible region. This reveals a pattern of regional imbalance in terms of trips accessible to the freeway system.

Figures 4.13 to 4.17 along with tables 4.8 to 4.12 describe the attraction components of the home based work, home based school, home based other, non-home based and combined indices respectively. It can be seen that while home based shop trip attractions index is similar in distribution to the productions index, the other indices show that a few TAZs have a markedly high value for the accessibility index. In the case of home based work attractions index (table 4.8), it can be seen that one TAZ contributes to about 50 of all accessible trips (totalling 612). The distribution further reveals that even though 359 TAZs lie the accessible region, the top 10 TAZs contribute to about 185 of the accessible trips. This implies that even though the number of accessible work attractions is almost the same as the other trip purpose totals, there is a marked imbalance in the distribution. However, it can be seen from figure 4.13 that most of the TAZs that contribute disproportionately to this imbalance lie in the resort corridor. Since work trips are location specific (dependent on the CBD), all that this represents is that the CBD in the study area lies very proximate to the freeway system.

The imbalance in the distribution is highlighted in the case of the home based school index (Figure 4.14 and table 4.19), which reveals an extremely high concentration at the top and reaches zero within an interval of 100 accessible TAZs. In this case however, it must be noted that school attractions are dependent on school locations. Most of the schools lie in just 100 TAZs.

The aggregate accessibility index depicted in figure 4.17 and table 4.12 assume special importance due to the high concentrations of accessible corridors found in the sub-

indices. However, an examination of the aggregate attractions index shows that there is a similar trend as noticed in the aggregate productions index with the exception that the top TAZs now exhibit higher accessibilities. Thus in general, the freeway system in the valley seems more accessible to trip attractions than productions. This may be due to the presence of very few freeways and their general orientation which favors movement away from the CBD much more readily.

Figures 4.18 to 4.23 depict the aggregate indices for each trip purpose. The trend in these indices is approximately the mean of the trends observed in the respective production and attraction components. Figure 4.23 and table 4.18 are of a special importance as these taken together reveal the combined accessibility index for all trips the valley by TAZ. It can be seen from the figure that there is no general trend exhibited now except that outlying areas seem to have lesser index values. The total number of accessible trips the valley (i.e., the valley wide accessibility index) is 613, which means that on an average 61.3 percent of all trips are accessible to the freeway system within a three minute driving distance. Table 4.18 however reveals that one TAZ exhibits a high value for the combined accessibility index.

Figures 4.24 to 4.28 depict accessibility indices for the five demographic characteristics chosen for the study area. Population accessibility distribution is shown in figure 4.24 and table 4.19. This index has been used for an alternatives analysis presented at the end of this chapter. An examination of the hotel/casino accessibility index depicted in figure 4.25 and table 4.20 shows a concentration of very high accessibility indices at the top of the ladder. This index is a relative measure of the accessible trips from hotel/casinos in terms of employees by TAZ. More over, this value soon reaches zero within 37 intervals. This means that 37 TAZs that consist of Hotels/Casinos lie in the accessible region. An

examination of figure 4.25 reveals that a plurality of these TAZs lie in the resort corridor. The imbalance in the distribution of the TAZs reflects that some casinos are accessible to a much higher degree than others. TAZ 491 stands out in this respect as the single most accessible TAZ in terms of a plurality of accessibility indices.

The other indices examined include the shop accessibility index and the office accessibility index. These indices show a similar trend with respect to each other. Figures 4.26 through 4.28 depict the distribution of the TAZs by these two indices respectively. The network accessibility index which is a relative measure of the fundamental ratio (r_i) is described by figure 4.29 and table 4.24.

Further, all the aggregate indices were chosen and plotted by distribution of the TAZs by accessibility index. Figures 4.30 and 4.31 show the distribution in terms of a bar chart for the combined accessibility index in terms of number of TAZs and cumulative number of TAZs respectively. It can be seen that a better representation can be made through the use of smooth curves of accessibility. Figures 4.32 to 4.39 represent the cumulative distribution of the TAZs by accessibility index values. It can be seen from the tables that there are very few TAZs that have an accessibility greater than 8. Most of them lie between zero and two. These must represent the TAZs that lie in the outer regions of the accessible network of streets. A second distribution of 60-70 TAZs can be found in the middle range of 2-8. These must represent the TAZs that directly benefit from the freeways. The TAZs having values greater than 8 are normally the ones that lie in the resort corridor or high income residential zones. Further, it can be seen that the behavior of all the indices is almost similar.

**Figure 4.8: Las Vegas Valley: Accessibility within 3 minutes from freeway system
Home Based Work Productions Index**

**Figure 4.10 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Home Based Shop Productions Index**

**Figure 4.11 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Home Based Other Productions Index**

**Figure 4.13 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Home Based Work Attractions Index**

**Figure 4.17 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Aggregate Trip Attractions Index**

**Figure 4.16 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Home Based Other Attractions Index**

**Figure 4.19 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Aggregate Home Based School Index**

**Figure 4.20 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Aggregate Home Based Shop Index**

**Figure 4.21 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Aggregate Home Based Other Index**

**Figure 4.22 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Aggregate Non-Home Based Trip Index**

**Figure 4.23 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Combined Accessibility Index**

**Figure 4.24 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Population Accessibility Index**

**Figure 4.25 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Hotel/Casino Accessibility Index**

**Figure 4.26 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Shop Accessibility Index**

**Figure 4.27 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Office Accessibility Index**

**Figure 4.28 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
School Accessibility Index**

**Figure 4.29 : Las Vegas Valley: Accessibility within 3 minutes from freeway system
Network Accessibility Index**

Figure 4.30: Las Vegas Valley: Bar Chart Distribution of TAZs by Combined Accessibility Index

Figure 4.31: Las Vegas Valley: Bar Chart Distribution of Cumulative number of TAZs by Combined Accessibility Index

Figure 4.32: Las Vegas Valley: Distribution of TAZs by Combined Accessibility Index

Figure 4.33: Las Vegas Valley: Distribution of TAZs by Aggregate Trip Productions Index

Figure 4.34: Las Vegas Valley: Distribution of TAZs by Aggregate Trip Attractions Index

Figure 4.35: Las Vegas Valley: Distribution of TAZs by Aggregate Home Based Work Trips Index

Figure 4.36: Las Vegas Valley: Distribution of TAZs by Aggregate Home Based School Trips Index

Figure 4.37: Las Vegas Valley: Distribution of TAZs by Aggregate Home Based Shop Trips Index

Figure 4.38: Las Vegas Valley: Distribution of TAZs by Aggregate Home Based Other Trips Index

Figure 4.39: Las Vegas Valley: Distribution of TAZs by Aggregate Non-Home Based Trips Index

Table 4.3: Top 40 TAZs by Home Based Work Productions Access Index

Rank	TAZ	HB Work Productions Index	Cumulative sum of Index
1	204	18.24	18.24
2	425	13.68	31.92
3	358	13.38	45.29
4	260	11.43	56.73
5	352	10.15	66.88
6	452	9.68	76.56
7	259	9.41	85.97
8	206	8.33	94.30
9	591	8.20	102.51
10	350	8.12	110.63
11	472	7.86	118.49
12	247	7.75	126.24
13	250	7.52	133.75
14	208	7.42	141.18
15	207	7.26	148.43
16	252	7.18	155.61
17	253	7.11	162.73
18	357	6.98	169.71
19	318	6.98	176.69
20	104	6.56	183.25
21	327	6.54	189.79
22	433	6.54	196.32
23	267	6.45	202.77
24	201	6.44	209.21
25	130	6.43	215.64
26	180	6.37	222.01
27	240	6.31	228.32
28	245	6.05	234.37
29	386	6.04	240.41
30	251	5.98	246.39
31	369	5.97	252.36
32	349	5.95	258.30
33	256	5.73	264.03
34	429	5.70	269.73
35	237	5.61	275.34
36	474	5.59	280.93
37	470	5.10	286.03
38	626	5.10	291.13
39	509	4.85	295.98
40	614	4.79	300.77

Table 4.4: Top 40 TAZs by Home Based School Productions Access Index

Rank	TAZ	HB School Productions Index	Cumulative sum of Index
1	204	21.35	21.35
2	425	12.78	34.13
3	358	12.50	46.63
4	352	11.88	58.51
5	260	10.68	69.19
6	206	9.75	78.94
7	591	9.60	88.54
8	452	9.05	97.58
9	259	8.79	106.38
10	250	8.79	115.17
11	207	8.50	123.67
12	252	8.41	132.07
13	253	8.32	140.40
14	357	8.17	148.57
15	104	7.68	156.24
16	327	7.66	163.90
17	433	7.65	171.56
18	350	7.59	179.14
19	201	7.53	186.68
20	472	7.34	194.02
21	247	7.23	201.26
22	251	7.00	208.25
23	208	6.93	215.19
24	256	6.71	221.90
25	474	6.54	228.44
26	318	6.52	234.96
27	267	6.02	240.98
28	130	6.01	246.99
29	626	5.97	252.96
30	180	5.95	258.91
31	245	5.65	264.56
32	386	5.64	270.20
33	614	5.61	275.81
34	369	5.57	281.38
35	349	5.55	286.93
36	319	5.39	292.32
37	429	5.32	297.64
38	459	5.10	302.74
39	428	4.62	307.36
40	509	4.53	311.89

Table 4.5: Top 40 TAZs by Home Based Shop Productions Access Index

Rank	TAZ	HB Shop Productions Index	Cumulative sum of Index
1	491	18.58	18.58
2	204	15.15	33.73
3	425	12.37	46.10
4	358	12.09	58.19
5	260	10.34	68.53
6	452	8.76	77.29
7	259	8.51	85.79
8	352	8.44	94.23
9	275	7.94	102.17
10	415	7.38	109.55
11	350	7.34	116.89
12	472	7.11	124.00
13	247	7.01	131.01
14	206	6.92	137.93
15	591	6.81	144.75
16	208	6.71	151.46
17	240	6.60	158.05
18	318	6.31	164.36
19	250	6.25	170.61
20	276	6.22	176.83
21	492	6.21	183.04
22	207	6.03	189.08
23	252	5.97	195.04
24	253	5.91	200.95
25	156	5.90	206.86
26	237	5.86	212.72
27	267	5.83	218.55
28	130	5.82	224.37
29	357	5.80	230.17
30	180	5.76	235.93
31	245	5.47	241.40
32	386	5.46	246.86
33	104	5.45	252.31
34	327	5.43	257.75
35	433	5.43	263.18
36	369	5.39	268.57
37	349	5.37	273.95
38	201	5.35	279.29
39	470	5.34	284.63
40	282	5.30	289.93

Table 4.6: Top 40 TAZs by Home Based Other Productions Access Index

Rank	TAZ	HB Other Productions Index	Cumulative sum of Index
1	491	15.90	15.90
2	204	14.33	30.22
3	425	12.90	43.12
4	358	12.61	55.74
5	260	10.78	66.52
6	452	9.13	75.65
7	259	8.87	84.53
8	352	7.98	92.51
9	350	7.66	100.17
10	415	7.59	107.75
11	472	7.41	115.17
12	240	7.35	122.52
13	247	7.31	129.83
14	208	7.00	136.83
15	275	6.78	143.61
16	318	6.58	150.19
17	206	6.55	156.73
18	237	6.53	163.27
19	591	6.44	169.71
20	156	6.27	175.98
21	267	6.08	182.06
22	130	6.07	188.13
23	180	6.00	194.14
24	470	5.95	200.08
25	250	5.91	205.99
26	245	5.70	211.69
27	386	5.70	217.39
28	207	5.70	223.09
29	252	5.64	228.73
30	369	5.63	234.36
31	349	5.61	239.97
32	253	5.59	245.55
33	357	5.48	251.04
34	492	5.38	256.42
35	429	5.37	261.80
36	276	5.32	267.12
37	104	5.15	272.27
38	327	5.14	277.41
39	433	5.13	282.55
40	201	5.06	287.60

Table 4.7: Top 40 TAZs by Aggregate Trip Productions Access Index

Rank	TAZ	Aggregate Trip Productions Index	Cumulative sum of Index
1	491	13.68	13.68
2	358	10.88	24.55
3	204	10.77	35.32
4	260	10.08	45.41
5	318	8.71	54.12
6	425	8.64	62.76
7	357	8.16	70.91
8	259	7.30	78.21
9	319	7.14	85.36
10	369	6.89	92.25
11	429	6.87	99.12
12	472	6.84	105.96
13	130	6.66	112.62
14	428	6.49	119.11
15	267	6.24	125.35
16	452	6.15	131.50
17	327	6.01	137.51
18	206	5.97	143.48
19	352	5.92	149.40
20	275	5.79	155.20
21	350	5.71	160.91
22	296	5.64	166.54
23	268	5.63	172.17
24	247	5.60	177.77
25	415	5.45	183.22
26	474	5.36	188.58
27	264	5.19	193.77
28	343	5.00	198.77
29	245	5.00	203.76
30	250	4.90	208.67
31	237	4.81	213.48
32	591	4.81	218.29
33	359	4.75	223.04
34	470	4.73	227.77
35	492	4.66	232.43
36	208	4.53	236.96
37	349	4.52	241.48
38	276	4.48	245.96
39	251	4.48	250.44
40	323	4.46	254.90

Table 4.8: Top 40 TAZs by Home Based Work Attractions Access Index

Rank	TAZ	HBW Attractions Index	Cumulative sum of Index
1	491	48.96	48.96
2	493	28.24	77.20
3	275	20.92	98.12
4	271	19.29	117.41
5	268	16.23	133.65
6	276	15.23	148.88
7	492	14.72	163.60
8	282	13.64	177.24
9	364	10.05	187.29
10	543	9.01	196.30
11	489	9.00	205.30
12	415	8.48	213.78
13	362	7.96	221.74
14	471	7.94	229.68
15	365	7.83	237.51
16	428	7.67	245.18
17	457	7.62	252.80
18	264	7.53	260.33
19	359	7.26	267.59
20	470	7.01	274.60
21	474	6.88	281.48
22	277	6.82	288.30
23	363	6.73	295.03
24	315	6.66	301.69
25	164	6.66	308.35
26	319	6.51	314.86
27	296	6.45	321.32
28	203	5.75	327.07
29	488	5.54	332.61
30	280	5.10	337.71
31	281	4.99	342.70
32	327	4.87	347.57
33	266	4.77	352.34
34	575	4.64	356.98
35	373	4.41	361.38
36	459	4.38	365.76
37	472	4.14	369.91
38	316	4.08	373.99
39	482	3.88	377.87
40	270	3.87	381.75

Table 4.9: Top 40 TAZs by Home Based School Attractions Access Index

Rank	TAZ	HB School Attractions Index	Cumulative sum of Index
1	471	129.28	129.28
2	470	129.26	258.55
3	181	23.99	282.54
4	233	22.71	305.25
5	301	16.87	322.12
6	358	15.02	337.14
7	315	14.34	351.47
8	437	10.84	362.31
9	454	10.01	372.31
10	350	9.99	382.30
11	264	8.94	391.24
12	237	8.74	399.98
13	184	7.80	407.78
14	428	7.67	415.45
15	452	7.46	422.90
16	429	6.73	429.64
17	511	6.60	436.24
18	207	6.46	442.69
19	243	6.07	448.77
20	373	5.94	454.71
21	221	5.80	460.50
22	157	5.21	465.71
23	253	5.13	470.84
24	400	5.10	475.94
25	156	5.02	480.96
26	334	4.66	485.62
27	479	4.65	490.27
28	105	4.62	494.89
29	266	4.61	499.50
30	509	4.54	504.04
31	260	4.39	508.43
32	252	4.39	512.82
33	356	4.38	517.20
34	238	4.37	521.57
35	474	4.28	525.85
36	223	4.24	530.09
37	320	4.05	534.13
38	503	4.03	538.16
39	256	4.02	542.18
40	116	4.01	546.19

Table 4.10: Top 40 TAZs by Home Based Shop Attractions Access Index

Rank	TAZ	HB Shop Attractions Index	Cumulative sum of Index
1	318	16.67	16.67
2	319	15.32	31.99
3	369	13.95	45.94
4	357	13.24	59.17
5	161	12.62	71.79
6	343	12.35	84.14
7	260	12.06	96.20
8	373	10.85	107.05
9	323	10.65	117.69
10	429	10.39	128.08
11	428	10.02	138.11
12	358	9.84	147.95
13	267	9.42	157.37
14	103	9.34	166.70
15	457	9.13	175.84
16	413	9.10	184.94
17	550	8.86	193.80
18	130	8.62	202.42
19	359	8.05	210.47
20	322	7.79	218.25
21	296	7.23	225.49
22	333	7.04	232.53
23	327	7.04	239.57
24	332	6.99	246.56
25	227	6.86	253.42
26	266	6.76	260.17
27	222	6.45	266.63
28	263	6.41	273.04
29	264	6.39	279.43
30	521	6.34	285.76
31	471	6.14	291.90
32	346	6.04	297.94
33	324	5.86	303.80
34	472	5.74	309.54
35	331	5.72	315.25
36	434	5.71	320.97
37	356	5.66	326.62
38	259	5.40	332.02
39	374	5.20	337.22
40	219	5.13	342.35

Table 4.11: Top 40 TAZs by Home Based Other Attractions Access Index

Rank	TAZ	HB Other Attractions Index	Cumulative sum of Index
1	491	32.42	32.42
2	493	19.27	51.69
3	268	14.77	66.46
4	275	13.89	80.36
5	428	12.36	92.71
6	276	10.54	103.25
7	492	9.95	113.20
8	282	9.89	123.08
9	271	8.68	131.77
10	264	8.32	140.08
11	319	7.57	147.66
12	471	7.36	155.02
13	474	7.35	162.37
14	260	7.26	169.63
15	318	7.12	176.74
16	358	6.94	183.68
17	470	6.83	190.52
18	415	6.48	197.00
19	365	6.47	203.47
20	296	6.43	209.90
21	369	6.42	216.32
22	472	6.21	222.53
23	327	6.06	228.59
24	457	6.05	234.64
25	359	5.82	240.46
26	357	5.81	246.26
27	373	5.63	251.89
28	315	5.57	257.46
29	343	5.30	262.76
30	323	5.20	267.96
31	267	5.19	273.15
32	362	5.11	278.26
33	164	5.10	283.36
34	204	4.97	288.33
35	429	4.83	293.16
36	259	4.62	297.78
37	277	4.24	302.02
38	116	4.18	306.20
39	130	4.15	310.35
40	161	4.14	314.48

Table 4.12: Top 40 TAZs by Aggregate Trip Attractions Index

Rank	TAZ	Aggregate Trip Attractions Index	Cumulative sum of Index
1	491	23.96	23.96
2	471	16.18	40.14
3	470	13.84	53.99
4	493	13.43	67.42
5	268	10.59	78.01
6	275	10.27	88.27
7	428	10.04	98.31
8	319	9.71	108.02
9	318	9.21	117.23
10	271	7.92	125.15
11	369	7.86	133.01
12	276	7.68	140.69
13	264	7.67	148.36
14	357	7.61	155.97
15	358	7.58	163.55
16	260	7.49	171.04
17	373	7.46	178.50
18	492	7.42	185.92
19	282	7.34	193.26
20	457	7.29	200.56
21	343	6.82	207.38
22	359	6.79	214.17
23	161	6.78	220.95
24	323	6.68	227.62
25	296	6.48	234.10
26	429	6.42	240.52
27	365	6.05	246.57
28	474	5.89	252.46
29	315	5.73	258.20
30	327	5.71	263.90
31	267	5.42	269.33
32	472	5.29	274.62
33	266	5.22	279.84
34	413	5.03	284.87
35	103	4.98	289.85
36	322	4.88	294.74
37	130	4.86	299.60
38	181	4.83	304.43
39	415	4.80	309.23
40	550	4.73	313.96

Table 4.13: Top 40 TAZs by Aggregate Home Based Work Trips Index

Rank	TAZ	Aggregate HBW Trips Index	Cumulative sum of Index
1	491	24.77	24.77
2	493	14.15	38.92
3	275	10.46	49.38
4	271	9.75	59.13
5	204	9.68	68.81
6	268	9.66	78.47
7	358	8.46	86.93
8	492	7.93	94.86
9	276	7.63	102.49
10	425	7.31	109.80
11	260	7.30	117.10
12	282	6.82	123.92
13	415	6.61	130.52
14	474	6.23	136.76
15	470	6.05	142.81
16	472	6.00	148.82
17	259	5.97	154.78
18	428	5.81	160.59
19	327	5.71	166.30
20	264	5.68	171.98
21	319	5.56	177.54
22	315	5.34	182.88
23	364	5.25	188.13
24	352	5.17	193.30
25	318	5.16	198.46
26	452	5.08	203.54
27	350	5.07	208.61
28	359	5.00	213.61
29	296	4.91	218.53
30	206	4.91	223.43
31	357	4.89	228.33
32	164	4.75	233.08
33	471	4.70	237.78
34	247	4.66	242.44
35	267	4.60	247.03
36	543	4.51	251.54
37	489	4.50	256.04
38	369	4.43	260.47
39	459	4.37	264.84
40	365	4.35	269.19

Table 4.14: Top 40 TAZs by Aggregate Home Based School Trips Index

Rank	TAZ	Aggregate HB School Trips Index	Cumulative sum of Index
1	470	66.43	66.43
2	471	65.15	131.58
3	181	14.09	145.67
4	358	13.76	159.42
5	204	11.83	171.25
6	233	11.35	182.61
7	301	10.12	192.73
8	350	8.79	201.52
9	315	8.59	210.10
10	452	8.25	218.35
11	260	7.54	225.89
12	207	7.48	233.37
13	454	7.01	240.37
14	253	6.73	247.10
15	206	6.68	253.78
16	252	6.40	260.18
17	425	6.39	266.57
18	259	6.36	272.93
19	237	6.35	279.27
20	264	6.26	285.53
21	428	6.14	291.67
22	429	6.03	297.70
23	352	5.94	303.64
24	437	5.85	309.49
25	250	5.63	315.12
26	357	5.44	320.56
27	474	5.41	325.97
28	256	5.37	331.34
29	472	5.24	336.58
30	247	4.90	341.48
31	243	4.82	346.30
32	591	4.80	351.10
33	245	4.63	355.72
34	201	4.61	360.33
35	509	4.54	364.86
36	614	4.40	369.27
37	184	4.32	373.59
38	156	4.11	377.70
39	356	3.88	381.58
40	104	3.84	385.41

Table 4.15: Top 40 TAZs by Aggregate Home Based Shop Trips Index

Rank	TAZ	Aggregate HB Shop Trips Index	Cumulative sum of Index
1	318	11.49	11.49
2	260	11.20	22.69
3	358	10.97	33.65
4	369	9.67	43.33
5	319	9.57	52.90
6	357	9.52	62.42
7	491	9.29	71.70
8	429	7.77	79.47
9	267	7.63	87.10
10	204	7.58	94.68
11	343	7.44	102.12
12	130	7.22	109.33
13	259	6.95	116.29
14	425	6.71	122.99
15	428	6.65	129.64
16	472	6.42	136.07
17	323	6.38	142.45
18	161	6.32	148.77
19	327	6.24	155.01
20	296	6.10	161.11
21	359	5.82	166.93
22	373	5.53	172.46
23	206	5.32	177.79
24	247	5.09	182.87
25	103	5.03	187.90
26	264	4.93	192.82
27	350	4.88	197.71
28	237	4.78	202.49
29	452	4.76	207.25
30	222	4.76	212.01
31	245	4.63	216.64
32	457	4.57	221.21
33	550	4.56	225.77
34	333	4.55	230.32
35	413	4.55	234.87
36	250	4.54	239.41
37	415	4.48	243.89
38	349	4.44	248.34
39	322	4.35	252.69
40	521	4.35	257.04

Table 4.16: Top 40 TAZs by Aggregate Home Based Other Trips Index

Rank	TAZ	Aggregate HBO Trips Index	Cumulative sum of Index
1	491	24.16	24.16
2	275	10.34	34.50
3	358	9.78	44.27
4	493	9.66	53.93
5	204	9.65	63.58
6	260	9.02	72.60
7	268	8.60	81.20
8	425	8.39	89.59
9	276	7.93	97.52
10	428	7.73	105.24
11	492	7.67	112.91
12	282	7.21	120.12
13	415	7.04	127.15
14	318	6.85	134.00
15	472	6.81	140.81
16	259	6.75	147.56
17	470	6.39	153.95
18	271	6.05	160.00
19	369	6.02	166.02
20	452	6.00	172.02
21	264	5.97	177.99
22	474	5.87	183.86
23	350	5.81	189.67
24	247	5.65	195.33
25	357	5.65	200.97
26	267	5.64	206.61
27	327	5.60	212.21
28	319	5.59	217.80
29	296	5.46	223.27
30	315	5.13	228.40
31	352	5.11	233.51
32	130	5.11	238.62
33	429	5.10	243.72
34	206	5.07	248.79
35	156	5.06	253.84
36	164	4.99	258.83
37	237	4.96	263.79
38	365	4.68	268.47
39	359	4.68	273.16
40	250	4.68	277.83

Table 4.17: Top 40 TAZs by Aggregate Non-Home Based Trips Index

Rank	TAZ	Aggregate NHB Trips Index	Cumulative sum of Index
1	491	20.70	20.70
2	318	12.14	32.84
3	319	12.05	44.89
4	428	11.03	55.92
5	493	10.62	66.54
6	357	10.45	76.98
7	268	10.32	87.30
8	369	9.60	96.90
9	161	9.05	105.95
10	275	8.91	114.86
11	260	8.71	123.57
12	343	8.55	132.12
13	429	8.50	140.62
14	457	8.18	148.81
15	323	8.17	156.98
16	296	7.79	164.77
17	358	7.74	172.51
18	264	7.74	180.25
19	359	7.43	187.68
20	130	6.93	194.61
21	103	6.85	201.46
22	276	6.80	208.26
23	373	6.78	215.04
24	471	6.72	221.75
25	282	6.57	228.32
26	413	6.54	234.86
27	492	6.44	241.30
28	267	6.40	247.70
29	327	6.32	254.02
30	365	6.21	260.22
31	322	5.92	266.14
32	550	5.92	272.05
33	474	5.80	277.86
34	271	5.79	283.65
35	472	5.75	289.40
36	266	5.64	295.03
37	227	5.62	300.66
38	333	5.12	305.78
39	332	5.04	310.82
40	222	4.77	315.59

Table 4.18: Top 40 TAZs by Combined Accessibility Index

Rank	TAZ	Combined Accessibility Index	Cumulative sum of Index
1	491	18.82	18.82
2	471	9.73	28.55
3	470	9.29	37.83
4	358	9.23	47.06
5	318	8.96	56.02
6	260	8.79	64.81
7	493	8.72	73.53
8	319	8.43	81.96
9	428	8.26	90.22
10	268	8.11	98.33
11	275	8.03	106.36
12	357	7.88	114.24
13	369	7.38	121.62
14	429	6.64	128.26
15	264	6.43	134.69
16	204	6.23	140.92
17	276	6.08	147.00
18	472	6.07	153.07
19	296	6.06	159.13
20	492	6.04	165.17
21	343	5.91	171.08
22	327	5.86	176.94
23	267	5.83	182.77
24	359	5.77	188.54
25	130	5.76	194.30
26	259	5.75	200.05
27	271	5.69	205.74
28	282	5.68	211.42
29	474	5.63	217.05
30	323	5.57	222.62
31	457	5.15	227.77
32	415	5.12	232.89
33	161	5.10	237.98
34	425	5.09	243.08
35	315	4.97	248.05
36	365	4.77	252.81
37	373	4.67	257.48
38	206	4.51	261.98
39	350	4.42	266.41
40	181	4.36	270.77

Table 4.19: Top 40 TAZs by Population Accessibility Index

Rank	TAZ	Population Accessibility Index	Cumulative sum of Index
1	204	15.86	15.86
2	358	13.05	28.91
3	452	10.85	39.75
4	260	10.43	50.19
5	259	9.88	60.06
6	240	9.55	69.61
7	237	9.14	78.75
8	425	9.03	87.79
9	247	8.80	96.58
10	350	8.68	105.26
11	352	8.51	113.78
12	318	8.31	122.08
13	180	8.08	130.17
14	208	7.74	137.91
15	206	7.73	145.63
16	250	7.71	153.35
17	349	7.70	161.04
18	253	6.83	167.87
19	591	6.54	174.41
20	156	6.25	180.66
21	256	6.12	186.78
22	433	6.11	192.89
23	201	6.00	198.89
24	130	5.98	204.87
25	252	5.93	210.80
26	207	5.85	216.64
27	245	5.68	222.32
28	509	5.64	227.96
29	241	5.60	233.55
30	104	5.59	239.14
31	181	5.54	244.68
32	472	5.40	250.07
33	315	5.39	255.46
34	239	5.29	260.75
35	267	5.29	266.05
36	357	5.21	271.26
37	369	5.08	276.34
38	386	4.96	281.29
39	251	4.94	286.24
40	232	4.77	291.01

Table 4.20: Top 40 TAZs by Hotel/Casino Accessibility Index

Rank	TAZ	Hotel/Casino Accessibility Index	Cumulative sum of Index
1	491	172.86	172.86
2	275	75.89	248.75
3	276	59.15	307.90
4	282	52.28	360.18
5	492	50.78	410.96
6	271	35.46	446.42
7	365	24.32	470.74
8	362	23.96	494.70
9	415	22.66	517.36
10	277	21.88	539.24
11	296	19.87	559.11
12	164	17.56	576.67
13	281	17.18	593.85
14	280	15.45	609.29
15	156	10.99	620.28
16	359	10.76	631.05
17	335	10.36	641.41
18	482	8.81	650.22
19	363	8.32	658.54
20	257	8.06	666.59
21	116	7.36	673.95
22	331	4.46	678.40
23	293	4.44	682.84
24	225	3.81	686.65
25	364	3.25	689.90
26	418	3.09	692.99
27	707	2.41	695.41
28	468	1.85	697.26
29	77	1.49	698.74
30	284	1.31	700.05
31	483	0.79	700.84
32	519	0.35	701.19
33	223	0.31	701.50
34	315	0.16	701.66
35	481	0.07	701.73
36	144	0.03	701.77
37	431	0.00	701.77
38	436	0.00	701.77
39	435	0.00	701.77
40	433	0.00	701.77

Table 4.21: Top 40 TAZs by Shop Accessibility Index

Rank	TAZ	Shop Accessibility Index	Cumulative sum of Index
1	268	43.44	43.44
2	493	36.96	80.40
3	264	20.61	101.01
4	428	16.07	117.08
5	474	14.91	131.99
6	457	11.72	143.70
7	472	11.17	154.87
8	260	10.58	165.45
9	471	10.40	175.85
10	343	10.21	186.05
11	327	10.11	196.16
12	315	10.03	206.19
13	323	9.95	216.14
14	470	9.85	225.99
15	373	9.49	235.48
16	238	8.95	244.43
17	369	8.22	252.65
18	227	7.93	260.58
19	161	7.44	268.02
20	429	7.20	275.22
21	358	6.10	281.32
22	319	6.03	287.35
23	274	5.91	293.26
24	266	5.43	298.69
25	413	5.36	304.05
26	359	5.27	309.32
27	350	5.20	314.52
28	219	5.05	319.57
29	181	4.95	324.52
30	263	4.53	329.05
31	357	4.46	333.51
32	296	4.34	337.85
33	245	4.21	342.06
34	550	4.20	346.26
35	332	4.17	350.43
36	222	4.17	354.59
37	333	4.11	358.70
38	324	3.93	362.64
39	374	3.69	366.32
40	365	3.51	369.83

Table 4.22: Top 40 TAZs by Office Accessibility Index

Rank	TAZ	Office Accessibility Index	Cumulative sum of Index
1	493	55.62	55.62
2	271	42.83	98.45
3	491	41.42	139.87
4	364	38.29	178.16
5	275	16.57	194.73
6	470	14.99	209.72
7	543	14.14	223.85
8	471	14.00	237.85
9	415	13.85	251.70
10	489	13.81	265.51
11	459	13.59	279.10
12	492	13.18	292.28
13	488	12.25	304.53
14	417	12.15	316.67
15	359	11.31	327.99
16	460	10.72	338.70
17	164	9.07	347.77
18	363	8.83	356.60
19	270	8.59	365.19
20	315	8.52	373.71
21	362	8.32	382.03
22	277	8.28	390.31
23	482	8.08	398.39
24	278	8.05	406.44
25	276	8.03	414.47
26	416	7.82	422.29
27	334	7.35	429.64
28	280	7.23	436.87
29	228	6.75	443.62
30	457	6.57	450.19
31	490	5.83	456.02
32	225	4.64	460.66
33	365	4.63	465.29
34	230	4.58	469.87
35	414	4.56	474.43
36	519	4.29	478.71
37	282	4.18	482.90
38	418	4.15	487.05
39	281	4.12	491.16
40	486	3.93	495.09

Table 4.23: Top 40 TAZs by School Accessibility Index

Rank	TAZ	School Accessibility Index	Cumulative sum of Index
1	470	87.83	87.83
2	471	82.01	169.84
3	233	30.76	200.60
4	181	29.67	230.27
5	301	22.17	252.44
6	315	20.03	272.47
7	358	20.00	292.47
8	454	16.58	309.05
9	437	13.50	322.55
10	264	12.61	335.16
11	237	12.08	347.24
12	452	11.87	359.11
13	429	10.68	369.79
14	428	9.88	379.67
15	503	8.17	387.83
16	243	7.49	395.33
17	221	7.41	402.73
18	157	7.09	409.82
19	400	7.09	416.91
20	105	6.97	423.88
21	479	6.76	430.64
22	474	6.51	437.15
23	350	6.46	443.61
24	334	6.41	450.03
25	266	6.41	456.44
26	223	6.39	462.84
27	373	6.31	469.14
28	207	6.10	475.25
29	238	5.91	481.16
30	245	5.85	487.01
31	509	5.83	492.84
32	260	5.73	498.57
33	356	5.69	504.26
34	259	5.52	509.77
35	256	5.48	515.25
36	116	5.15	520.40
37	252	4.99	525.39
38	132	4.91	530.30
39	704	4.75	535.05
40	495	4.46	539.51

Table 4.24: Top 40 TAZs by Network Accessibility Index

Rank	TAZ	Network Access Index	Cumulative Sum of Index
1	276	1.000	1.000
2	273	1.000	2.000
3	265	1.000	3.000
4	267	1.000	4.001
5	293	1.000	5.001
6	308	1.000	6.001
7	316	1.000	7.002
8	184	1.000	8.002
9	311	1.000	9.002
10	490	1.000	10.002
11	259	1.000	11.003
12	355	1.000	12.003
13	303	1.000	13.003
14	272	1.000	14.003
15	400	1.000	15.003
16	432	1.000	16.003
17	304	1.000	17.003
18	433	1.000	18.004
19	474	1.000	19.004
20	333	1.000	20.004
21	269	1.000	21.004
22	425	1.000	22.004
23	305	1.000	23.004
24	271	1.000	24.004
25	233	1.000	25.004
26	221	1.000	26.004
27	307	1.000	27.004
28	180	1.000	28.004
29	657	1.000	29.004
30	306	1.000	30.004
31	449	1.000	31.004
32	470	1.000	32.004
33	318	1.000	33.004
34	287	1.000	34.004
35	391	1.000	35.004
36	266	1.000	36.004
37	162	1.000	37.004
38	288	1.000	38.004
39	309	1.000	39.004
40	284	1.000	40.004

4.8.5 Correlation of individual accessibility indices with Combined Accessibility Index

Table 4.25 compares the accessibilities by trip productions and trip attractions. Table 4.26 lists the aggregate indices and shows the sum totals of accessibility indices for each of the aggregate indices.

Table 4.25: Comparison of Productions and Attractions Accessibilities for the entire study area

S.No	Accessibility Measure	Sum total for all TAZs Productions Indices	Sum total for all TAZs Attractions Indices
1	Home Based Work Productions Index	604.26	612.26
2	Home Based School Productions Index	601.84	627.61
3	Home Based Shop Productions Index	613.84	606.74
4	Home Based Other Productions Index	613.10	628.21
5	Aggregate Trip Productions Index	606.96	619.33

Table 4.26: Sum total of Aggregate Indices for the whole study area

S.No	Accessibility Measure	Sum total for all TAZs
1	Aggregate Home Based Work Trips Index	608.26
2	Aggregate Home Based School Trips Index	626.34
3	Aggregate Home Based Shop Trips Index	610.29
4	Aggregate Home Based Other Trips Index	620.86
5	Aggregate Non-Home Based Trips Index	610.18
6	Combined Accessibility Index	613.14

It can be seen that all the totals lie between 600 to 627 with the combined accessibility index lying in the range of the mean of the others. The individual accessibilities seem to correlate well with the combined accessibility index, even though this can be ascertained only after

rigorous statistical tests. The aim of this thesis was to arrive at one number that reasonably captures all the parameters of trip making. Since the combined accessibility index is a measure of the mean accessibilities for trip making by different trip purposes, the index is a good measure of a study area's accessibility. This measure can therefore be used along with another explanatory demographic variable such as population to assess the utility of planned changes to a network. For the Las Vegas study area two alternatives were studied. The results are discussed next.

4.9 Alternatives Analysis

The base year network was changed to incorporate new ramps to the freeway network. The accessibility model was employed to assess changes in accessibility due to addition of new on and off ramps. Two scenarios were studied. In the first case, an existing interchange at the intersection of Spring Mountain Road, an arterial and the freeway I-15 was converted from a partial interchange to a full interchange. In the second case, a new full interchange was introduced at the intersection of an arterial called Windmill lane and I-15. Changes in accessibility were then calculated.

Case 1: Spring Mountain Road and I-15 Interchange

Tables 4.27 and 4.28 show the top 40 TAZs with their population and combined accessibility indices respectively. Tables 4.18 and 4.19 show the corresponding tables for the base network case. The total number of TAZs lying in the accessible region remained the same for both the base network and the changed network. The Combined accessibility index increased only marginally from 613.145 to 613.178. The population accessibility index totals also registered only a marginal increase.

Table 4.27: Top 40 TAZs by Population Accessibility Index**Case 1: Addition of ramps at Spring Mountain Road Interchange**

Rank	TAZ	Population Accessibility Index	Cumulative sum of Index
1	204	15.86	15.86
2	358	13.05	28.91
3	452	10.85	39.75
4	260	10.43	50.19
5	259	9.88	60.06
6	240	9.55	69.61
7	237	9.14	78.75
8	425	9.03	87.79
9	247	8.80	96.58
10	350	8.68	105.26
11	352	8.51	113.78
12	318	8.31	122.08
13	180	8.08	130.17
14	208	7.74	137.91
15	206	7.73	145.63
16	250	7.71	153.35
17	349	7.70	161.04
18	253	6.83	167.87
19	591	6.54	174.41
20	156	6.25	180.66
21	256	6.12	186.78
22	433	6.11	192.89
23	201	6.00	198.89
24	130	5.98	204.87
25	252	5.93	210.80
26	207	5.85	216.64
27	245	5.68	222.32
28	509	5.64	227.96
29	241	5.60	233.55
30	104	5.59	239.14
31	181	5.54	244.68
32	472	5.40	250.07
33	315	5.39	255.46
34	239	5.29	260.75
35	267	5.29	266.05
36	357	5.21	271.26
37	369	5.08	276.34
38	386	4.96	281.29
39	251	4.94	286.24
40	232	4.77	291.01

Table 4.28: Top 40 TAZs by Combined Accessibility Index**Case 1: Addition of ramps at Spring Mountain Road Interchange**

Rank	TAZ	Population Accessibility Index	Cumulative sum of Index
1	491	18.82	18.82
2	471	9.73	28.55
3	470	9.29	37.83
4	358	9.23	47.06
5	318	8.96	56.02
6	260	8.79	64.81
7	493	8.72	73.53
8	319	8.43	81.96
9	428	8.26	90.22
10	268	8.11	98.33
11	275	8.03	106.36
12	357	7.88	114.24
13	369	7.38	121.62
14	429	6.64	128.26
15	264	6.43	134.69
16	204	6.29	140.99
17	276	6.08	147.07
18	472	6.07	153.13
19	296	6.06	159.19
20	492	6.04	165.23
21	343	5.91	171.14
22	327	5.86	177.00
23	267	5.83	182.83
24	359	5.77	188.60
25	130	5.76	194.36
26	259	5.75	200.11
27	271	5.69	205.80
28	282	5.68	211.48
29	474	5.63	217.11
30	323	5.57	222.68
31	457	5.15	227.83
32	415	5.12	232.95
33	161	5.10	238.05
34	425	5.09	243.14
35	315	4.97	248.11
36	365	4.77	252.87
37	373	4.67	257.54
38	206	4.51	262.05
39	350	4.42	266.47
40	181	4.36	270.83

Case 2: Introduction of an Interchange at I-15 and Windmill

Tables 4.29 and 4.30 summarize the top 40 TAZs in this case. It was found that the distribution of the accessibility did not change at all when compared to the base year, but the combined accessibility index registered a change of about 1.42 from 613.15 to 614.57. The corresponding population accessibility index changed from 602.8 to 605 registering an increase of about 2.2.

Table 4.29: Top 40 TAZs by Population Accessibility Index**Case 2: Addition of a full Interchange at Windmill Lane**

Rank	TAZ	Population Accessibility Index	Cumulative sum of Index
1	204	16.01	16.01
2	358	13.05	29.06
3	452	10.85	39.91
4	260	10.43	50.34
5	259	9.88	60.22
6	240	9.55	69.77
7	237	9.14	78.91
8	425	9.03	87.94
9	247	8.80	96.74
10	350	8.68	105.42
11	352	8.51	113.93
12	318	8.31	122.24
13	180	8.08	130.32
14	208	7.74	138.07
15	206	7.73	145.79
16	250	7.71	153.51
17	349	7.70	161.20
18	253	6.83	168.03
19	591	6.54	174.57
20	156	6.25	180.82
21	256	6.12	186.94
22	433	6.11	193.05
23	201	6.00	199.05
24	130	5.98	205.02
25	252	5.93	210.95
26	207	5.85	216.80
27	245	5.68	222.48
28	509	5.64	228.11
29	241	5.60	233.71
30	104	5.59	239.30
31	181	5.54	244.84
32	472	5.40	250.23
33	315	5.39	255.62
34	626	5.35	260.97
35	239	5.29	266.26
36	267	5.29	271.56
37	357	5.21	276.77
38	369	5.08	281.85
39	386	4.96	286.80
40	251	4.94	291.75

Table 4.30: Top 40 TAZs by Combined Accessibility Index**Case 2: Addition of a full Interchange at Windmill Lane**

Rank	TAZ	Population Accessibility Index	Cumulative sum of Index
1	491	18.82	18.82
2	471	9.73	28.55
3	470	9.29	37.83
4	358	9.23	47.06
5	318	8.96	56.02
6	260	8.79	64.81
7	493	8.72	73.53
8	319	8.43	81.96
9	428	8.26	90.22
10	268	8.11	98.33
11	275	8.03	106.36
12	357	7.88	114.24
13	369	7.38	121.62
14	429	6.64	128.26
15	264	6.43	134.69
16	204	6.29	140.99
17	276	6.08	147.07
18	472	6.07	153.13
19	296	6.06	159.19
20	492	6.04	165.23
21	343	5.91	171.14
22	327	5.86	177.00
23	267	5.83	182.83
24	359	5.77	188.60
25	130	5.76	194.36
26	259	5.75	200.11
27	271	5.69	205.80
28	282	5.68	211.48
29	474	5.63	217.11
30	323	5.57	222.68
31	457	5.15	227.83
32	415	5.12	232.95
33	161	5.10	238.05
34	425	5.09	243.14
35	315	4.97	248.11
36	363	4.77	252.87
37	373	4.67	257.54
38	206	4.51	262.05
39	350	4.42	266.47
40	181	4.36	270.83

4.9.1 Comparative study

A synopsis of the findings are tabulated table 4.31

Table 4.31: Comparative study of interchange utility

Accessibility Index	Base Network	Base Network +Spring Mountain Interchange	Base Network + Windmill Interchange
Combined Accessibility Index	613.15	613.18	614.57
Population Index	602.76	602.88	605.00

The above table shows that the model is sensitive to network changes, but since the TRANPLAN step was not performed, the volume to capacity ratios the changed conditions ratios were still considered the same. Thus, the Spring Mountain interchange does not seem useful as compared to the Windmill interchange. This may be due to the presence of the Flamingo Interchange located just half a mile away. Three minute driving distances from the Flamingo interchange almost cover the range of the Spring Mountain Interchange, thus eating away the "market" for the Spring Mountain Interchange. There is some advantage adding a full interchange at Windmill lane which reflects a change in combined accessibility of 1.42. This implies that one more average TAZ is added to the accessible region. This implies that 1.42 additional trips are made accessible for every 1000 trips made in the valley. Considering that the valley attracts four million person trips per day, this translates to 5,600 additional accessible trips. The population accessibility index also increased by 2.2 which implies that more than one average TAZ is now added to the accessible region. The above procedure can be refined and applied to perform a more detailed analysis, taking to account factors such as the costs involved, the consumer's surplus etc..

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

This chapter contains a brief summary of work documented in this thesis. Recommendations for further study have also been presented.

5.1 Summary

The primary contribution this thesis is the development of a methodology to quantify accessibility from a network point of view and use this measure as a decision support tool for urban transportation planning analysis. A systems approach has been developed with the use of existing methods and analytical methods developed the research.

The procedure developed integrates the 4 step planning process along with a GIS program called Arc/Info. A menu driven system has been developed order to facilitate analysis and computation of accessibility measures for a urban transportation system. The results are graphically displayed as per user requirements addition to tabular outputs. The results obtained can be used to support policy analysis, decision making, planning and operations management. An illustration of application of the methodology and programs for the Las Vegas study area is also presented.

5.2 Recommendations

The system developed allows model linkage, quantitative analysis and graphical presentation of results. It is a macroscopic tool and can be made more useful by addition of microscopic level analysis. These would help in better quantification of travel demand characteristics and hence better decision making capabilities.

In terms of the Las Vegas Valley study area, problems such as geo-reference matching of coverages have to be attended to. The TRANPLAN and the street center line coverages do not exactly match. Another coverage that can be used is the parcel land use coverage. This coverage too does not match with the street center line coverage. Some of these problems are being addressed currently. In the analysis of the alternatives, it was seen that the model was sensitive to changes in the network, but the lack of an interface with the TRANPLAN output made the results approximate. It is therefore recommended that the outputs from the TRANPLAN be integrated in to the street network coverage.

Another important consideration is that the trip generation model used is not sensitive to automobile ownership. The present model is being revised currently to include automobile ownership as a stage of the planning process itself. Thus, changes in the transportation system would mean a new number of accessible automobiles which would reflect trip generation and therefore in the accessibility measures developed. It should be noted that it is essential to have a good transportation demand model for the analysis this thesis to be effective.

It was also seen that intersection delays were not considered in the implementation scheme. The program can be modified to include intersection delays as described in section 3.4 of the methodology. Turning impedances can be coded differently so that the effect of

permitted and protected movements may be correctly accounted for. Another extension would be to create impedances based on direction of movement on the streets. The implementation scheme did not consider the effect of multiple lanes in a link. This issue could also be included in the model so that it can estimate changes in accessibility in a shared lane configuration (where the directionality of movement is changed during peak period and off peak period times).

The methodology can be implemented and extended to other components of the transportation system such as rail accessibilities, transit accessibilities etc., so that a complete model that can estimate the utility of various modes may be developed.

Appendix 1

List of notations used

$A(P)_{ij}$ = Production Accessibility index for TAZ j for trip purpose i .

a_{AUTO} = Regression Coefficient (trip rate for AUTO)

A^{AUTO} = Auto-ownership index for the study area

Ac_i = Accessibility of zone i to opportunities in zones $j= 1, \dots, n$.

a_{HHI} = Regression Coefficient (trip rate for HHI)

A^{HHI} = Household Income Accessibility index for the study area

a_{HHS} = Regression Coefficient (trip rate for HHS)

A^{HHS} = Household Size Accessibility index for the study area

A^{hotel} = Hotel employment accessibility index

A_i^{HHS} = Household Size Accessibility index for TAZ I

ar_j = Buffered area of the accessible portion of arc j

A_j = Total trips attracted to zone j

Ar_j = Total Area of TAZ j

a_{ki}, b_{ki} = Trip making characteristics associated with each demographic variable k for trip purpose i

A^{office} = Office employment accessibility index

A^{retail} = Retail employment accessibility index

$AUTO_i$ = Average Automobile ownership for TAZ i

c = Capacity of the link

CAI = Combined Accessibility Index

c_{ij} = Cost of travel from zone i to j

d = average vehicle delay

d_1 = Non-random delay term

d_2 = Overflow delay term

EAI = Employment accessibility index

F_{ij} = Friction factor between traffic analysis zones i and j

g = green time per cycle

h = green time / cycle length ratio

HHI = Average Household Income

HHI_i = Average Household Income for TAZ i

HHS = Average Household Size

HHS_i = Average Household size for TAZ i

j = TAZ number

k = Subscript of relevant demographic or socio-economic variables for TAZ j ($k = 1, 2, \dots, m$)

k_c = A variable parameter derived by calibrating the steady-state expression in random delay computation

K_{ij} = Socio-economic adjustment factor for interchange ij

l = Total number of trip purposes

l_j = Length of the accessible portion of arc j

L_j = Total Length of arc j

n = number of zones the study area

P_i = Total trips produced from zone i

Pr_t = Proportion of activities that have been passed up to time t

RAI = Residential accessibility index for the study area

r_i = Fundamental ratio for TAZ i

S_f = Free flow speed

S_v = Travel speed corresponding to a volume of traffic of v

t = Specific time ordinate.

$T(A)_{ij}$ = Trip attractions for TAZ j by trip purpose i .

$T(P)_{ij}$ = Trip productions for TAZ j by trip purpose $i = 1, 2, \dots, I$.

T_i = Duration of flow period in hours

T_{ij} = Number of trips produced zone i and attracted to zone j

$\bar{t}$ = Mean travel time to reach activity centers

v = Volume of traffic on the link

W_j = Measure of attractiveness of zone j

x = volume to capacity ratio

x_0 = Degree of saturation below which the overflow term (or random delay) is zero

X_{kj} = Measure of Relevant demographic or socio-economic variable k for TAZ j

Appendix 2

AML Program

```
/* *****  
/* Module 1 : Visualization of primary and secondary streets and  
/* extraction of the sub-network of roads and streets.  
/* *****  
&Sv method = [getchoice cursor street_database none -prompt~  
    'Please indicate the preferred method of extracting the subnetwork']  
&select %method%  
&when cursor  
&goto method1  
&when street_database  
&goto method2  
&when none  
&return  
&End  
  
&label method1  
&end  
&if [exists new -cover] &then  
    kill new all  
    create new  
    ae  
    &station 9999  
    editcover function  
    editfeature arc  
    draworder backcover last  
    backcover func1 13  
    backcover func2 9  
    backcover func3 5  
    backcover new 2  
    be arcs  
    drawselect all
```

```

de arcs
draw
setdrawsymbol 7
&sv i = 0
&sv answer = .TRUE.
&do &While %answer%
  &Sv i = %i% + 1
  &popup first.prompt 8 50 3 2
  sel *
  &s number = [show number selected]
  &if %number% = 0 &then &do
    &popup second.prompt 8 50 3 2
    &sv i = %i% - 1
    &goto 10
  &end
  &Else &do
    statistics func_class
    n
    sum length
    end
    &s num = [show case 1]
    statistics street.name
    n
    sum func_Class
    end
    &sv road%i% = [show case 1]
    sel func_class = %num%
    &if %i% = 1 &then
      put new
    &else &do
      put new
      y
    &end
  &label 10
&End
  &sv num = [getchoice YES NO -prompt ~
    'do you want to select another street? yes|no']
  &if %num% = YES &then &sv answer = .TRUE.
  &Else &sv answer = .FALSE.
&end
clear
draw
&popup prompt3.pro
QUIT
&goto control1

```

```

&label method2
&end
&if [exists new -cover] &then
  kill new all
  create new
  ae
  &station 9999
  editcover function
  editfeature arc
  draworder backcover last
  backcover func1 13
  backcover func2 9
  backcover func3 5
  backcover new 2
  be arcs
  drawselect all
  de arcs
  draw
  setdrawsymbol 7
  &sv i = 0
  &sv answer = .TRUE.
  &do &While %answer%
    &sv fun = [getfile *.sup -info -noext ~
      'Please select the functional class' -none]
    &if %fun% = '' &then &goto 30
    &if %fun% = /trc/rtc/access/info!arc!freeways &then
      sel func_Class lt 200
    &if %fun% = /trc/rtc/access/info!arc!principal_arterials &then
      sel func_class gt 200 and func_class lt 300
    &if %fun% = /trc/rtc/access/info!arc!minor_arterials &then
      sel func_Class gt 300 and func_Class lt 400
    &sv i = %i% + 1
    &sv road%i% = [getunique %fun%.sup -info street.name ~
      'Please select a street name' -none]
    &Sv faci = [unquote [value road%i%]]
    &if [value road%i%] = '' &Then &sv i = %i% - 1
    &else &do
      &if %i% = 1 &then &do
        resel street.name lk [quote %faci%]
        put new
      &end
    &else &do
      resel street.name lk [quote %faci%]
      put new
    &end
  &end
  y

```



```

        &End
    &end
    &label 30
    &sv num = [getchoice YES NO -prompt ~
        'do you want to select another street? yes|no']
    &if %num% = YES &then &sv answer = .TRUE.
    &Else &sv answer = .FALSE.
&end

clear
draw
&popup prompt3.pro 8 50 3 2
QUIT
/*****
/* Module 2 : Allocation and subsequent methods of extracting the
/* accessible service area.
*****/

&label control1
&sv anal = [getchoice arc buffer polygon -prompt ~
    'choose type of analysis']
&sv impedx = [getchoice 1 2 3 4 5 -prompt ~
    'Select maximum impedance']
&Sv conges = [getchoice .1 .2 .3 .4 .5 .6 .7 .8 .9 1 1.2 1.4 1.6 1.8 2 ~
    -prompt 'select the v/c ratio' -none]
&if [exists /trc/rtc/access/newb -cover] &then
    kill /trc/rtc/access/newb all
copy new newb
display 0
/* This step is to verify that freeways are selected or not
/* Whenever freeways are selected, I will proceed to extract ramps instead
&label 100
&sv index = 2
&sv j = 0
&do nc = 1 &TO %i% &BY 1
    &sv faci = [unquote [value road%nc%]]
    &SELECT [UPCASE [quote %faci%]]
    &when 'I 215'
        &goto 106
    &when 'I 15'
        &goto 101
    &WHEN 'US 95'
        &GOTO 102
    &when 'SUMMERLIN'
        &goto 103
    &OTHERWISE

```

```

        &goto 104
    &end
&LABEL 101
&END
/* The index is set in order that I know later on that freeways exist
/* in the sub-network.
    ae
    editc new
    editf arc
    sel street.name lk 'I 15*'
    delete
    save all
    y
    quit
    &sv index = 1
    &Sv %j% = %j% + 1
    &sv road%nc% = 'RAMP *I 15*'
    &sv ramp%j% = 'RAMP*I 15*'
    &sv i = %i% + 1
    &Sv j = %j% + 1
/* Ramp connectors should be added in order that airport connectors are
/* taken in to account
    &sv road%i% = 'RAMP*CONN*'
    &Sv ramp%j% = 'RAMP*CONN*'
    &GOTO 104
&LABEL 102
&END
    ae
    editc new
    editf arc
    sel street.name lk 'US*95*'
    delete
    save all
    y
    quit
    &sv index = 1
    &Sv j = %j% + 1
    &SV road%NC% = 'RAMP*US*95*'
    &Sv ramp%j% = 'RAMP*US*95*'
    &GOTO 104
&label 103
&end
    ae
    editc new
    editf arc

```

```

sel street.name lk 'SUMMERLIN*'
delete
save all
y
quit
&sv index = 1
&Sv j = %j% + 1
&Sv road%nc% = 'RAMP*SUM*'
&sv ramp%j% = 'RAMP*SUM*'
&goto 104
&label 106
&end
ae
editc new
editf arc
sel street.name lk 'I 215*'
delete
save all
y
quit
&sv index = 1
&Sv j = %j% + 1
&SV road%NC% = 'RAMP*I215*'
&Sv ramp%j% = 'RAMP*I215*'
&GOTO 104
&LABEL 104
&END
/* This is the second verification that all indeed is in order
  &do nc = 1 &to %i% &by 1
    &type %i%
    &type road%nc% = [value road%nc%]
  &end

&works /trc/rtc/access
&if [exists /trc/rtc/access/street -cover] &then
  kill /trc/rtc/access/street all
copy street1 street
&select %conges%
&when ''
  &goto iva
&otherwise
&end
tables
sel street.aat
calc to_max_imped = to_max_imped * ( ( 1 + %conges% * %conges% * %conges%~

```

```

* %conges% * 0.15 ) / 0.8 )
  calc fro_max_imped = fro_max_imped * ( ( 1 + %conges% * %conges% * %conges%~
* %conges% * 0.15 ) / 0.8 )
  quit
&goto ivan

&label iva
&end
&label ivan
/* routine for allocation.
/* This is where the index comes to use
&select %index%
&when 1
  &goto 200
&otherwise
  &goto 210
&end
/* when index is 1 that means freeways are present
&label 200
&end
&if [exists /trc/rtc/access/ramps -cover] &then
  kill /trc/rtc/access/ramps all
ae
editcover street
editfeature arc
&Sv k = 1
&Sv faci = [unquote [value ramp%k%]]
select street.name lk [upcase [quote %faci%]]
put ramps
&do k = 2 &to %j% &by 1
&Sv faci = [unquote [value ramp%k%]]
select street.name lk [upcase [quote %faci%]]
put ramps
y
&End
save all
y
[unquote '']
quit

&if [exists /trc/rtc/access/blue -cover] &then
  kill /trc/rtc/access/blue all
&if [exists /trc/rtc/access/blue1 -cover] &then
  kill /trc/rtc/access/blue1 all

```

```

densifyarc ramps blue 10000000 arc
nodepoint blue blue1
tables
additem blue1.pat index_item 4 5 b
sel blue1.pat
calc index_item = 19
q stop
pointnode blue1 freecover 100
build freecover node
&if [exists /trc/rtc/access/rpoints -cover] &then
  kill /trc/rtc/access/rpoints all
nodepoint freecover rpoints
pointnode rpoints street 100
&goto 211

```

```

&label 210
&end
&label 211
ae
editcover new
editfeature arc
sel all
&sv numb = [show number selected]
&if %numb% eq 0 &then &do
  quit
  &goto 1000
&end
quit
&if [exists /trc/rtc/access/new1 -cover] &then
  kill /trc/rtc/access/new1 all
&if [exists /trc/rtc/access/new2 -cover] &then
  kill /trc/rtc/access/new2 all
densifyarc new new1 1000000 arc
nodepoint new1 new2
tables
additem new2.pat index_num 4 5 b
sel new2.pat
  calc index_num = 10
q stop
pointnode new2 street 100

```

```

&label 1000
tables
additem street.nat old_street-id 4 5 b

```

```

sel street.nat
calc old_street-id = street-id
calc street-id = street#
q stop

display 0
ap
clearsel
&if [exists /trc/rtc/access/street.cen -info] &then
  &s x = [delete /trc/rtc/access/street.cen -info]
&if [iteminfo street -node index_item -exists] &then &do
  &if [iteminfo street -node index_num -exists] &then &do
    resel street node index_num = 10 or index_item = 19
    infofile street node street.cen street-id
  &end
  &else &do
    resel street node index_item = 19
    infofile street node street.cen street-id
    clearsel
  &end
&end
&else &do
  resel street node index_num = 10
  infofile street node street.cen street-id
&end
quit

tables
additem street.cen route_id 4 5 b
additem street.cen max_imped 4 5 b
select street.cen

calc route_id = 1
calc max_imped = %impedx% * 60
q stop

ap
clearsel

/* allocation stage
netcover clear
netcover street from_acs
impedance fro_max_imped fro_max_imped
centers street.cen route_id max_imped
allocate centers out connected

```

```

clearsel
quit
/* conversion of allocated sub-coverage in to main coverage
&if [exists /trc/rtc/access/fromacs -cover] &then
    kill /trc/rtc/access/fromacs all
&if [exists /trc/rtc/access/toacs -cover] &then
    kill /trc/rtc/access/toacs all

```

```

sectionarc street from_acs fromacs
build fromacs line
dropfeatures street section.from_acs
ap
netcover clear
netcover street to_acs
impedance to_max_impd to_max_impd
centers street.cen route_id max_impd
allocate centers in connected
quit
sectionarc street to_acs toacs
build toacs line
dropfeatures street section.to_acs

```

```

/* Now three types of analysis can be performed.

```

```

&select %anal%
&when arc
    &goto 300
&when buffer
    &goto 400
&otherwise
    &goto 500
&end

```

```

&label 300
&end
/* Creation of intersect covers for both from and to covers
&if [exists /trc/rtc/access/taz_from -cover] &then
    kill /trc/rtc/access/taz_from all
intersect fromacs taz1990 taz_from line
&if [exists /trc/rtc/access/taz_to -cover] &then
    kill /trc/rtc/access/taz_to all
intersect toacs taz1990 taz_to line

```

```

/* -----

```

```

/* Creation of label covers for each of the from and to access covers
/* This method can be used to demarcate boundary arcs
/* -----

```

```

&if [exists /trc/rtc/access/from_left -cover] &then
  kill /trc/rtc/access/from_left all
&if [exists /trc/rtc/access/from_right -cover] &then
  kill /trc/rtc/access/from_right all
arclabel taz_from from_left left 15 taz
arclabel taz_from from_right right 15 taz
build from_left labels
build from_right labels
&if [exists /trc/rtc/access/to_left -cover] &then
  kill /trc/rtc/access/to_left all
&if [exists /trc/rtc/access/to_right -cover] &then
  kill /trc/rtc/access/to_right all
arclabel taz_to to_left left 15 taz
arclabel taz_to to_right right 15 taz
build to_left labels
build to_right labels

```

```

/* All these point covers are now intersected with the TAZ cover
/* so that the labels and hence the arcs in the taz_from or taz_To
/* covers are correctly indexed with reference to the zones they
/* really belong to.

```

```

&if [exists /trc/rtc/access/from_r -cover] &then
  kill /trc/rtc/access/from_r all
&if [exists /trc/rtc/access/from_l -cover] &then
  kill /trc/rtc/access/from_l all
&if [exists /trc/rtc/access/to_l -cover] &then
  kill /trc/rtc/access/to_l all
&if [exists /trc/rtc/access/to_r -cover] &then
  kill /trc/rtc/access/to_r all
intersect to_left taz1990 to_l point
intersect to_right taz1990 to_r point
intersect from_left taz1990 from_l point
intersect from_right taz1990 from_r point

```

```

/* Please note that arcs are represented by internal# in the
/* arc intersect covers. These numbers are replicated in the
/* label covers that are generated. Hence the initial internal
/* numbers represent the arc internal numbers in the AAT table.
/* In this step I will index these as a relno so that I can use
/* this number for a joinitem later on. The real left_taz

```


/* and right taz numbers for each of the arcs is also demarcated

```

additem to_l.pat to_l.pat left_taz 4 5 b
additem to_l.pat to_l.pat relno 4 5 b
additem to_r.pat to_r.pat right_taz 4 5 b
additem to_r.pat to_r.pat relno 4 5 b
additem from_l.pat from_l.pat left_taz 4 5 b
additem from_l.pat from_l.pat relno 4 5 b
additem from_r.pat from_r.pat right_taz 4 5 b
additem from_r.pat from_r.pat relno 4 5 b
additem taz_to.aat taz_to.aat relno 4 5 b
additem taz_from.aat taz_from.aat relno 4 5 b

```

/* Calculation of the relno is also done for the taz_intersect

/* covers instead of altering the internal numbers

/* Simultaneously sorting by relno would help in joinitem later on

```

tables
sel taz_from.aat
calc relno = taz_from#
sort relno
sel
sel taz_to.aat
calc relno = taz_to#
sort relno
sel
sel to_l.pat
calc left_taz = taz
calc relno = to_left#
sort relno
sel
sel to_r.pat
calc right_taz = taz
calc relno = to_right#
sort relno
sel
sel from_l.pat
calc left_taz = taz
calc relno = from_left#
sort relno
sel
sel from_r.pat
calc right_taz = taz
calc relno = from_right#
sort relno

```

q stop

/* An indexitem greatly increases the speed of a relate

```
indexitem taz_to.aat relno
indexitem taz_from.aat relno
indexitem to_l.pat relno
indexitem to_r.pat relno
indexitem from_l.pat relno
indexitem from_r.pat relno
```

/* now all the labels are returned to the origin arc covers

/* for an examination of boundary arcs

```
joinitem taz_to.aat to_l.pat taz_to.aat relno taz linear
joinitem taz_to.aat to_r.pat taz_to.aat relno taz linear
joinitem taz_from.aat from_l.pat taz_from.aat relno taz linear
joinitem taz_from.aat from_r.pat taz_from.aat relno taz linear
additem taz_from.aat taz_from.aat len1 8 18 f 6
additem taz_from.aat taz_from.aat len2 8 18 f 6
additem taz_to.aat taz_to.aat len1 8 18 f 6
additem taz_to.aat taz_to.aat len2 8 18 f 6
```

tables

```
sel taz_from.aat
```

/* This is for those arcs that lie on the boundary of the valley

/* these arcs can be allocated only to one taz for there exists

/* no two tazes that can share these arcs

```
resel left_taz eq 0 or right_taz eq 0
```

```
calc left_taz = taz
```

```
calc right_taz = taz
```

```
asel
```

```
resel left_taz = right_taz
```

```
calc len1 = length
```

```
asel
```

```
resel left_taz ne right_taz
```

```
calc len1 = length
```

```
calc len2 = length
```

```
sel
```

```
sel taz_to.aat
```

```
resel left_taz eq 0 or right_taz eq 0
```

```
calc left_taz = taz
```

```
calc right_taz = taz
```

```
asel
```

```
resel left_taz = right_taz
```

```
calc len1 = length
```

```

asel
resel left_taz ne right_taz
calc len1 = length
calc len2 = length
sel
q stop

      .
&if [exists /trc/rtc/access/fromleft.sum -info] &then
  &s x = [delete /trc/rtc/access/fromleft.sum -info]
&if [exists /trc/rtc/access/toleft.sum -info] &then
  &s x = [delete /trc/rtc/access/toleft.sum -info]
&if [exists /trc/rtc/access/fromright.sum -info] &then
  &s x = [delete /trc/rtc/access/fromright.sum -info]
&if [exists /trc/rtc/access/toright.sum -info] &then
  &s x = [delete /trc/rtc/access/toright.sum -info]
&if [iteminfo /trc/rtc/access/froml.sum -info sum-len1 -exists] &then
  dropitem /trc/rtc/access/froml.sum froml.sum sum-len1
&if [iteminfo /trc/rtc/access/froml.sum -info sum-len2 -exists] &then
  dropitem /trc/rtc/access/froml.sum froml.sum sum-len2
&if [iteminfo /trc/rtc/access/tol.sum -info sum-len1 -exists] &then
  dropitem /trc/rtc/access/tol.sum tol.sum sum-len1
&if [iteminfo /trc/rtc/access/tol.sum -info sum-len2 -exists] &then
  dropitem /trc/rtc/access/tol.sum tol.sum sum-len2
&if [iteminfo /trc/rtc/access/tol.sum -info l2 -exists] &then
  dropitem /trc/rtc/access/tol.sum tol.sum l2
&if [iteminfo /trc/rtc/access/froml.sum -info l1 -exists] &then
  dropitem /trc/rtc/access/froml.sum froml.sum l1

/* can now find sum of lengths of all allocated arcs
ap
clearsel
sort taz_from arc left_taz
statistics taz_from arc left_taz fromleft.sum
sum len1
end
clearsel
sort clear taz_from arc
sort taz_from arc right_taz
statistics taz_from arc right_taz fromright.sum
sum len2
end
sort clear taz_from arc
clearsel

```

```

sort taz_to arc left_taz
statistics taz_to arc left_taz toleft.sum
sum len1
end
clearsel
sort clear taz_to arc
statistics taz_to arc right_taz toright.sum
sum len2
end
sort clear taz_to arc
quit
dropitem toleft.sum toleft.sum frequency
dropitem toright.sum toright.sum frequency
dropitem fromleft.sum fromleft.sum frequency
dropitem fromright.sum fromright.sum frequency

/* the left_taz and right_taz numbers are the real taz values.
/* these can therefore be alternately named
tables
sel fromleft.sum
alter left_taz left_taz 5 b taz
sort taz
sel
sel fromright.sum
alter right_taz right_taz 5 b taz
sort taz
sel
sel toleft.sum
alter left_taz left_taz 5 b taz
sort taz
sel
sel toright.sum
alter right_taz right_taz 5 b taz
sort taz
sel
q stop

indexitem froml.sum taz
indexitem fromleft.sum taz
indexitem fromright.sum taz
indexitem toleft.sum taz
indexitem toright.sum taz
indexitem tol.sum taz

joinitem froml.sum fromleft.sum froml.sum taz taz

```

```

joinitem from l.sum from right.sum from l.sum taz taz
joinitem to l.sum to left.sum to l.sum taz taz
joinitem to l.sum to right.sum to l.sum taz taz
tables
sel from l.sum
calc s1 = sum-len1 + sum-len2
sel
sel to l.sum
calc s2 = sum-len1 + sum-len2
sel
q stop
dropitem from l.sum from l.sum
sum-len1
sum-len2
end
dropitem to l.sum to l.sum
sum-len1
sum-len2
end
indexitem tazs.sum taz
&if [iteminfo tazs.sum -info ratio1 -exists] &then
  dropitem tazs.sum tazs.sum ratio1
&if [iteminfo tazs.sum -info ratio2 -exists] &then
  dropitem tazs.sum tazs.sum ratio2
&if [iteminfo tazs.sum -info s1 -exists] &then
  dropitem tazs.sum tazs.sum s1
&if [iteminfo tazs.sum -info s2 -exists] &then
  dropitem tazs.sum tazs.sum s2
/* do a joinitem with tazs.sum-a file that contains tazs and
/* sum of all lengths
joinitem tazs.sum from l.sum tazs.sum taz len
joinitem tazs.sum to l.sum tazs.sum taz len
tables
additem tazs.sum ratio1 8 18 f 5
additem tazs.sum ratio2 8 18 f 5
sel tazs.sum
resel len eq 0
calc ratio1 = -1
calc ratio2 = -1
asel
resel len gt 0
calc ratio1 = s1 / len
calc ratio2 = s2 / len
q stop
&if [exists /trc/rtc/access/res.dat -info] &then

```

```

&s x = [delete /trc/rtc/access/res.dat -info]
/* traz.dat is an already prepared tripgen and tripatt table
joinitem tazs.sum traz.dat res.dat taz taz

&goto 560

&label 400
&end

/* In this case only buffer the arcs and perform an areal analysis
&if [exists /trc/rtc/access/to -cover] &then
  kill /trc/rtc/access/to all
&if [exists /trc/rtc/access/from -cover] &then
  kill /trc/rtc/access/from all
buffer toacs to # # 200 # line
buffer fromacs from # # 200 # line
&goto 520

/* end of label 400 as of now
&label 500
&end
/* First we need to convert the whole arc coverage
/* in to a tin coverage
tables
additem fromacs.aat spot 4 5 f 1
additem toacs.aat spot 4 5 f 1
sel fromacs.aat
calc spot = 0.0
sel
sel toacs.aat
calc spot = 0.0
q stop

&if [exists /trc/rtc/access/to_tin -tin] &then
  kill /trc/rtc/access/to_tin all
&if [exists /trc/rtc/access/from_tin -tin] &then
  kill /trc/rtc/access/from_tin all
arctin toacs to_tin line
arctin fromacs from_tin line

/* Now convert from a tin to a polygon coverage
&if [exists /trc/rtc/access/from -cover] &then
  kill /trc/rtc/access/from all
&if [exists /trc/rtc/access/to -cover] &then

```

```

    kill /trc/rtc/access/to all
    tinarc to _tin to hull
    tinarc from _tin from hull
    build to poly
    build from poly
    &goto 520

&label 520

/* Intersection with taz is a poly intersect

&if [exists /trc/rtc/access/frompoly -cover] &then
    kill /trc/rtc/access/frompoly all
&if [exists /trc/rtc/access/topoly -cover] &then
    kill /trc/rtc/access/topoly all
intersect from taz1990 frompoly poly
intersect to taz1990 topoly poly
    &if [exists /trc/rtc/access/from.sum -info] &then
        &s x = [delete /trc/rtc/access/from.sum -info]
    &if [exists /trc/rtc/access/to.sum -info] &then
        &s x = [delete /trc/rtc/access/to.sum -info]
ap
sort frompoly poly taz
statistics frompoly poly taz from.sum
sum area
end
sort clear frompoly poly
sort topoly poly taz
statistics topoly poly taz to.sum
sum area
end
sort clear topoly poly
quit
tables
additem from.sum s1 8 18 f 6
sel from.sum
calc s1 = sum-area
q stop
dropitem from.sum from.sum
sum-area
frequency
end
tables
additem to.sum s2 8 18 f 6
sel to.sum

```

```

calc s2 = sum-area
q stop
dropitem to.sum to.sum
sum-area
frequency
end
&goto 540

&label 540
&if [exists /trc/rtc/access/taz2.sum -info] &then
  &s x = [delete /trc/rtc/access/taz2.sum -info]
indexitem taz1990.pat taz
indexitem from.sum taz
indexitem to.sum taz
joinitem taz1990.pat from.sum taz2.sum taz taz90area
joinitem taz2.sum to.sum taz2.sum taz taz90area
tables
additem taz2.sum ratio1 8 18 f 8
additem taz2.sum ratio2 8 18 f 8
sel taz2.sum
resel taz lt 10
purge
y
asel
calc ratio1 = s1 / area
calc ratio2 = s2 / area
sort taz
q stop
dropitem taz2.sum taz2.sum
s1
s2
end

  &if [exists /trc/rtc/access/res.dat -info] &then
    &s x = [delete /trc/rtc/access/res.dat -info]
indexitem traz.dat taz
indexitem taz2.sum taz
joinitem traz.dat taz2.sum res.dat taz taz linear

&label 560
&r res2.aml
&r final.aml
&return

```



```

/*****
/* Module 3: Estimation of indices for the various categories
/* res2.aml
/* declaration of variables already defined in traz.dat
/*****

&sv prod1 = PROD_HBW
&sv prod2 = PROD_HBSC
&sv prod3 = PROD_HBSH
&sv prod4 = PROD_HBO
&sv prod5 = PROD_NHB
&sv prod6 = TOT_PROD
&sv att1 = ATT_HBW
&sv att2 = ATT_HBSC
&sv att3 = ATT_HBSH
&sv att4 = ATT_HBO
&sv att5 = ATT_NHB
&sv att6 = TOT_ATT
&sv gen1 = population
&sv gen2 = hotel_emp
&sv gen3 = tot_shop
&sv gen4 = tot_off
&sv gen5 = tot_Sch
&sv gen6 = tot_demo
/* definition of accessible trips for various trip purposes
&sv aprod1 = acc_phbw
&sv aprod2 = acc_phbse
&sv aprod3 = acc_phbsh
&sv aprod4 = acc_phbo
&sv aprod5 = acc_pnhb
&sv aprod6 = acc_ptot
&sv aatt1 = acc_ahbw
&sv aatt2 = acc_ahbse
&sv aatt3 = acc_ahbsh
&sv aatt4 = acc_ahbo
&sv aatt5 = acc_anhb
&sv aatt6 = acc_atot
&sv agen1 = acc_population
&sv agen2 = acc_hotel_Emp
&sv agen3 = acc_tot_shop
&sv agen4 = acc_tot_off
&sv agen5 = acc_tot_Sch
&sv agen6 = acc_tot_demo
/* definition of accessibility indicators
&sv pro_acc1 = hbw_p_ind

```

```

&sv pro_acc2 = hbse_p_ind
&sv pro_acc3 = hbsh_p_ind
&sv pro_acc4 = hbo_p_ind
&sv pro_acc5 = nhb_p_ind
&sv pro_acc6 = total_p_ind
&sv att_acc1 = hbw_a_ind
&sv att_acc2 = hbse_a_ind
&sv att_acc3 = hbsh_a_ind
&sv att_acc4 = hbo_a_ind
&sv att_acc5 = nhb_a_ind
&sv att_acc6 = total_a_ind
&Sv gen_Acc1 = population_ind
&Sv gen_Acc2 = hotel_index
&Sv gen_Acc3 = tot_shop_index
&Sv gen_Acc4 = tot_off_index
&sv gen_Acc5 = tot_Sch_index
&sv gen_Acc6 = tot_demo_index
&sv vpro_acc1 = vhbw_p_ind
&sv vpro_acc2 = vhbse_p_ind
&sv vpro_acc3 = vbsh_p_ind
&sv vpro_acc4 = vbbo_p_ind
&sv vpro_acc5 = vnhb_p_ind
&sv vpro_acc6 = vttotal_p_ind
&sv vatt_acc1 = vhbw_a_ind
&sv vatt_acc2 = vhbse_a_ind
&sv vatt_acc3 = vbsh_a_ind
&sv vatt_acc4 = vbbo_a_ind
&sv vatt_acc5 = vnhb_a_ind
&sv vatt_acc6 = vttotal_a_ind
&Sv vgen_Acc1 = vpopulation_ind
&Sv vgen_Acc2 = vhotel_index
&Sv vgen_Acc3 = vtot_shop_index
&Sv vgen_Acc4 = vtot_off_index
&sv vgen_Acc5 = vtot_Sch_index
&sv vgen_Acc6 = vtot_demo_index
&sv pur1 = tot_hbw
&sv pur2 = tot_hbse
&Sv pur3 = tot_hbsh
&sv pur4 = tot_hbo
&Sv pur5 = tot_nhb
&sv pur6 = tot_alltrips
&sv vpur1 = vtot_hbw
&sv vpur2 = vtot_hbse
&Sv vpur3 = vtot_hbsh
&sv vpur4 = vtot_hbo

```

```

&Sv vpur5 = vtot_nhb
&sv vpur6 = vtot_alltrips
/* routine to define all the indicators using tables
tables
&do i = 1 &to 6 &by 1
  additem res.dat [value aprod%i%] 5 5 i
  additem res.dat [value aatt%i%] 6 6 i
  additem res.dat [value pro_acc%i%] 8 8 f 4
  additem res.dat [value att_acc%i%] 8 8 f 4
  additem res.dat [value agen%i%] 8 8 i
  additem res.dat [value gen_Acc%i%] 8 8 f 4
  additem res.dat [value vpro_acc%i%] 8 8 f 4
  additem res.dat [value vatt_acc%i%] 8 8 f 4
  additem res.dat [value vgen_Acc%i%] 8 8 f 4
  additem res.dat [value pur%i%] 8 8 f 4
  additem res.dat [value vpur%i%] 8 8 f 4
&end
sel res.dat
resel ratio1 gt 0 or ratio2 gt 0
calc mean_Ratio = ( ratio1 / 2 ) + ( ratio2 / 2 )
&do i = 1 &to 6 &by 1
  calc [value aprod%i%] = ratio1 * [value prod%i%]
  calc [value aatt%i%] = ratio2 * [value att%i%]
  calc [value agen%i%] = mean_ratio * [value gen%i%]
&end
quit
ap
resel res.dat info ratio1 gt 0 or ratio2 gt 0
&do i = 1 &to 6 &by 1
  statistics res.dat info
  sum [value prod%i%]
  sum [value att%i%]
  sum [value gen%i%]
  sum [value aprod%i%]
  sum [value aatt%i%]
  sum [value agen%i%]
end
[unquote '']
&sv num_prod%i% = [show statistic 1 1]
&sv num_att%i% = [show statistic 2 1]
&sv num_gen%i% = [show statistic 3 1]
&sv num_aprod%i% = [show statistic 4 1]
&sv num_aatt%i% = [show statistic 5 1]
&sv num_agen%i% = [show statistic 6 1]
&end

```

```

quit
tables
sel res.dat
resel ratio1 gt 0 or ratio2 gt 0
&do i = 1 &to 6 &by 1
  calc [value pro_Acc%i%] = ( [value aprod%i%] / [value num_aprod%i%] ) * 1000
  calc [value att_acc%i%] = ( [value aatt%i%] / [value num_aatt%i%] ) * 1000
  calc [value gen_Acc%i%] = ( [value agen%i%] / [value num_Agen%i%] ) * 1000
  calc [value pur%i%] = ( [value pro_Acc%i%] + [value att_Acc%i%] ) / 2
  calc [value vpro_Acc%i%] = ( [value aprod%i%] / [value num_prod%i%] ) * 1000
  calc [value vatt_acc%i%] = ( [value aatt%i%] / [value num_att%i%] ) * 1000
  calc [value vgen_Acc%i%] = ( [value agen%i%] / [value num_gen%i%] ) * 1000
  calc [value vpur%i%] = ( [value vpro_Acc%i%] + [value vatt_Acc%i%] ) / 2
&End
quit
additem res.dat res.dat taz1 4 5 b
tables
sel res.dat
calc taz1 = taz
quit
&if [exists taz10 -cover] &then
  kill taz10 all
  copy taz1990 taz10
tables
sel taz10.pat
alter taz taz 5 b taz1
quit
joinitem taz10.pat res.dat taz10.pat taz1 taz1 linear
tables
sel taz10.pat
calc mean_ratio = ( ratio1 + ratio2 ) / 2
quit
&return

/*****
/* Module 4: Development of a query tool to access the database
/* Final.aml
*****/

&sv sec = .true.
&do &while %sec%
display 0

&Sv choice1 = [getchoice network facility valley_wide -prompt~
               'Select the model you wish to query']
&Select %choice1%

```

```

&when network
  &goto 1
&when facility
  &goto 2
&when valley_wide
  &goto 3
&end

&label 1
&end
/* Here is the place the spatial utility index is to be described
&sv var = ratio1
&goto control

&label 2
&End
&Sv choice2 = [getchoice production attraction combined demographic -prompt~
               'Please select the type of sub-model for presentation']
&select %choice2%
&when production
  &goto 21
&when attraction
  &goto 22
&when combined
  &goto 23
&when demographic
  &goto 24
&end

&label 21
&end
&sv choice3 = [getchoice HBW HBSC HBSH HBO NHB TOTAL -prompt~
               'Select the category for presentation']
&sv var = %choice3%_p_ind
&goto control

&label 22
&end
&sv choice3 = [getchoice HBW HBSC HBSH HBO NHB TOTAL -prompt~
               'Select the category for presentation']
&sv var = %choice3%_a_ind
&goto control

&label 23

```

```

&end
&sv choice3 = [getchoice HBW HBSC HBSH HBO NHB ALLTRIPS -prompt~
                'Select the category for presentation']
&sv var = tot_%choice3%
&goto control

&label 24
&end
&sv choice3 = [getchoice Population Hotel Shops Office School All -prompt~
                'Select the category for presentation']
&select %choice3%
&when Population
    &Sv var = population_ind
&when Hotel
    &sv var = hotel_index
&when Shops
    &sv var = tot_shop_index
&when Office
    &sv var = tot_off_index
&when School
    &sv var = tot_sch_index
&when All
    &Sv var = tot_demo_index
&end
&goto control

&label 3
&end
&Sv choice2 = [getchoice production attraction combined demographic -prompt~
                'Please select the type of sub-model for presentation']
&select %choice2%
&when production
    &goto 21
&when attraction
    &goto 22
&when combined
    &goto 23
&when demographic
    &goto 24
&end

&label 21
&end
&sv choice3 = [getchoice HBW HBSC HBSH HBO NHB TOTAL -prompt~

```

```

        'Select the category for presentation']
&sv var = v%choice3%_p_ind
&goto control

&label 22
&end
&sv choice3 = [getchoice HBW HBSC HBSH HBO NHB TOTAL -prompt~
        'Select the category for presentation']
&sv var = v%choice3%_a_ind
&goto control

&label 23
&end
&sv choice3 = [getchoice HBW HBSC HBSH HBO NHB ALLTRIPS -prompt~
        'Select the category for presentation']
&sv var = vtot_%choice3%
&goto control

&label 24
&end
&sv choice3 = [getchoice Population Hotel Shops Office School All -prompt~
        'Select the category for presentation']
&select %choice3%
&when Population
    &Sv var = vpopulation_ind
&when Hotel
    &sv var = vhotel_index
&when Shops
    &sv var = vtot_shop_index
&when Office
    &sv var = vtot_off_index
&when School
    &sv var = vtot_sch_index
&when All
    &Sv var = vtot_demo_index
&end
&label control
TABLES
sel taz10.pat
resel taz gt 0
sort %var% (d)
calc rank = $recno
sort taz
quit

```

```

ae
editc taz10
editf poly
sel %var% gt 0
&Sv numinter = [show number selected]
sel all
quit
&sv choice4 = [getchoice 5 10 15 20 25 30 35 40 45 50 60 70 100 -prompt ~
    'Select percentile']
&sv inter_siz1 = %numinter% * ( %choice4% / 100 )
&sv inter_size = [round %inter_siz1%]
ap
display 9999
&popup prompt3.pro 8 50 3 2
make poly taz10
linecolor green
arcs function
linecolor yellow
arcs toacs
linecolor red
arcs taz10
&sv quer = .true.
&Sv i = 1
&do &while %quer%
    clearsel
    &sv j = ( %i% - 1 ) * %inter_size%
    &Sv k = %i% * %inter_size%
    &sv c = [getsymbol -shade -range 1-25 -prompt~
        'Select the shade colours for the interval']
    make poly taz10
    resel taz10 poly rank gt %j% and rank le %k%
    polygonshades taz10 %c%
    &sv quer = [getchoice yes no -Prompt 'continue? yes|no']
    &if %quer% = no &then &sv quer = .false.
    &else &sv quer = .true.
    &sv i = %i% + 1
&end
&sv again = [getchoice yes no -prompt ' Do you want another query?']
&if %again% = no &then &sv sec = .false.
&else &sv sec = .true.
&popup prompt2.pro 8 50 3 2
clear
quit
&end
&return

```


Bibliography

Akcelic, R. and Rouphail, N. M. (1993). "Estimation of Delays at Traffic Signals for Variable Demand Conditions." *Transportation Research-B*, 27B, 109-131.

Arentze, T., Borgers, A., and Timmermans, H., (1992). "Geographical Information Systems, accessibility and Multipurpose Travel; A New Measurement Approach." *Proceedings of the third European conference on Geographical Information Systems (EGIS 92)*, Utrecht: Egis Bureau, 438-450

Bach L. (1981). "The Problem of Aggregation and Distance Analyses of Accessibility and Access Opportunity in Location-allocation Models." *Environment and Planning A*, 1981.vol. 13 pp 955-978.

Baxter R. S. and G. Lenzi(1975). "The Measurement of Relative Accessibility." *Regional Studies*. Vol 9,pp 15-26. 1975.

Black J. and M. Conroy(1977). " Accessibility Measures and Social Evaluation of Urban Structure." *Environment and Planning A*, Vol 9. pp 1013-10312. 1977.

Bruce Allen, Dong Liu and Scott Singer(1992)."Geographical Information Systems, Accessibility and Multipurpose Travel: a New Measurement Approach." *EGIS 1992 Proceedings*, 1992, pp 438-450.

Bruce Allen, Dong Liu and Scott Singer(1993)."Accessibility Measures for U.S. Metropolitan Areas. *Transportation Research*." Vol27b,no.6,pp 439-449, 1993.

Bruce Allen, Dong Liu and Scott Singer(1987). " Accessibility and Intraurban Travel" *Environment and Planning A*, Vol. 19. pp 735-748.

BRW INC. (1991). "Las Vegas Regional Transportation Model Documentation Report." *Regional Transportation Commission of Clark County*, December, 1991.

Burli, Sandeep (1996). "A GIS-based Decision Support System for Travel Demand Analysis " *M.S. Thesis, Department of Civil and Environmental Engineering, University of Nevada, Las Vegas*. 1996.

- Burns Lawrence D.(1979).** "Transportation, Temporal and Spatial Components of Accessibility." *Lexington Books. D.C. Heath and Company. Massachussets. 1979.*
- Caliper Corporation.** "TRANSCAD (1996)" *Newton, Massachusetts, 1996*
- Clark County Department of Comprehensive Planning. (CCDCP, 1997).** "Clark County Demographics Summary." *Clark County Department of Comprehensive Planning, Clark County, Nevada, January 1997.*
- Comsis Corporation.** "MINUTP (1996)." *Silver Spring, Maryland, 1996.*
- Coopers & Lybrand. (1996).** "1996 Planning Variables Database Update." *Regional Transportation Commission of Clark County, December, 1996.*
- Coopers & Lybrand. (1992).** "1992 Planning Variables Database Update." *Regional Transportation Commission of Clark County, December, 1992.*
- Coopers & Lybrand(1991).** "Technical Memorandum to RTC Regarding Clark County Socio-economic Projections: 2000-2010." *Regional Transportation Commission of Clark County, May 28, 1991.*
- Current John R., Charles S. Revelle and Jared L. Cohon(1987).** "The Median Shortest Path Problem: A Multiobjective Approach to Analyze Cost vs. Accessibility in the Design of Transportation Networks." *Transportation Science, Vol.21, No.3, pp.188-197.*
- Dalvi M. Q. and K. M. Martin.** "The Measurement of Accessibility: Some Preliminary Results." *Transportation. Vol 5. pp 17-42. 1976.*
- Davidson K. B.(1977).** "Accessibility in Transport/land-use Modeling and Assessment." *Environment and Planning A, Vol 9, pp 1401-1416. 1977.*
- Domanski R.(1979).** "Accessibility, Efficiency and Spatial Organization." *Environment and Planning A. Vol 11. pp 1189-1206. 1979.*
- Environmental Systems Research Institute (ESRI). (1993a)** "Understanding GIS, The ARC/INFO method." *Longman Scientific and Technical, 1993.*
- Environmental Systems Research Institute (ESRI). (1993b)** "Map Display and Query." *March, 1992.*
- Environmental Systems Research Institute (ESRI). (1993c)** "Network Analysis -Modeling Network Features." *May 1992.*
- Environmental Systems Research Institute (ESRI). (1993d)** "Dynamic Segmentation - Modeling Linear Features " *May 1992.*

Garrison William L.(1960). " Connectivity of Highway Networks." *Papers and Proceedings of the Regional Science Association, Vol. 6, 1960.*

Gould Micheal, Javier Guterrez, Sara Garcia and Andrez Monzon(1993). "Implementation of a National Motor way Accessibility Model." *EGIS, Conference Proceedings, 1993. pp1373-1380.*

Gould R.(1969). "Spatial Distribution, Commission on College Geography." *Assoc. Am. Geogr., Washington, D.C.*

Handy Susan(1994). " Highway Blues: Nothing a Little Accessibility Can't Cure." *Access. Fall 1994, No. 5.1994.*

Hansen, Walter G. (1959). " How Accessibility Shapes Land Use." *Journal of American Institute of Planners. Vol 25. pp 73-76. 1959.*

Ingram D. R.(1971). "The Concept of Accessibility: a Search for an Operational Form." *Regional Studies. Vol. 5, pp. 101-107. 1971.*

Intro Consultants Inc. "EMME2 (1996)." *Montreal, 1996.*

IVHS America (1995). "IVHS Architecture." *Volume 1, 1995. Washington D.C.*

Jannelle (1969). "Spatial Reorganization - A model and a concept." *Ann. Assoc. Am. Geogr. 59, pp 348-364.*

Johnston R. R. (1996). "An Index of Accessibility and its Use in the Study of Bus Services and Settlement Patterns." *Tijdschrift Voor Econ. En Soc. Geografie-jan/feb. 1996.pp33-57.*

Linneker B.J. and N.A.Spence(1991). "An Accessibility Analysis of the Impact of the M25 London Orbital Motor way on Britain." *Regional Studies. February 1991,pp31-47.*

Mackiewicz Andrzej and Waldemar Ratajczak(1996). " Towards a New Definition of Topological Accessibility." *Transportation Research-B, Vol. 30, No. 1. pp47-79.1996.*

Meyer, Micheal D. and Eric J. Miller. (1984) "Urban Transportation Planning - A Decision-oriented Approach." *McGraw Hill, New York, 1984.*

Morris J. M., P. L. Dumble and M. R. Wigan (1979). " Accessibility Indicators for Transport Planning." *Transportation Research -A. Vol 13a. pp 91-109. 1979.*

National Cooperative Highway Research Program (NCHRP), 1991 "Assessment of Advanced Technologies for Relieving Traffic Congestion." *NCHRP, Special Report 340, pp-3, 1991.*

Papacostas C. S. (1987). "Fundamentals of Transportation Engineering." *Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632, 1987.*

Safwat Nabil Ali K.(1988). "A Combined Trip Generation, Trip Distribution, Modal Split and Trip Assignment Model." *Transportation Science. Vol. 18. No. 1, February 1988.*

Pirie G. H. (1978) "Measuring Accessibility: a Review and Proposal." *Environment and Planning A, Vol. 11, pp 299-312. 1978.*

Rasas Justin P. and Shashi, K. Sathisan (1995) "Allocation of Census Data to Traffic Analysis Zones." *Transportation Research Center, University of Nevada, Las Vegas. September 1995.*

Regional Transportation Commission. (1995) "Resort Corridor Major Investment Study - Draft Statement and the Purpose of the Need." *Regional Transportation Commission of Clark County, Clark County, 1995.*

Reid Ewing(1995). "Beyond Density, Mode Choice and Single-purpose Trips." *Transportation Quarterly, Vol 49, Fall 1995. pp 15-24. 1995.*

Transportation Research Board (TRB), 1992. "ISTEA and intermodal planning: Concept, Practice and Vision: Proceedings of a conference." *National Research Council. Special report 240, December 1992.*

Transportation Research Board (TRB), 1994. "Highway Capacity Manual." *National Research Council. Special report 209, 1994.*

Urban Analysis Group (1995) "Urban/sys. Version 8.0." *Danville, California, 1995.*