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16. Abstract <p>The Surface Transportation Assistance Act (STAA) of 1982 established a nationally uniform maximum limit to the length, width, and weight of commercial vehicles. In accordance with the act, a national network of routes that could safely and structurally accommodate the large and heavier vehicles was established. The objective of this study was to develop procedures for identifying truck routes and for determining accessibility to the selected network.</p> <p>This goal was accomplished in two stages. First potential demand for access to the network was identified. Emphasis was placed on counties that have large economic and demographic bases, and on areas that are currently small yet have exhibited recent growth trends.</p> <p>The second stage focused on the network or the spatial structure of routes. A hierarchy of four coverage patterns was evaluated in terms of the amount of demand satisfied by the network. The four networks varied in degree of complexity.</p>					
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**SOME MEASURES OF ACCESSIBILITY OF LARGE TRUCKS
TO THE TEXAS HIGHWAY SYSTEM**

Julie Fesenmaier
Dock Burke

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Dock Burke

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

Executive Summary

The Surface Transportation Assistance Act (STAA) of 1982 established a nationally uniform maximum limit to the length, width, and weight of commercial vehicles. In accordance with the act, a national network of routes that could safely and structurally accommodate the larger and heavier vehicles was established. The objective of this study was to develop procedures for identifying truck routes and for determining accessibility to the selected network.

This goal was accomplished in two stages. First potential demand for access to the network was identified. Emphasis was placed on counties that have large economic and demographic bases, and on areas that are currently small yet have exhibited recent growth trends. Two spatial trends are evident:

- High growth counties are located adjacent to the large urban areas.
- A large portion of the high growth counties are spatially contiguous to the I-35 and I-45 corridors.

The second stage focused on the network or the spatial structure of routes. A hierarchy of four coverage patterns was evaluated in terms of the amount of demand satisfied by the network. The four networks varied in degree of complexity:

- 1) the most skeletal network comprised of the highway segments that outline the Texas Triangle,
- 2) the Interstate network,
- 3) a network defined by the FHWA made up of the Interstates and some Federal-Aid Primary (FAP) highways, and
- 4) the most complex and extensive network comprised of the Total FAP highways and the Interstate network.

A coverage index was calculated in order to estimate the amount of demand that is not served by the system at each level of the hierarchy. The physical extent of each coverage pattern was evaluated in terms of the average distance from demand centers to a facility. Results show that the Texas Triangle and the Interstate Networks, (numbers 1 and 2 above), cannot provide adequate access to a facility for all Texas counties. In contrast, the FHWA and the Total networks (numbers 3 and 4 above) can provide reasonable access to all of Texas. The FHWA network is accessible within 20 miles to 84 percent of all counties, and the Total network is accessible within 11 miles to 84 percent of all counties.

This procedures presented in this report should be a useful decision making tool for SDHPT to evaluate highway networks for the purposes of designating segments accessible to the larger/heavier commercial vehicle classes.

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Introduction

The Surface Transportation Assistance Act (STAA) of 1982 increased the maximum allowable size and weight dimensions for commercial vehicles. The Act required states to develop a policy for providing access to the larger/heavier trucks on State highways. The goal of this research report is to define areas within the State that will need access to a facility that is open to this type of vehicle traffic. The American Trucking Associations, acting as a representative of the trucking industry, is taking the initiative to fight for liberal access laws. States are obliged to devise a solution to the access problem that simultaneously considers the safety and design aspects of the facility, as well as the fundamental needs of the trucking industry. This report is designed to provide information that SDHPT administrators can use in fitting policy recommendations to benefit the people of Texas and the trucking industry.

Surface Transportation Assistance Act of 1982

The Surface Transportation Assistance Act of 1982 was designed to raise funds, via vehicle use taxes, to improve and maintain the nation's highways. An underlying emphasis of the bill was to shift the burden away from the smaller vehicles which have traditionally been known to subsidize use of the highways by heavy trucks. Some of the original tax laws have since modified by the Omnibus Deficit Reduction Act (ODRA) of 1984. The total tax package of the STAA plus the recent modifications includes:

- o Sales tax on new trucks and trailers was increased from 10 percent wholesale to 12 percent retail
- o A total increase in heavy vehicle use tax up to 700 percent by 1988
- o A six cent diesel differential to be paid by trucks
- o A minimum of \$550 annual use tax on trucks over 55,000 pounds
- o A tire tax of 9.75 cents per pound to 50 cents per pound for tires over 90 pounds

Additionally, Congress passed several provisions in the Act that dealt with the maximum allowable length, width, and weight of commercial motor vehicles. The maximum 80,000 pound gross vehicle weight (GVW) limit was established nationwide. Prior to the Act, three states, (Arkansas, Illinois, and Missouri), did not permit the 80,000 pound gvw vehicles. The STAA set national length standards for commercial vehicles to 48 feet for singles and 28 feet for doubles. Federal width restrictions increased from 96 inches to 102 inches. Prior to this legislation, States had imposed different weight and size limits which impeded the free flow of interstate traffic. For this reason all states had to allow the new vehicle size limits on all Interstate and designated Federal-Aid Primary (FAP) highways or risk losing federal highway funds. The Secretary of Transportation was charged with designating the FAP system. In June 1984, the Federal Highway Administration published the final rule for the interim national highway network. This system includes 60 percent of the Nation's primary route mileage, specifically, 42,000 miles of interstates plus approximately 139,000 of FAP routes. (Parker, J., 1984, 1).

It is left to each State's initiative to modify the FAP system within its borders to meet with its route selection criteria. It is thus important for States to develop procedures for adding and deleting routes. The FHWA received diverging responses from the States; for example, 13 States (including Texas) recommended that 100 percent of their FAP network be accessible to heavy vehicle use; six States recommended over 50 percent; 11 States recommended from 10 to 50 percent; and 22 States recommended from 0 to 10 percent of the FAP highway system (Federal Register, June 5, 1984, 23305). Traditionally, the western states have had more liberal size and weight laws. This is demonstrated by the distribution of the ratio of designated routes to the total FAP state network (Parker, J., 1984, 1).

In addition to co-operating with the Federal government to develop the "National Network", states must co-operate with the trucking industry to provide "reasonable" access from the designated routes to terminals, facilities for food, fuel, and rest; and for household good carriers to points of loading and unloading. Response from the states to this matter is varied. For example, Iowa has established a five-mile limit away from the designated route (Walton et al., 1982, 3). Many states, however, are not committing to one set maximum, but issue permits on a case by case basis.

Some Effects of Larger and Heavier Vehicles on Highways

The larger size dimensions specified by STAA 1982 are favored by the trucking industry. The lack of uniform size and weight regulation across the states, prior to STAA 1982, has hindered the assimilation of larger trucks into the vehicle mix. It has been shown that economies of scale can be realized with increased utilization of the larger/heavier trucks (Brown, et al., 1978, Chow, 1978). Some advantages are:

- 1) **Reduced operating costs** - overhead and indirect costs, driver wages and subsistence costs, repair servicing and lubricating costs. These operating cost reductions accrue over time, and the savings are not equitable across all vehicle classes.
- 2) **Weight limited carriers** - realize 15 to 21 percent more freight per shipment.
- 3) **Less-Than-Truckload (LTL) carriers** - achieve economies because the larger vehicles can haul more small shipments within one unit. In contrast, the Truckload (TL) carriers will not accrue significantly greater benefits since less than 10 percent of the total ton-miles hauled by TL carriers have been subject to the previous vehicle size constraints. Due to the more liberal size restrictions in the Western

States, many truck fleets have already accepted the new carriers. It may be assumed that with the uniform laws and the benefits gained from the larger vehicles, the trend towards the use of the larger vehicles will continue.

Some Safety and Structural Considerations

Accident and safety issues are closely related to the structural/geometric characteristics of the road segment. An area of concern is the capability of the current highways structures to accommodate the new vehicle dimensions. The most apparent road design characteristic that is an important determinant to the safe operation of the larger vehicles is the lane and shoulder width proportions. Wright (1984), reported in his study for the Georgia State Department of Transportation, that for conventional size (96-inch wide, 45-foot long trailers) vehicles on two-lane U.S. highways, the overall accident rate exceeded the rate for all classes of vehicles by a factor of 2.8. Furthermore, the fatality rate for large trucks on those highways was approximately 15 times that of all vehicles. In support of the new 102-inch width restrictions, there are operational benefits to the 102-inch wide vehicle. Studies reporting on the safety of the 102 inch wide carriers are limited, yet it is generally agreed that there are several operational characteristics that make these vehicles somewhat safer on multi-lane highways. Wright (1984) reported on improved tire and braking performance, also greater overall stability. A study by the University of Michigan Safety Research Institute demonstrated that 102-inch tanker trucks with longer axles were 14 percent more resistant to rollover than were 96-inch wide tankers (after Federal Register, June 5, 1984, 23312).

The increased length limits generate some difficulties to maneuverability. With multiple trailer truck combinations there are problems of swerving and whipping. Generally, there are not serious problems under normal conditions.

However, hazardous weather and operations at higher speeds will have a negative effect on maneuverability. (Saunders, J. and D. Burke, 1982, 13). Also, the longer length requires a larger turning radius, particularly at on/off ramps and within urban areas. Other significant problems, such as increased probability of off-tracking and longer required passing distances, need consideration. Weir et al. (1971) report on the problems of windblasts to other vehicles on the road segment can be serious. This problem is not as grave in the case of multi-trailer trucks because the flow of air between trailers offsets the crosswind to the passing vehicles Saunders and Burke (1982) report that on a multi-lane highway, the longer trucks do not require greater stopping distances, as long as all equipment is functioning properly.

The increased GVW limits effect the weight/horsepower ratio which is critical in determining the acceleration rate of the vehicle. This factor increases the passing time and the distance required to execute a pass. This is a critical problem on a two-lane highway. The lower weight/horsepower ratio also effect the critical length of grade that must be adjusted to accommodate the speed reduction.

To summarize, Burke and Walton (1978) identify the highway design elements that need to be evaluated in terms of their ability to accommodate the larger vehicle dimensions. The list of design principles is divided into three categories:

- 1) Design Elements
 - o Stopping sight distance
 - o Passing sight distance
 - o Pavement widening and curves
 - o Critical length of grades.
- 2) Cross Section Elements
 - o Lane width
 - o Width of shoulders

- 3) Intersection design elements
 - o Minimum design for sharpest turns
 - o Width of turning roadways
 - o Sight distance at at-grade intersections
 - o Median openings

With consideration to the above design principles, the State of Texas has determined the criteria for selecting highways which may not be capable of accommodating the larger/heavier loads. The following is a list of road characteristics that may restrict a road from the "National Network"; (Thomason, Henry A. Jr., Personal Communications, January 26, 1984):

1. All roadway sections with lanes 9 feet wide or less.
2. All roadways with drainage or overpass structures 20 feet or less overall width.
3. All two lane highways with:
 - A. 10 foot lanes and
 - B. truck traffic 10% or greater and
 - C. ADT of 2000 or greater
4. Other highways which the District personnel are unsafe for wide loads due to climate, roadway geometry, etc.

It is evident that there are many structural and design features that need upgrading to accommodate the larger/heavier vehicles that are becoming prominent in the general vehicle mix. Until structural improvements can be financed and completed, it is important to identify highways that can presently serve the larger vehicles.

The intent of this research report is to identify the centers of demand and to match the Interstate and FAP network to those centers. The following chapter will describe the demographic and economic trends with Texas. Chapter 3 will identify a highway network that corresponds to those trends.

Demand Surface Analysis

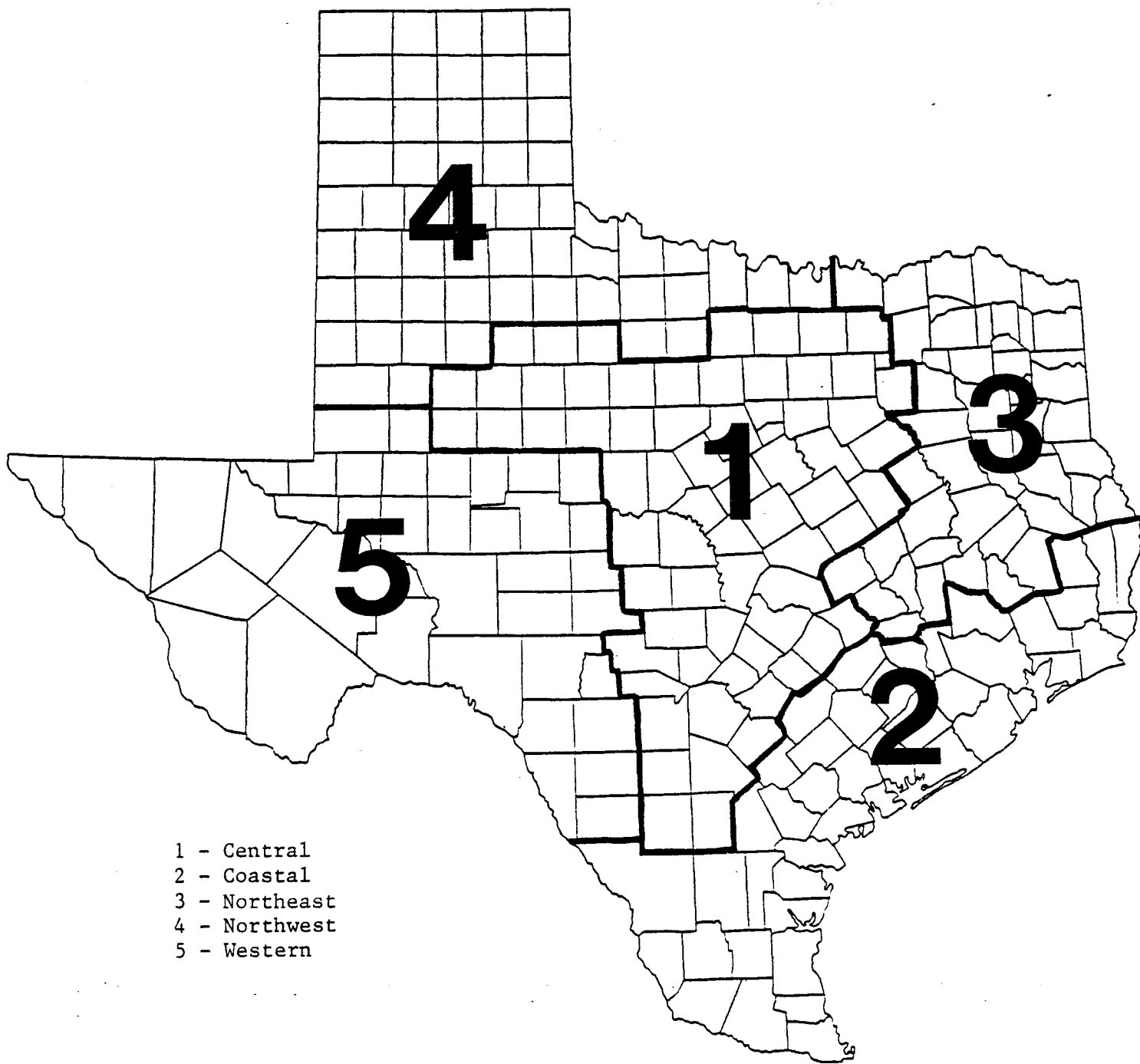
Transportation planning needs to reflect the regional economic trends of the surrounding planning area. Hence, it is important to identify the spatial patterns of demand for use of intercity thoroughfares. Demand Surface Analysis incorporates many demographic and economic indicators to represent one comprehensive scenario that is able to manifest the direction of growth in the the State of Texas. The demand surface is a product of a multivariate statistical analysis which calculates a new dimension based on a wide set of socio-economic variables. The new dimension is used as a surrogate of demand. The demand surface is a graphical representation that describes the state within a framework of this demand dimension.

Data management for the Demand Surface Analysis was accomplished in two stages. First, county data were examined to define patterns exhibited across the State in general, and then, for comparison, to define patterns at the local or regional level. The State of Texas was divided into the five planning regions as used by the Texas SDHPT for its 1982 twenty-year Operational Planning Document. (Figure 1). Examining growth by planning regions allows for a more comprehensive understanding of economic activities at a county/regional level. However, analytical comparisons cannot be made across regions unless all the data is considered simultaneously; hence, the need for analysis also at the statewide level.

Data Description

The basic data for the Demand Surface Analysis are population, income, employment/unemployment, and property value reports. **Population:** 1970 and 1980 population data were acquired from the census. In addition, Texas Department of

PLANNING REGIONS



Health population projections were used for population estimates for the years 1985, 1990, 1995, 2000. These population projections account for growth that is attributed to both natural increases and to migration. These projections should be considered upper boundary level since they are based on the assumption that growth in Texas will follow a similar trend to that experienced between 1970 and 1980. The nature of these predictions did not effect the Demand Surface Analysis, since the numbers were not considered in absolute terms, but rather, for comparison purposes, in ones that are relative. In other words, population growth was compared on a county by county basis, in order to highlight regions that show a strong growth trend. Consequently, demand surface analysis can only be used as a descriptive tool. No further statistical inference was made from these Department of Health predictions. Also, a cumulative average population change from 1970 to 1980 was calculated to identify population growth solely in relative terms.

Employment/Unemployment: Employment and unemployment totals were collected from the Texas Employment Commission. Yearly employment data from 1972 to 1983 were the basis for time series analysis to forecast employment for the years 1985 and 1990. Due to the lack of adequate historical data, forecasts beyond 1990 could not yield reliable estimates. Ideally more than 12 data points are needed for a time series analysis which requires an estimation of a relatively large number of parameters. The derived predicted values were be used for description and not inference. A time series regression analysis, was used to forecast the employment data. In basic terms the model shows that employment is dependent on patterns of the previous year. The resulting estimates were imputed into a demand surface that can be used to reflect the direction of growth in the state.

Two types of models were calibrated to the time series data. The linear model assumes growth in a constant linear fashion; whereas, the quadratic model depicts a parabolic form. The linear model can be mathematically expressed as:

$$x_t = b_0 + b_1t + e_t \quad 2.1$$

The quadratic model can be written;

$$x_t = b_0 + b_1t + b_2t^2 + e_t \quad 2.2$$

The R square derived from the calibration of these models describes the relationship between time and the employment statistic. R square was accepted when greater than .5000 at the .05 significance level. A high R square indicates that a relationship does exist and consequently the predicted values should be good, provided that the existing linear or quadratic trend continues.

The R squares obtained from the regression models represent the minimal variance that could be explained. This type of analysis requires the testing of autoregressive parameters in order to determine the degree with which past values are a function of future estimates. The autoregressive parameters were included in the model if the significance level was less than .2. This model can be written as:

$$x_t = b_0 + b_1t + b_2t^2 + a_0 + a_1x_{t-1} + a_2x_{t-2} + a_3x_{t-3} + e_t \quad 2.3$$

If this model followed a linear trend then b_2t^2 equals zero. The first autoregressive parameter (a_1x_{t-1}) if significant, represents a correlation between the current employment figure and that of the previous year. If a_2x_{t-2} is significant, then the current year is correlated with the second prior year. And if a_3x_{t-3} is significant, then the current employment statistic is correlated with the third prior year. The combined estimation of the autoregressive parameters and the regression parameters allows us to understand the nature and strengths of the relationship between the independent variable (time) and the dependent variable (employment).

In general, the linear model best fit the total employment figures. Significant R squares could not be derived from the quadratic model, and thus forecasts were solely based on the linear trend. This suggests that total employment in Texas can be described by an upward trend.

Unemployment totals were imputed into the analysis for 1980, 1982 and 1983. Predictions for unemployment could not be statistically simulated, due to the unavailability of comparable historical data. The Demand Surface Analysis is extracted from indicators that most likely reflect a positive correlation with growth. However, the unemployment indicator is the only one that is negatively correlated to growth and thus, must be interpreted separately from the other variables. As is apparent, the unemployment variable is an indicator of no growth or economic stagnation.

Property values: The 1970 and 1980 property value data were published in the Annual Reports to the Comptroller of Public Accounts. The total value figures are the sum of two categories, "Land Assessed in Acres" and "Town Lots". Total appraised value is the total market value of both types of property. All other properties such as rolling stock, telephone/telegraph lines, etc. were not included in the total figure.

Income: Effective Buying Income (EBI) by county for the years 1977 and 1982 were collected from Sales & Marketing Management. EBI represent the general ability to buy. More specifically, it is total personal income less personal tax and non-tax payment, e.g., fines, penalties, or social insurance. A five year cumulative average income change per year (between 1977 and 1982) was calculated to illustrate relative growth within the State.

Table 1 summarizes the 18 variables that were collected for each county in the subsequent analysis.

Table 1: DATA INPUTS FOR THE DEMAND SURFACE ANALYSIS

- 1) Population 1970, 1980
Forecasts 1985, 1990, 1995, 2000
- 2) Employment 1980, 1982
Forecasts 1985, 1990
- 3) Unemployment 1980, 1982, 1983
- 4) Property Values 1970, 1980
- 5) Effective Buying Income 1982
- 6) Income Change between 1977 and 1982
- 7) Population Change between 1970 and 1980

Methodology

The multivariate methodology to derive the demand surface was conducted in three steps: 1) factor analysis for data reduction; 2) cluster analysis for data classification; and 3) multivariate analysis of variance for data verification. This procedure was used to develop categories that are based on the total dataset, that is, one representing the entire State of Texas, and on a segmented dataset representing one planning region at a time.

Analysis for the State of Texas

Factor Analysis: This calibration results in a principal component analysis, whereby each dimension is a linear combination of the original variables. The principal components are also referred to as factors or dimensions. The 18 variables were reduced to three dimensions, and thus, the multicollinearity that naturally exists in data of this nature was eliminated. The result is a smaller set of composite dimensions or factors.

The prior communality estimates were used to define factors that were significant in explaining the variance of the original variables. More specifically, the latent root criterion identified significant factors based on the eigenvalues. When factors do not have eigenvalues greater than one, then it may be assumed that those factors cannot explain the variance of a least one variable, and thus, those factors can be disregarded. In this analysis three factors were found significant. The following table summarizes the cumulative variance

explained by the three factors for the State considered as a whole, and for the five planning regions.

Table 2: CUMULATIVE VARIANCE EXPLAINED BY PLANNING REGION AND STATEWIDE

Factor	Total State	Central	Coastal	NEast	NWest	West
1	.7072	.7145	.7193	.6538	.6582	.6980
1 & 2	.8531	.8405	.8694	.7884	.7848	.8414
1,2,& 3	.9646	.9354	.9610	.8760	.8683	.9246

For all planning regions together, the first three factors collectively explain 96.46 percent of the variance contained in the 18 variables. The first three factors in the Northeast and the Northwest Planning Regions, do not explain as much of the variance of the variables, as in the other planning regions. This would suggest that in those planning regions the amount of variance is greater, and consequently the three factors cannot summarize the information contained by the variables as well as in the other planning region.

Each factor consists of factor loadings which represents the correlation between the original variables and the linear combination of the variables. Squaring the factor loadings yields the percent of variance explained by the factor. In instances where multicollinearity obviously exists between the variables, it is necessary to orthogonally rotate the factor pattern which re-distributes the variance. This rotation technique minimizes the specific variance (that is associated with unique variables) and error variance (which is random variance due to sampling procedures, calibration inaccuracies, etc.).

In all five planning regions and for the statewide analysis, the factor loading patterns are similar. Table 3 lists the factor loadings for the statewide analysis.

Table 3. ROTATED FACTOR PATTERN

	FACTOR1	FACTOR2	FACTOR3
POP70	0.98580	0.03470	-0.00909
POP80	0.99455	0.03393	0.02339
POP85	0.99505	0.03593	0.03815
POP90	0.99377	0.03753	0.05597
POP95	0.98935	0.03964	0.07286
POP20	0.98252	0.04034	0.08949
PCHANGE	0.08421	0.04338	0.91793
EMP80	0.99512	0.00841	-0.01027
EMP82	0.99567	0.00696	-0.00734
TEMP85	0.99614	0.00180	-0.00502
TEMP90	0.99603	0.00539	-0.00241
UNEMP80	0.00298	0.85642	0.01853
UNEMP82	0.03159	0.96042	0.06367
UNEMP83	0.03208	0.95165	0.05227
PRPV70	0.98718	0.00169	-0.01455
PRPV80	0.94978	-0.00276	0.04104
INC82	0.99756	0.00370	0.02807
INCHANGE	-0.01832	0.07443	0.91704

VARIANCE EXPLAINED BY EACH FACTOR

FACTOR1	FACTOR2	FACTOR3
12.730031	2.577359	1.712106

Three dimensions can be identified, factor 1 loads high with population totals (1970, 1980, 1985, 1990, 1995, and 2000), Employment (1980, 1982, 1985, and 1990), property values (1970 and 1980), and income (1982). These variables all relate to total figures for economic or demographic magnitudes for each county, hence, this factor dimension is referred to as the Size factor. Factor 2 loads high with the unemployment statistics (1980, 1982, and 1983) and is referred to as the Unemployment factor. Since this dimension represents a negative correlation to growth it was expected that the factor analysis would isolate and combine the unemployment variables into one dimension. Finally, factor 3 summarizes the change variables, population change and income change. By

emphasizing the comparative level of growth, rather than growth in absolute totals, factor 3 can be referred to as the Growth potential factor.

Cluster Analysis: Cluster analysis is a classification technique that can be used to display and summarize data by describing the natural clusters that are known to exist within the dataset. Anderberg offers several philosophical guidelines to the utilization of cluster analysis (Anderberg, 1973, 22-23). Mainly, he postulates that clustering methods simultaneously impose a structure on the data, and reveal the structure or "natural groups" that exist in the data.

For the following analysis, the clustering routine organizes economic and demographic variables into a form that highlights the growth aspects of the counties of Texas. The 254 counties were segmented into meaningful groupings that manifest similar characteristics for the three factor dimensions described above. The factor scores produced by the factor analysis for each county were the input to this cluster analysis. The clustering algorithm is designed to minimize the within group variance and concurrently maximize the between group variance. This technique provides a valuable approach to arrive at a useful description of the sample or counties and to discover unsuspected clusterings. The product of this cluster analysis is an arrangement of counties according to past and predicted demographic and economic trends.

The maximum number of clusters that are to be used in the cluster analysis must be specified a priori. This initial decision appears to be subjective in nature. There is no reliable statistical method to determine the optimal number of clusters that will best classify the data. The clustering algorithm computes the cubic clustering criterion and some analysts (Everitt, 1977, Anderberg, 1973) argue that the breakpoint of the cubic clustering criterion is an indicator of the "best" cluster pattern. This statistic follows a linear trend until some optimal cluster pattern is achieved. A break in the clustering criteria

suggests that at the point the different group or clusters are clearly distinct. There can be several breakpoints and therefore this statistic should be used in conjunction with a priori theory. Cluster analysis is a descriptive tool; hence, rational theory based on a priori information about the counties is the usual criterion for determining the best descriptive cluster pattern.

Texas has a wide diversity of economic and demographic characteristics. Initially, it was assumed that a four cluster solution would best describe the natural groupings within the diverse dataset. The four clusters would group counties according to the factors: Size, Unemployment, and Growth potential as well as one cluster representing counties that score slightly below average on all three factors. This latter group would have, in all cases, the largest membership, and thus, it can be referred to as "average".

To evaluate the actual cluster pattern, computer runs specifying three to ten clusters were analyzed. This provided some additional insights to the cluster pattern. The cluster history revealed that, based on the cubic clustering criterion a five cluster solution did a better job in describing the demand surface. When five clusters were specified, Harris County was itself a cluster on the basis of its extremely great association with factor 1, size. When four clusters were specified, Harris and Dallas Counties were grouped together. Bexar and Tarrant Counties were smoothed along with those counties that were classified as having below average or average Size, Unemployment, and Growth. When six or more clusters were specified, Harris, Dallas, and Starr Counties each comprised an individual cluster. The other counties maintain the same pattern as in the five cluster solution. Based on this information, it is postulated that a five cluster solution provides the best description of the demand surface. The data were categorized without hiding the growth trends of counties that would otherwise be overshadowed by the large size Harris County.

Table 4: CLUSTER MEANS, TOTAL STATE DEMAND SURFACE

Cluster	Members	Factor 1 "Size"	Factor 2 "Unemp."	Factor 3 "Growth"
1	3	4.82032	-0.18667	-0.42226
2	29	-0.07723	-0.33528	1.95030
3	3	-0.18840	5.93827	-0.38959
4	1	12.33863	-0.19587	-0.01558
5	216	-0.11109	-0.03396	-0.25064

Table 4 identifies the clusters according to the location of the cluster means in reference to the three factors. The five clusters contain counties that:

- 1) Have relatively high population, income, employment, and property value totals (cluster 1).
- 2) Have experienced relatively high population and income growth (cluster 2).
- 3) Have experienced high unemployment trends (cluster 3).
- 4) Have extremely large population, income, employment, and property value totals (cluster 4). And
- 5) Score slightly below average on the three factor dimensions (cluster 5).

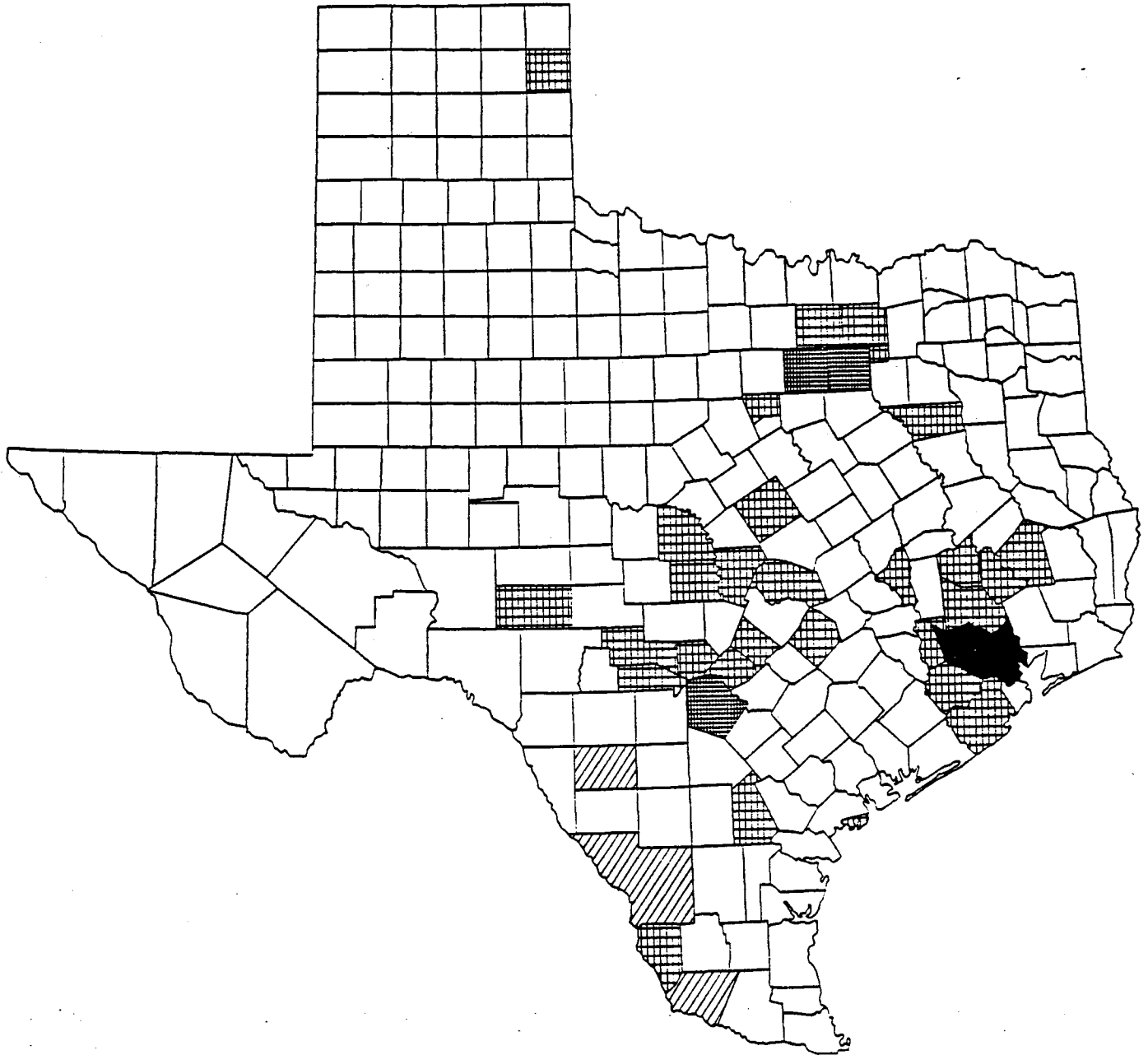
Figure 2 illustrates the spatial pattern of the cluster analysis.¹

The distances between the cluster means of clusters 1 and 4 are substantial. It is evident that cluster 4 with a membership of only one county, represents an outlier to the entire dataset; more specifically, Harris County (cluster 4) is unique and must be treated as an individual cluster. A complete profile of the county indicates that unemployment rates are slightly below average which means that actual unemployment rates are low. Growth trends are positive, yet insignificantly low. Cluster 1 is also closely associated with factor 1 and also has low unemployment figures. In contrast, however, the

¹Note Caldwell and Maverick Counties were not included in the analysis due to missing data.

Figure 2

DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS OF TEXAS



LEGEND: CLUSTER



1 FACTOR1B SIZE
3 FACTOR2 UNEMP
5 AVE LOADINGS



2 FACTOR3 GRTH
4 FACTOR1A SIZE

growth trends of the three counties that represent cluster 1 are somewhat negative. The 29 counties comprising cluster 2 can be labeled as the high growth counties of the state. Growth has been defined as relative increases in population since 1970 and in effective buying income since 1978. The majority of the Growth counties are located adjacent to the major metropolitan centers of Houston, San Antonio, and Dallas/Ft. Worth. These are tied to the urban corridor defined by the Interstate Highways. Hemphill County in the Texas Panhandle and Sutton County in West Texas are not associated with any urban growth trends yet are classified with cluster 2 due to the rise in oil and gas production within the past five years. Also, in cluster 2 the size factor is slightly lower than average; and as would be expected, cluster 2 has little unemployment.

The unemployment factor scores high with cluster 3. This classifies three counties that are located near the Mexico national border. The border area is the most economically depressed in the state since, its two most revenue generating activities, tourism and oil production, have declined.

Lastly, 85 percent of all counties are classified in cluster 5. The cluster means are negative with relatively low population, average unemployment rates and negative mid-range growth rates. Counties containing 72 percent of the total MSA's are represented by this cluster. With this cluster solution, it appears that the Demand Surface is not complete since these MSA's are generator of much of the large truck traffic in the state. The regional analysis, then, is used to exhibit a more accurate and edifying demand surface; since the MSA's play a more dominant role on the regional economy.

Multivariate Analysis of Variance: (Manova) A model was used to test the hypothesis that all mean vectors of the dependent variables are equal across all groups. In other words, this model was applied to the clustered data to determine whether a real difference exists between clusters. The model first

tested the degree to which each factor contributed to the differentiation among clusters, and then how all three factors, simultaneously contributed to the clustering. The F approximation that tested the hypothesis was found significant at the alpha = .001 level. Because there are no statistical tests to verify the clustering algorithm, the Manova procedure demonstrates a degree of confidence in the cluster pattern.

Planning Regions

When data in the above analysis were analyzed for the State as a whole, many MSA's and other regional irregularities were masked by the averages. For this reason, separate regional analyses were undertaken. The step by step methodology described in the previous section was followed for each planning region. This section, then, is an interpretation of the findings. The number of clusters specified in each planning region was either four or five clusters, depending on the demographic and economic heterogeneity of the region. By not holding the number of clusters specified constant by planning region, interpretation and hence understanding of each area are more complete.

Central Planning Region

The rotated factor pattern is similar to that derived for the State as a whole. The 18 variables were reduced to three dimensions that collectively explain 93.54 percent of the variance in the original variables. The size factor is the most powerful in that, alone, it captures 71.45 percent of the variance. (Table 5). The three dimensions are the basis for all further analysis in this planning region.

Table 5: CUMMULATIVE PROPORTION OF VARIANCE EXPLAINED, CENTRAL PLANNING REGION

Factor	Cummulative Proportion of Variance Explained
1	.7145
1 & 2	.8405
1,2, & 3	.9354

Five clusters are used to describe the Central Planning Region. This cluster pattern isolates Dallas County into one cluster due to its strong correlation with the size dimension. Bexar, Tarrant, and Travis Counties are classified together as secondary population centers. (Figure 3). For comparison, a four cluster solution would group the three largest counties based on the size factor (Dallas, Tarrant, and Bexar) to form one cluster while assimilating Travis County with the cluster representing the "average", cluster 3. Examining cluster plots and the cluster means table, it is evident that based on factor 1, Dallas County is very different from the other counties in the region. For this Demand Surface Analysis, it is desirable to isolate the outliers or extremely different counties; and thus, the five cluster pattern was found to best describe the Central Planning Region. (Table 6).

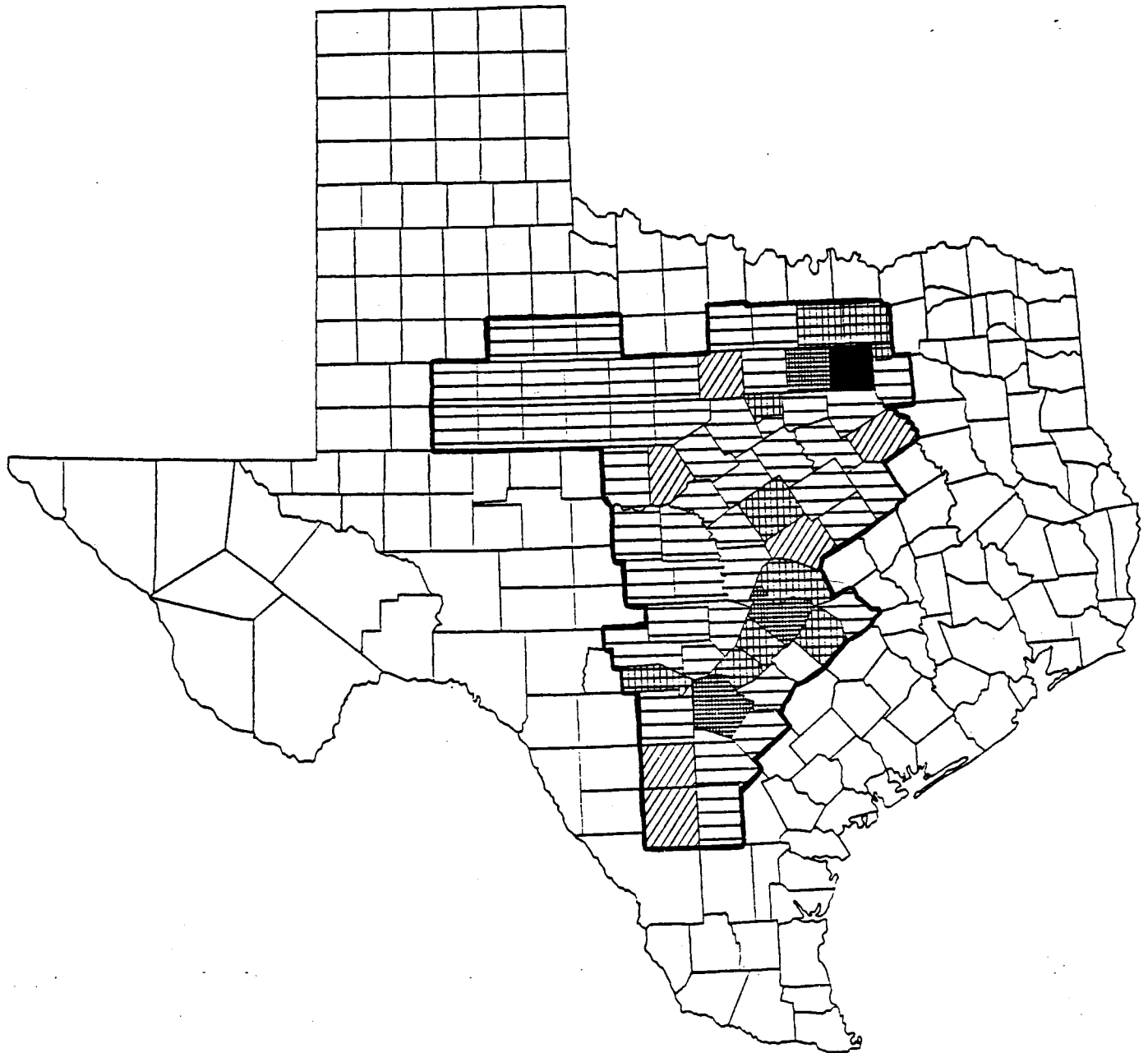
Table 6: CLUSTER MEANS, CENTRAL PLANNING REGION

Cluster	Members	Factor 1 "Size"	Factor 2 "Unemp."	Factor 3 "Growth"
1	1	6.482074	-0.401341	-0.500070
2	10	-0.078412	0.072159	1.778618
3	48	-0.236121	-0.321427	-0.322420
4	6	-0.315092	2.288293	-0.285654
5	3	2.508796	0.459490	-0.032007

Cluster 2 represents the 10 counties that are the high growth counties of the region. They are located adjacent to the population centers of San Antonio, Austin, and Dallas/Ft. Worth. All are similar in size and are differentiated because they have all experienced extremely high population growth since 1970 (above 25% per year). A population increase is usually followed by positive income change, and in this region the effective buying income in most of these counties grew in excess of 100 percent, per year between 1978 and 1982.

Figure 3

DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS CENTRAL PLANNING REGION



LEGEND: CLUSTER



1 FACTOR1A SIZE
3 AVE LOADINGS
5 FACTOR1B SIZE



2 FACTOR3 GROWTH
4 FACTOR2 UNEMP

Six counties are classified with the unemployment factor. To emphasize that this cluster pattern represents relative unemployment for this planning region alone, it was found that none of these counties were grouped into this category in the statewide analysis. The relatively high unemployment rates can be explained by the downturn in the national economy that was felt to a greater extent by the local business of these counties.

Seventy-one percent of all counties in this region are classified with Cluster 3. This cluster represents counties that score below average on all three factors; specifically, the cluster means are second to the lowest for the three factors. This cluster represents counties that, on a relative scale, have experienced little change and since this cluster is the largest, it can be referred to as "Average". A cluster with a similar profile is present in all the consecutive planning regions and is always the largest cluster. Tertiary MSA's, such as, Temple, Waco, and Abilene are classified with this cluster and regardless of the number of clusters specified, these MSA's are not isolated from this group. To maintain objectivity in this analysis, it is important to use the breakpoint of the clustering criterion as a guideline to specify the number of clusters to use. Thus the five cluster solution is accepted as the best descriptor of the region.

The multivariate analysis of variance verified the cluster analysis by demonstrating that the clusters are, in fact, statistically different. Also, each factor was shown to contribute to the cluster separation.

Coastal Planning Region

The factor analysis on this region's data showed a similar pattern as reported in the previous analysis. The three factors explain 96.1 percent of the original variance. Again, the size factor is most important, followed by the unemployment factor and then the growth factor. (Table 7). In this stage the multi-collinearity existing in the data set was removed; and thus, the

factor scores were able to be reliably imputed into the cluster analysis.

Table 7: CUMMULATIVE PROPORTION OF VARIANCE EXPLAINED, COASTAL PLANNING REGION

Factor	Cummulative Proportion of Variance Explained
1	.7193
1 & 2	.8694
1,2, & 3	.9610

Using the clustering criterion as a guide, it was determined that five clusters best describe this region. (Figure 4). The cluster means (Table 8) describe the profiles of each cluster with reference to the three factors.

Table 8: CLUSTER MEANS, COASTAL PLANNING REGION

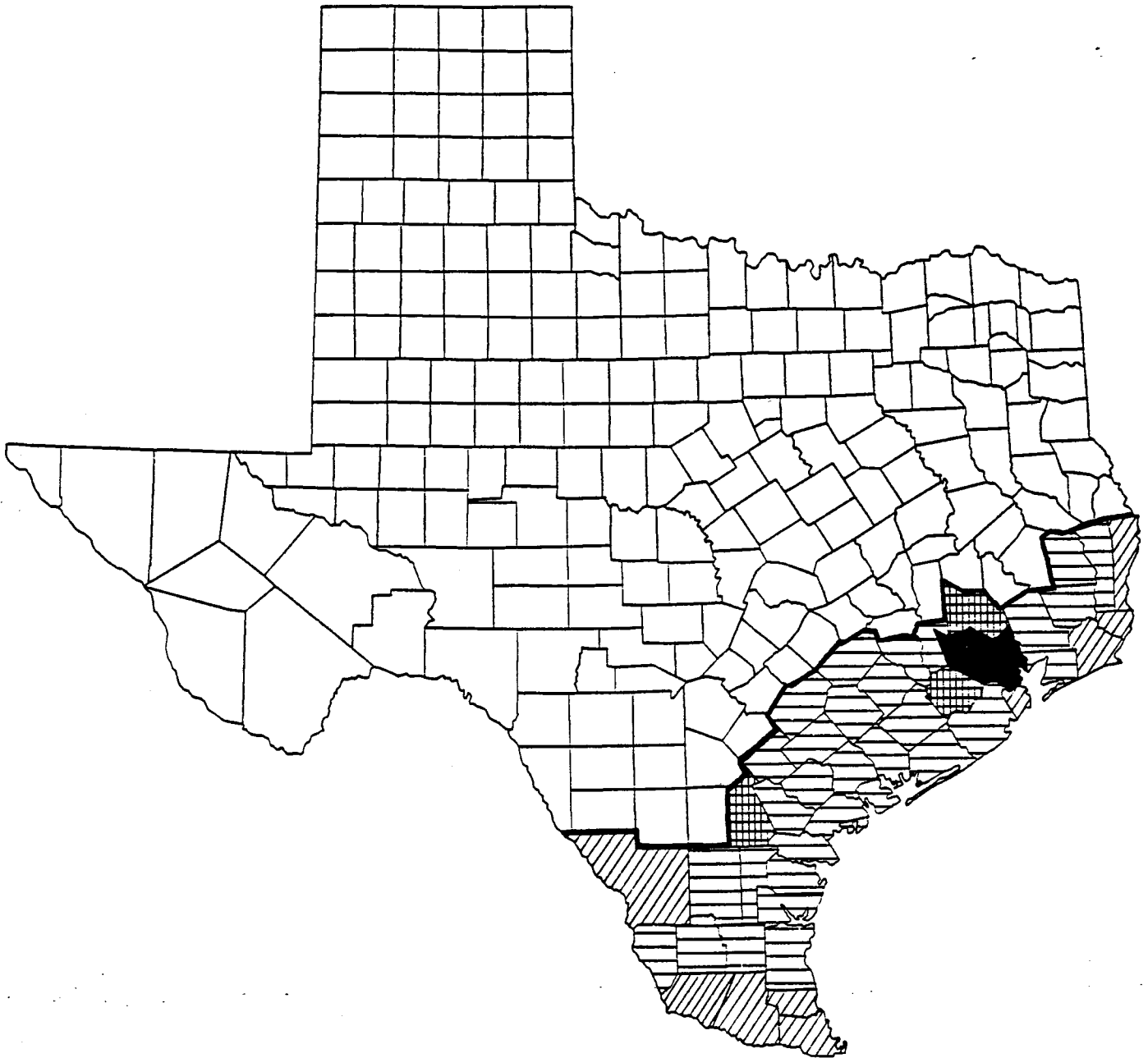
Cluster	Members	Factor 1 "Size"	Factor 2 "Unemp."	Factor 3 "Growth"
1	32	-0.203167	-0.318637	-0.139863
2	8	0.045247	0.892738	-0.471204
3	1	-0.179205	5.027560	0.462251
4	1	6.448121	-0.256145	-0.186885
5	3	-0.043179	-0.572315	2.656624

Two clusters (Nos. 3 and 4) are comprised of one county each, and judging from the cluster diagrams it is evident that these two clusters are outliers to others in this planning region. Specifically, the cluster means of Starr County (Cluster 3) are greatly affected by the unemployment dimension. Harris County (Cluster 4) is described by the size dimension. Both these counties were demonstrated to be unique in the analysis of the total state demand surface.

The second cluster in this planning region represents counties that are somewhat associated with the unemployment factor, yet not as much as those associated with cluster 4; however, unlike cluster 4, cluster 2 has experienced extremely low growth. Four of these counties, [Cameron, Hidalgo, Willacy, and Webb] are regionally tied to the economic recession along the Mexico border. Galveston, Jefferson, Orange, and Newton Counties are also geographically

Figure 4

DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS COASTAL PLANNING REGION



LEGEND: CLUSTER

- | | | | |
|---|------------------|---|------------------|
|  | 1 AVE LOADINGS |  | 2 FACTOR2B UNEMP |
|  | 3 FACTOR2A UNEMP |  | 4 FACTOR1 SIZE |
|  | 5 FACTOR3 GRTH | | |

associated along the East Texas Gulf of Mexico shore and the Louisiana State border. The economies of these counties are connected to the petro-chemical, shipbuilding, and lumber industries, all of which have experienced a slow down at the National level. Several MSA's are included in this classification, [Beaumont-Port Arthur, McAllen-Edinburg-Mission, and Brownsville-Harlingen]; yet were classified with cluster 5 (the average) in the total state demand surface.

The high growth counties, represented by cluster five, are Montgomery, Fort Bend, and Live Oak. The counties score low on the size variables and have low unemployment rates. Several counties are classified high growth on the total state demand surface yet are not classified as such at the regional level. This characteristic emphasizes the extreme growth factor scores that these counties have in relative terms to the other counties of this planning region. The counties excluded from the high growth cluster in this regional analysis are Aransas, Brazoria, Waller, and Zapata, all are classified with cluster 1.

Cluster 1 represents the majority of the counties, 32 in total. This cluster can be generalized as the "Average", having low factor scores for the factor one variables, the unemployment variables, and the growth variables. Other than three MSA's, Aransas, Brazoria, and Victoria, classified with this cluster, these counties are generally rural.

The Manova model confirmed that the five clusters do represent different profiles; and hence, it may be assumed that county trends are correctly classified.

Northeast Planning Region

The three factors representing the 18 variables of the Northeast Planning Region explain 87.6 percent of the variance. (Table 9). The factors do not summarize the data as well in this planning region as in the others. Most likely, the data behave in an irregular fashion, and due to averaging,

information is lost. The ability of the factors to summarize the data is somewhat reduced since the property value variables contribute less to factor 1, and the Growth variables (population change and income change) contribute less to factor 3. The first factor captures relatively less variance, 65.38 percent, than was explained by the first factor in the previous analyses.

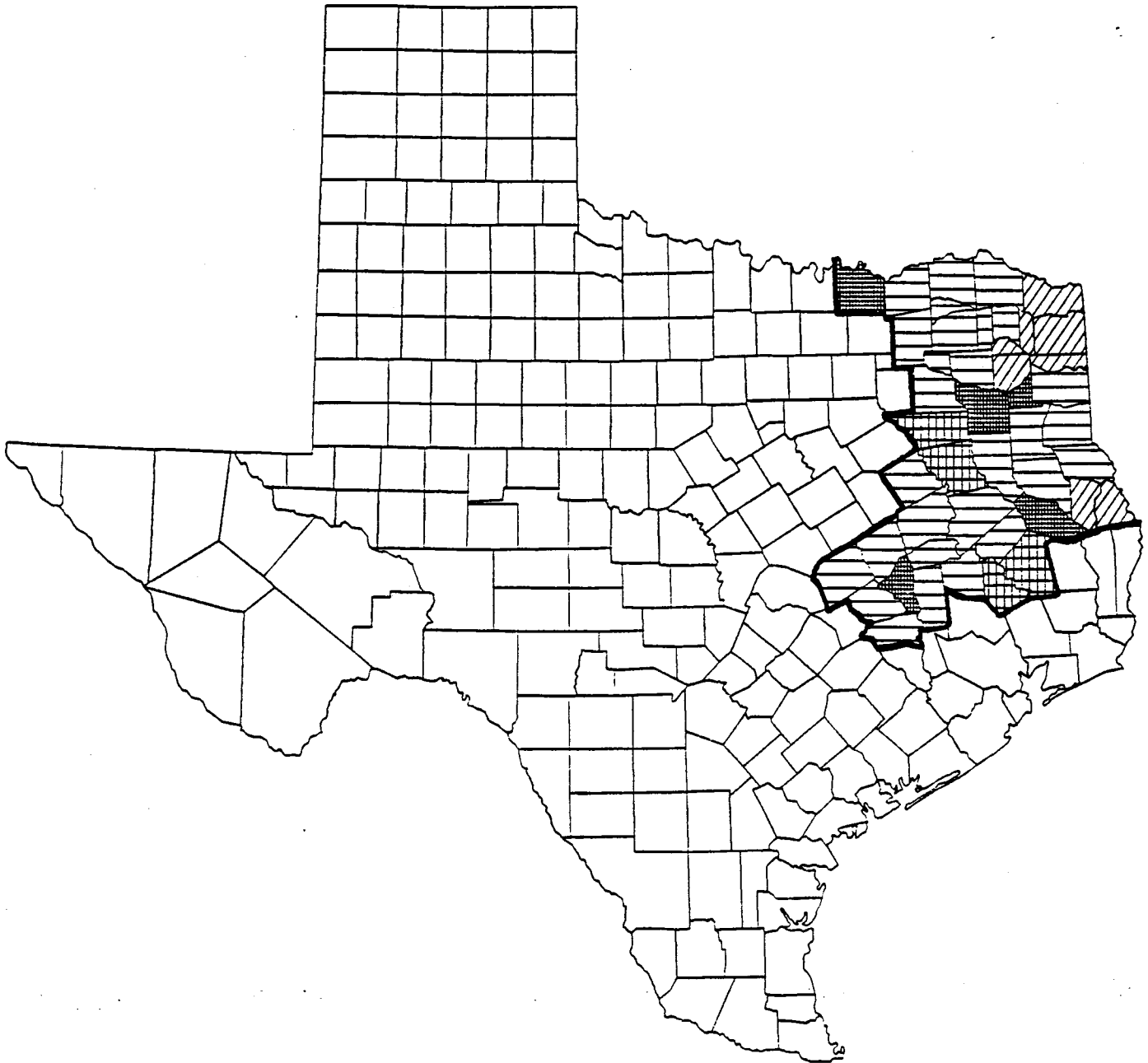
Table 9: CUMMULATIVE PROPORTION OF VARIANCE EXPLAINED, NORTHEAST PLANNING REGION

Factor	Cummulative Proportion of Variance Explained
1	.6538
1 & 2	.7884
1,2, & 3	.8760

A four cluster pattern was used to describe this planning region. (Table 10). Alternatively, a five cluster solution provided marginal insight to the trends of this region. The additional cluster closely resembled Cluster 1 of the four-cluster solution. The first cluster is the largest, comprising 28 counties. These counties have low population and other size dimension variables, low unemployment, and extremely low growth. The eight counties making-up cluster 2 have factor scores closely associated with the unemployment factor. Cluster 3 represents the counties closely interrelated with the size factor. Smith, Brazos, Grayson, and Longview Counties are all classified in this cluster and all are Metropolitan Statistical Areas. Angelina County, although it is not a MSA, is also classified in the cluster because in relative terms, Lufkin is associated to a greater extent with factor 1. It would be expected that Bowie County be classified with this group rather than with cluster 2; however the unemployment factor scores outweigh those of the size dimension. Finally, cluster 4 represents the high growth counties (such as San Jacinto and Polk Counties) where growth can be attributed to the urban spill-over from Harris County and to the development of recreational support activities in the area. (Figure 5).

Figure 5

DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS NORTHEAST PLANNING REGION



LEGEND: CLUSTER



1 AVE LOADINGS
3 FACTOR1 SIZE



2 FACTOR2 UNEMP
4 FACTOR3 GRTH

Table 10: CLUSTER MEANS, NORTHEAST PLANNING REGION

Cluster	Members	Factor 1 "Size"	Factor 2 "Unemp."	Factor 3 "Growth"
1	28	-0.312695	-0.534827	-0.283683
2	8	-0.361764	1.695834	-0.079289
3	5	2.302424	-0.048231	0.074919
4	4	0.034362	0.412410	2.050709

The Manova model upholds the cluster pattern. From the analysis it is evident that each factor contributes to the differentiation among groups.

Northwest Planning Region

The three-factor pattern explains 86.83 percent of the variance exhibited in the variables that describe this planning region. As in the Northeast Planning Region, the percent variance explained by factor 3 for the change variables is lower. The most powerful factor explains 68.82 percent of the variance. (Table 11).

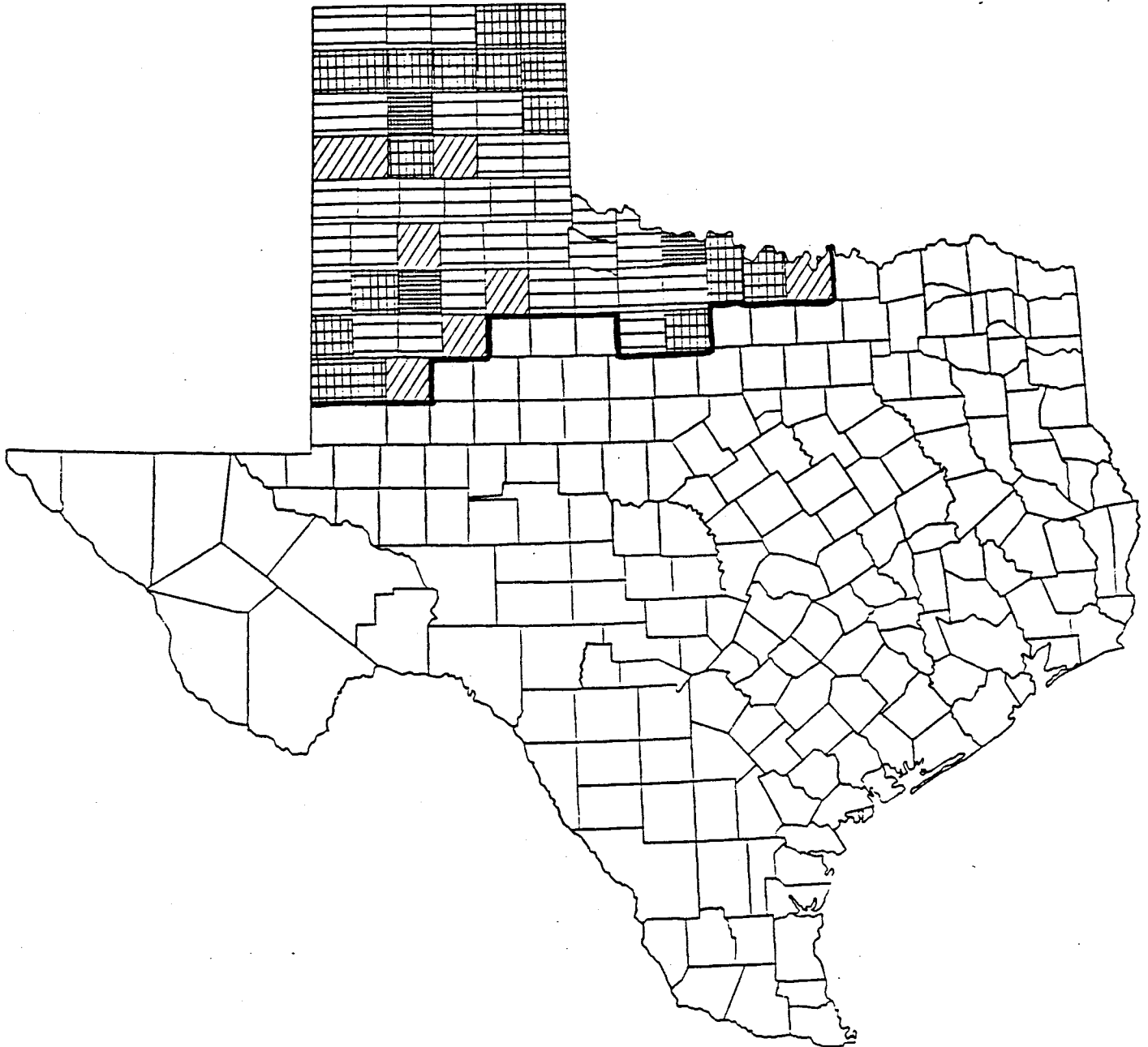
Table 11: CUMMULATIVE PROPORTION OF VARIANCE EXPLAINED, NORTHWEST PLANNING REGION

Factor	Cummulative Proportion of Variance Explained
1	.6582
1 & 2	.7848
1,2, & 3	.8683

A five-cluster pattern was adopted to differentiate between the relatively high growth counties, the positive growth counties, and the counties having relatively high unemployment. (Figure 6). For comparison, in a four-cluster solution the boundaries of these three categories were not clearly distinct and hence, a greater number of counties were aggregated into the Unemployment cluster. Also, because of the strong correlation between Hemphill County and factor 3 the cluster means were inordinately pulled up; and consequently, counties with relatively positive growth trends were excluded from the Growth cluster. The cluster means are reported in Table 12.

Figure 6

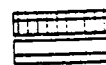
DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS NORTHWEST PLANNING REGION



LEGEND: CLUSTER



1 FACTOR2 UNEMP
3 FACTOR3A GRTH
5 FACTOR1 SIZE



2 FACTOR3B GRTH
4 AVE LOADINGS

Table 12: CLUSTER MEANS, NORTHWEST PLANNING REGION

Cluster	Members	Factor 1 "Size"	Factor 2 "Unemp."	Factor 3 "Growth"
1	7	-0.274526	1.878690	-0.041030
2	14	-0.110962	-0.508236	1.113523
3	1	-0.852663	0.630965	3.614501
4	31	-0.224939	-0.255027	-0.594732
5	3	3.766971	0.413118	-0.159975

Cluster 1 comprises counties that have the highest unemployment figures in this region. This cluster has 7 counties that are scattered throughout the region. There are two classifications that group the Growth counties, cluster 2 and cluster 3. Fourteen counties comprise cluster 2, they can be characterized as having relative high growth, low unemployment, and low population and other size dimension variables. Growth in these counties can be explained by either urbanization, as in the case of, Hockley, Randall, or Clay Counties, or by the increase of mineral production, such as in Lipscomb, Wheeler or Ochiltree Counties. Cluster 3 contains Hemphill County and is classified alone because of the recent trends the county has experienced. Hemphill County was also identified as a growth county on the total state demand surface. Unemployment figures are moderate and population (Size) is extremely low. Cluster 4, the largest group, represents 31 counties that are characterized by low values for the three factor dimensions. Cluster 5 identifies the three MSA's in this planning region. These three counties score relatively low on the Growth dimension, moderate on the unemployment dimension, and by definition, high on the size dimension.

The MANOVA verification of this cluster pattern was significant. Each factor was found to contribute significantly to the separation between clusters.

Western Planning Region

The factor pattern of this planning region does a better job explaining the variance of the original variables than in the previous two planning regions. Specifically, factor 1 explains 69.80 percent of the variance and the three factors together explain 92.46 percent of the variance. (Table 13).

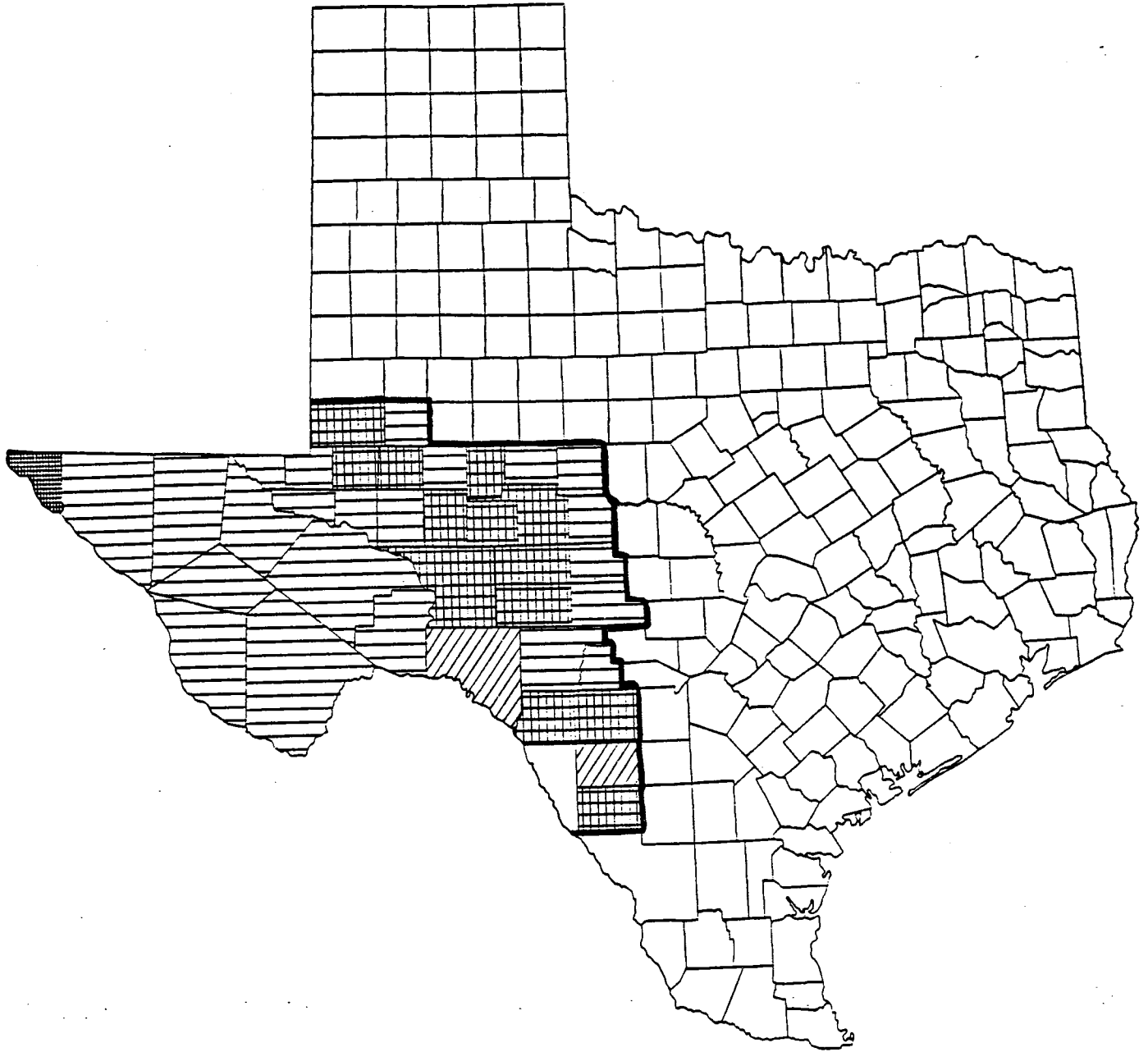
Table 13: CUMMULATIVE PROPORTION OF VARIANCE EXPLAINED, WESTERN PLANNING REGION

Factor	Cummulative Proportion of Variance Explained
1	.6980
1 & 2	.8414
1,2, & 3	.9246

Very little difference was found between the four cluster solution and the five cluster solution. For purposes of efficiency, the four cluster solution was used to describe this region. (Table 14). El Paso County is isolated in one cluster due to its strong correlation with factor 1. This cluster, like all those associated with the size factor, has moderately high means on the unemployment and low means on the on the growth factors. Cluster 2 is the "Average" cluster and has a largest membership of 22 counties. This group of counties have agricultural-based economies. Cluster 3 is made up of two counties that have a strong relationship to factor 2. Of these two counties, Zavala County was grouped with the unemployment cluster in the total state analysis. Val Verde County has relatively high factor 2 scores for this region, and is grouped in this cluster. Quite a large number of counties comprise Cluster 4 which can be described as the high Growth cluster. Most of these counties are economically tied to the oil production activities in the Permian Basin. (Figure 7).

Figure 7

DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS WESTERN PLANNING REGION



LEGEND: CLUSTER

1 FACTOR1 SIZE
3 FACTOR2 UNEMP

2 AVE LOADINGS
4 FACTOR3 GRTH

Table 14: CLUSTER MEANS, WESTERN PLANNING REGION

Cluster	Members	Factor 1 "Size"	Factor 2 "Unemp."	Factor 3 "Growth"
1	1	5.502623	0.753467	-0.189381
2	22	-0.175520	-0.293911	-0.644257
3	2	-0.504096	3.323807	-0.101869
4	13	-0.048692	-0.071926	1.120521

The cluster pattern was strongly supported by the Manova Model. The three factors were significant in formulating the clusters.

Conclusions

The demand surface analysis that was applied to the demographic/economic data structured the information in such a way that recent growth trends were highlighted and isolated. This analysis concentrated on these demographic and economic characteristics: 1) counties that have a large demographic and economic base; 2) counties that have experienced above average growth in population and per capita income; and 3) counties that have experienced increasing unemployment rates since 1980.

Based on the above multivariate analyses, six demand surface maps describing the demographic and economic trends were composed. The first demand surface utilized all the data for all counties simultaneously. The other analyses related to counties within each of five planning regions. The most evident feature of the total state demand surface was the high growth associated with the I-35 and I-45 corridor that links the three largest metropolitan areas in the state (The Texas Triangle). The demand surface of the Central Planning Region reinforces the total state analysis, in that, the Growth counties are generally aligned with the I-35 corridor. In particular, the regional growth is related to that experienced by the cities of Dallas/Ft. Worth, Austin, and San Antonio. This relationship also holds for the Coastal Planning Region in which the high growth counties of the region are linked to Harris County. Growth in

the Northeast planning region is not strictly connected to the counties with the large demographic/economic base, nor to the I-45 corridor. Furthermore, in this planning region, there is some regional unemployment which suggests some type of economic slowdown. The Northwest planning region shows the most diversity in the location patterns of the three characteristics. Likewise, growth trends in this regional analysis are not exclusively linked to the large urban areas. The highest Growth county, Hemphill County, is rural in nature. Finally, the demand surface for the Western region shows 13 mostly rural counties that are classified as high Growth counties, and all correspond to the oil production in the state.

In summary, growth has primarily been focused around the Texas Triangle and around counties that have a substantial demographic/economic base. If this trend is perpetuated, policy recommendations need to reflect this orientation. In addition, attention must be focused on the rural type counties that are presently small yet show above average evidence of growth.

In the following section, a methodology for identifying highways that will comprise the State network of designated highways will be developed. Briefly, this methodology will connect the centers of demand, that were identified in this section, to the final network. Whereas, the demand surface analysis was described by clusters that simultaneously represented the three factor scores, in the next chapter, demand will be described solely by the size and growth factor scores. The Unemployment factor, although it was a necessary input to the total demand surface, will be dropped from any further analysis, since it is not a feasible indicator of, in this case, demand.

The demand surface analysis provided valuable insight to the growth trends of the State. The derived size and growth factors will consequently become the surrogates of demand in the subsequent network analysis.

Spatial Structure of Routes

The previous chapter identified some economic and demographic spatial patterns that reflect demand for inter-city highways. The purpose of this section, then, is to match the demand patterns with an adequate network of roads. A hierarchy of four networks will be evaluated in terms of, how well they interconnect the major urban areas, and moreover, how well a particular network reaches all the demand points in the state. The most skeletal network is composed of the highways that define the Texas Triangle. The next level of complexity is the Interstate System, followed by the FHWA designated network. The final and most complex system is comprised of all the FAP highways, the Interstates and those U.S. highways that provide the only access to certain MSA's, for example, SH 6, and SH 288. This latter network will be referred to as the Total network. Figures 8 to 11 illustrate the network spatial structures. The road network maps were produced by computer graphic software available at Texas A&M University. The outline of the State is recognizable; however, to greatly minimize programming time the county and state boundaries were not included in the software package. Nevertheless, major highway segments can be easily identified because this computerized road data set is an accurate representation of Texas highway patterns.

Network Connectivity

The study of highway transportation networks can be described within the context of graph theory. Garrison (1960) modeled a portion of the U.S. Interstate system within the structure of a graph or matrix. Using graph theory to model transportation networks can reveal some topological properties of transportation systems. For example, each network can be assessed in terms of topological, rather than absolute, distance. In this sense, topological refers to the effect of a network on the accessibility or reachability of certain

Figure 8

TEXAS TRIANGLE

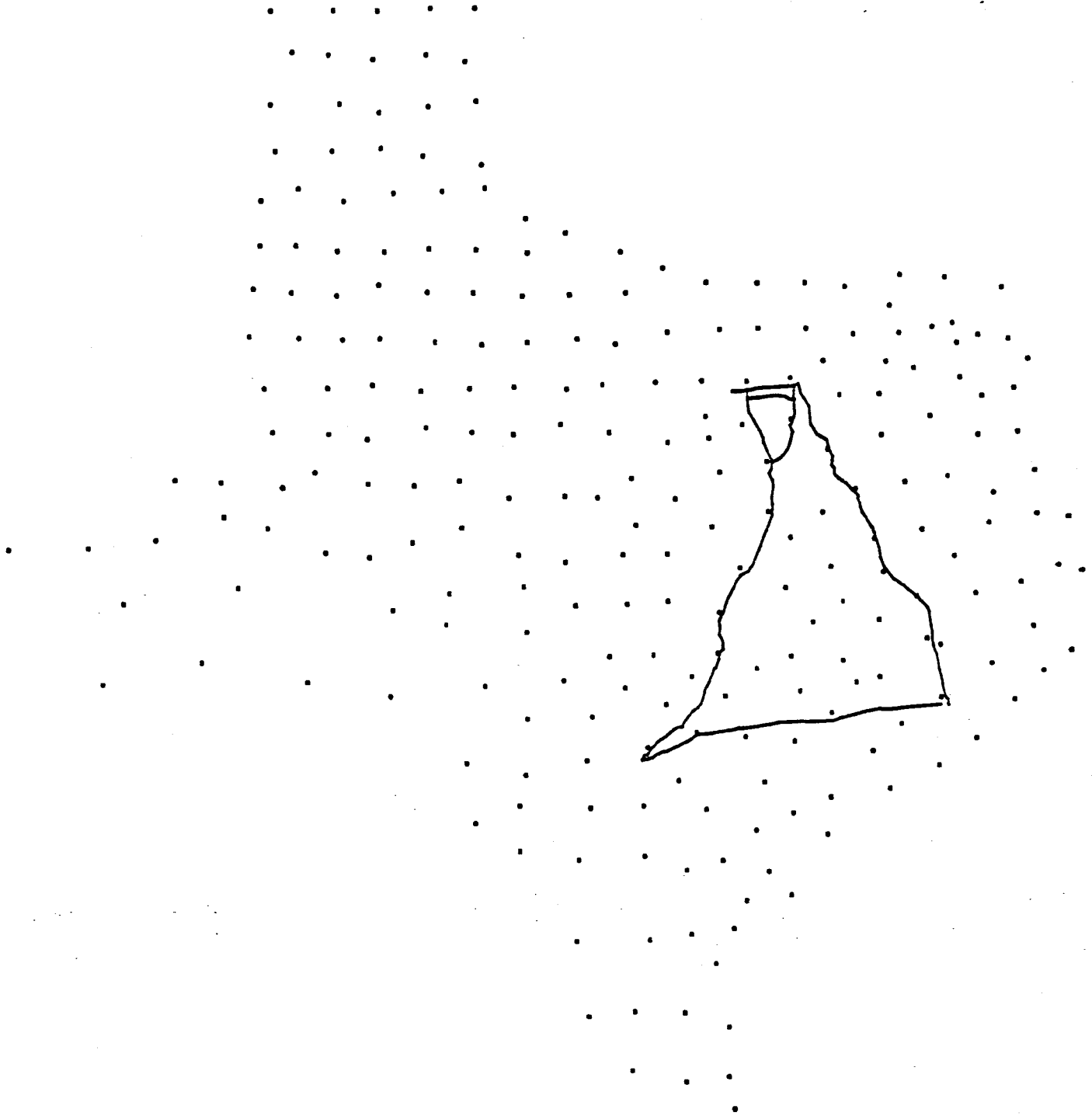


Figure 9

INTERSTATE NETWORK

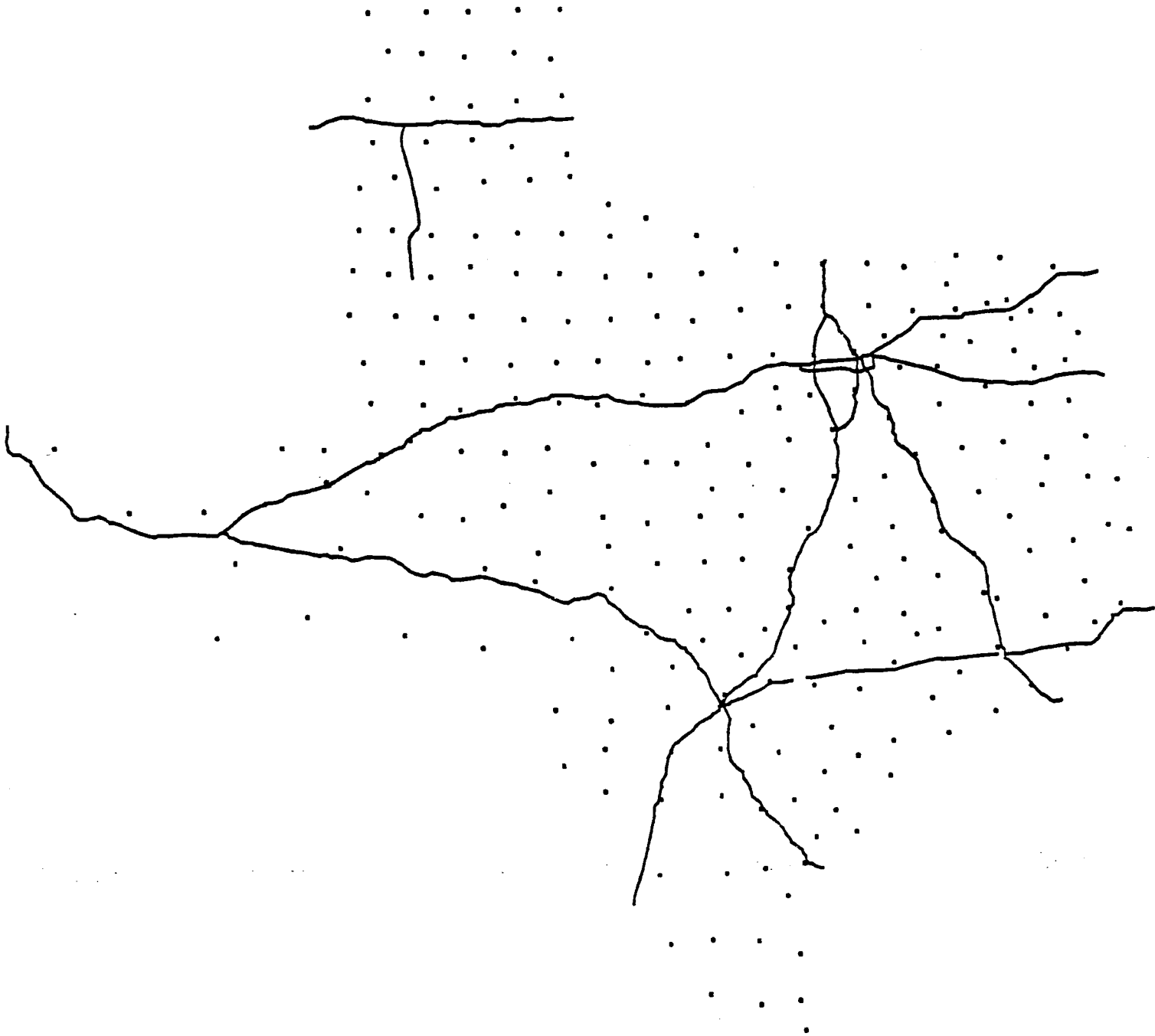
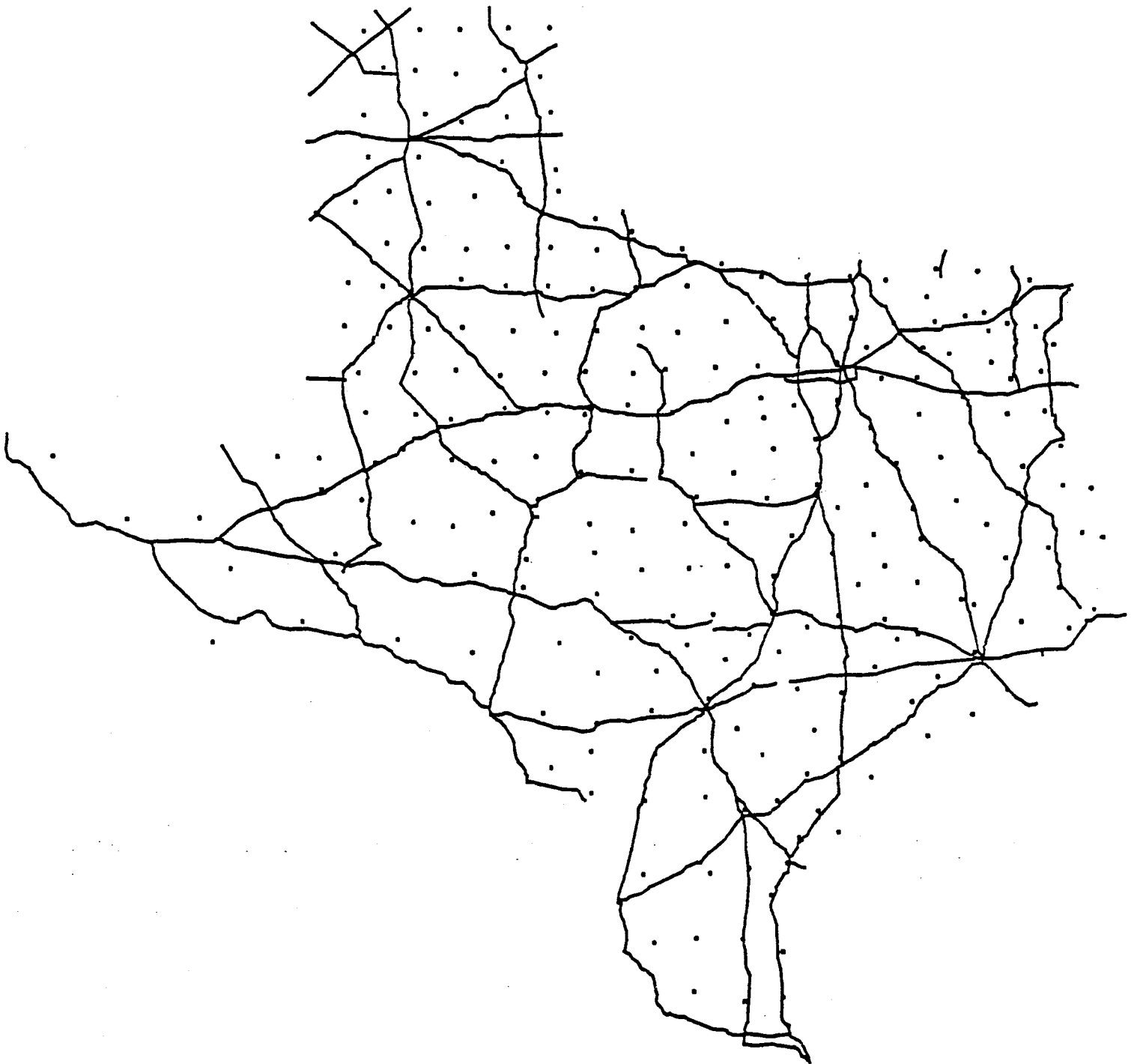


Figure 10

FHWA DEFINED NETWORK



places. For example, within the context of a particular network, the topological distance between Houston and Dallas is relatively small since the two cities are joined by one high speed four-lane thoroughfare in comparison, Bryan, College Station and Houston, although they are much closer in physical distance, are more distant in terms of this abstract measure of connectivity.

Thirty Metropolitan Statistical Areas (MSA) in Texas defined the perimeters of a connectivity matrix. (Table 15). The connectivity matrix is a summary of each network where the rows represent the origin MSA's and the columns represent the destination MSA's. The interior of the matrix is comprised of "1's" and "0's" depending on the presence or absence of a road or link between the centers. The topological distance is calculated for each level of the hierarchy in order to determine the accessibility of these 30 MSA's. Accessibility of a particular MSA is calculated by summing the corresponding row or column of the connectivity matrix for that MSA. Equation 3.1 represents the algebraic expression of accessibility. A high value for A_i infers that the MSA is well connected; therefore; it has relatively more access to the entire network of MSA's.

$$A_i = \sum_{j=1}^n d_{ij} \quad 3.1$$

where: A_i - is the accessibility of origin i , (row/column sum) and

d_{ij} - is the topological distance between origin i and destination j .

Some of the cities that comprise the connectivity matrix are not directly linked; for example, the MSA's of Abilene and Houston are separated by at least two links. Therefore, it is necessary to identify the existing indirect or multi-link connections. This is achieved by powering the connectivity matrix

Figure 11

TOTAL NETWORK

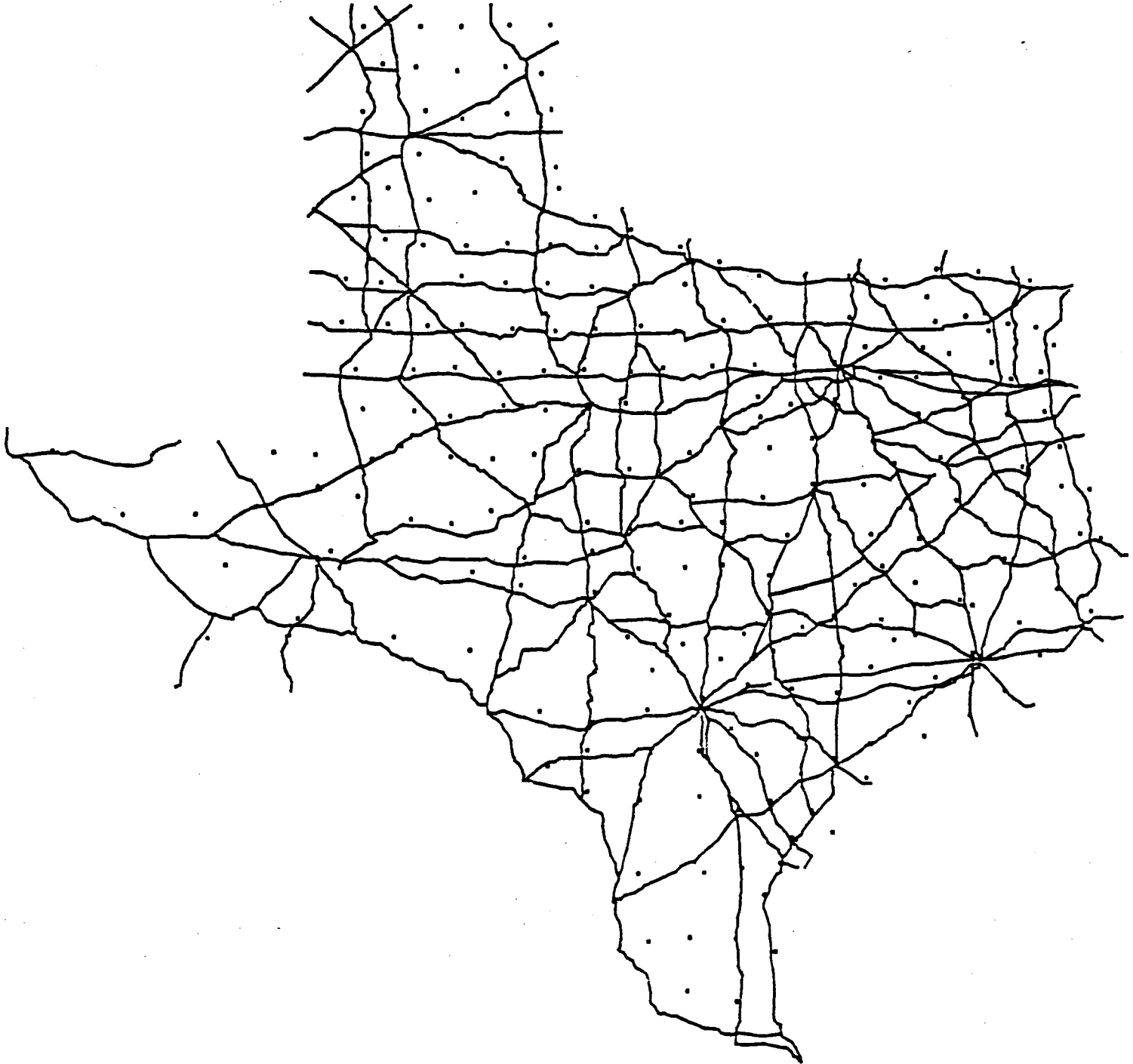


Table 15

METROPOLITAN STATISTICAL AREAS (MSA) IN TEXAS

LEVEL A - POPULATION 1,000,000 OR MORE

1. HOUSTON
2. DALLAS
3. SAN ANTONIO

LEVEL B - POPULATION 250,000 TO 1,000,000

4. FORT WORTH
5. AUSTIN
6. EL PASO
- 7/8. BEAUMONT / PORT ARTHUR
9. CORPUS CHRISTI
10. MCALLEN-EDINBURG-MISSION

LEVEL C - POPULATION 100,000 TO 250,000

11. LUBBOCK
12. BROWNSVILLE-HARLINGEN
13. GALVESTON-TEXAS CITY
14. AMARILLO
15. WACO
16. BRAZORIA
- 17/18. KILLEEN / TEMPLE
19. TYLER
20. WICHITA FALLS
21. ODESSA
22. ABILENE
23. TEXARKANA

LEVEL D - POPULATION UNDER 100,000

24. LONGVIEW
25. LAREDO
26. BRYAN-COLLEGE STATION
27. SHERMAN-DENISON
28. SAN ANGELO
29. MIDLAND
30. VICTORIA

until all elements are non zero. This occurs when all the one step plus all the multi-step links are enumerated. The connectivity matrix then becomes:

$$T = C + C^2 + C^3 + \dots + C^n = \sum_{i=1}^n C^i \quad 3.2$$

Where: T - is the total accessibility index, and

C^n - is the connectivity matrix powered n times.

Each value for n, in the above equation (3.2) denotes the number linkages, or the number of multi-step paths that are possible between 2 centers. The row or column sums of the connectivity matrix represent the relative accessibility rank of each of the 30 MSA's. The higher the row/column sum, the higher is the accessibility for that node. As the level of complexity of the network increases, the matrix will require more manipulation to enumerate all the multi-step linkages. Therefore, as n becomes larger, the accessibility index becomes extremely large for some centers, due to the number of redundant or circular paths that are now included.

The accessibility indices based on the cumulative connectivity matrix (equation 3.2), were calculated for each network and are graphically displayed in Figures 12 to 15. These graphs illustrate the relative accessibility of the 30 MSA's with reference to each of the four networks.

Texas Triangle (Figure 12)

The demand surface analyses, performed in the previous section, identified the Texas Triangle as the fastest growing area in the State. Furthermore, the 4 MSA's that outline this area are the largest in Texas. Therefore, it is evident that those sections of I-35, I-45, and I-10 that define the triangle, serve a greater than average portion of the demand. Seven of the 30 MSA's are

interconnected by this network. But the other 27 cities have an accessibility index of zero. Dallas and San Antonio are the most accessible by this network, and Houston the least accessible.

Interstate Network (Figure 13)

The Interstate network interconnects considerable more MSA's, 19 in total. Dallas is the most accessible MSA followed by Fort Worth and San Antonio. Houston represents the median in terms of accessibility rank. The least accessible cities are Lubbock and Amarillo since they are, in no way, linked to the other MSA's.

The FHWA Defined Network (Figure 14)

All but three MSA's are joined by this network. Dallas and Ft. Worth remain the most accessible cities on the network. Houston, however, is relatively more accessible within this network structure. Lubbock and Amarillo are somewhat better connected to the other MSA's; yet, their relative accessibility is low.

The Total FAP and Interstate Network (Figure 15)

This network interconnects all 30 MSA's. The relative accessibility of San Antonio and Austin have increased to the second rank. The relative rank of Houston is lower than would be expected for the largest urban area in Texas. However, given the geographical distribution of cities in this state, Houston's position cannot be realistically improved. The accessibility index reflects the fact that Houston does not have a direct link to the many smaller MSA's in West and Central Texas, and thus cannot be at the upper end of the accessibility index.

Figure 12

ACCESSIBILITY OF TEXAS CITIES FROM THE TEXAS TRIANGLE

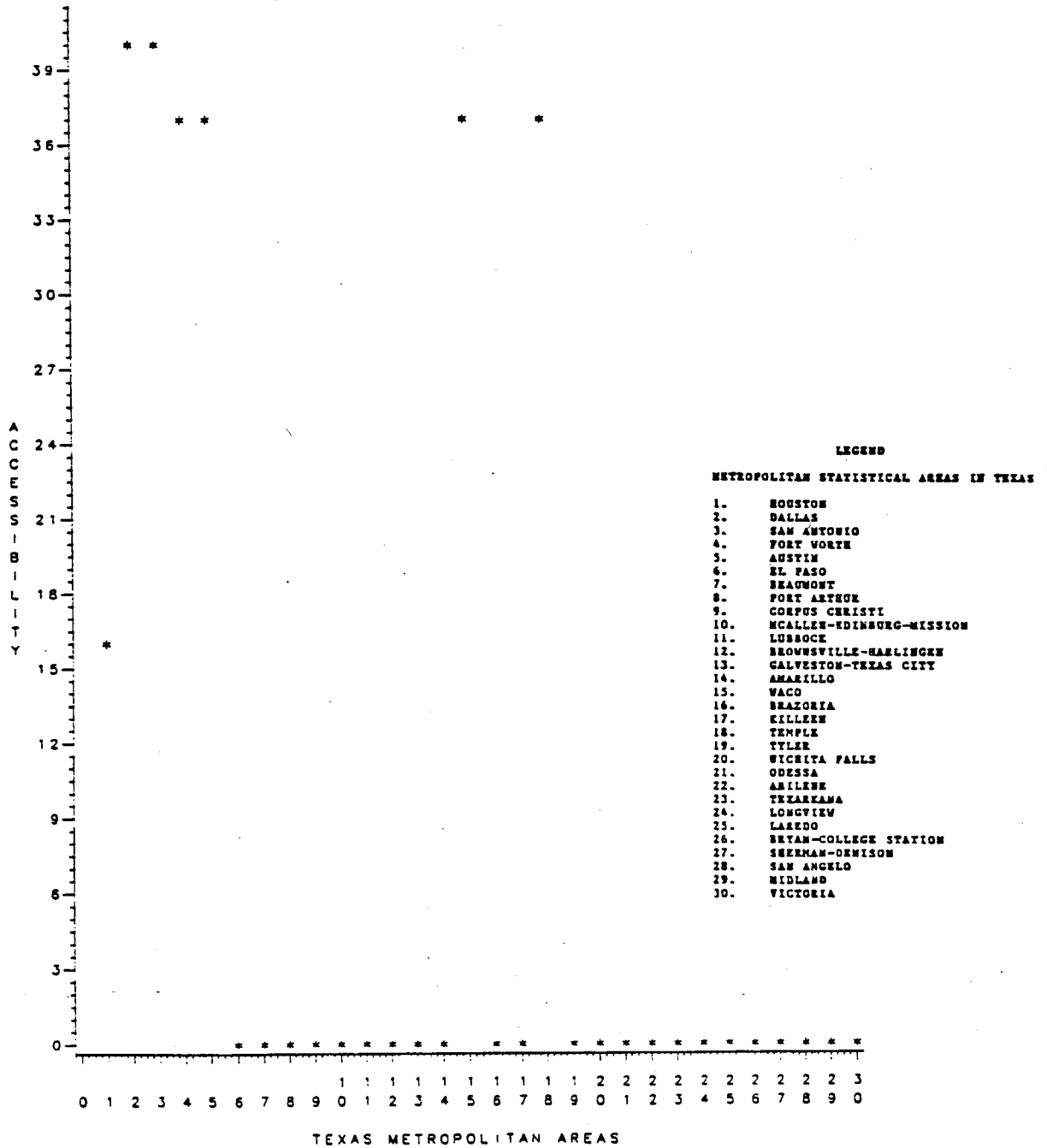


Figure 13

ACCESSIBILITY OF TEXAS CITIES FROM THE INTERSTATE SYSTEM

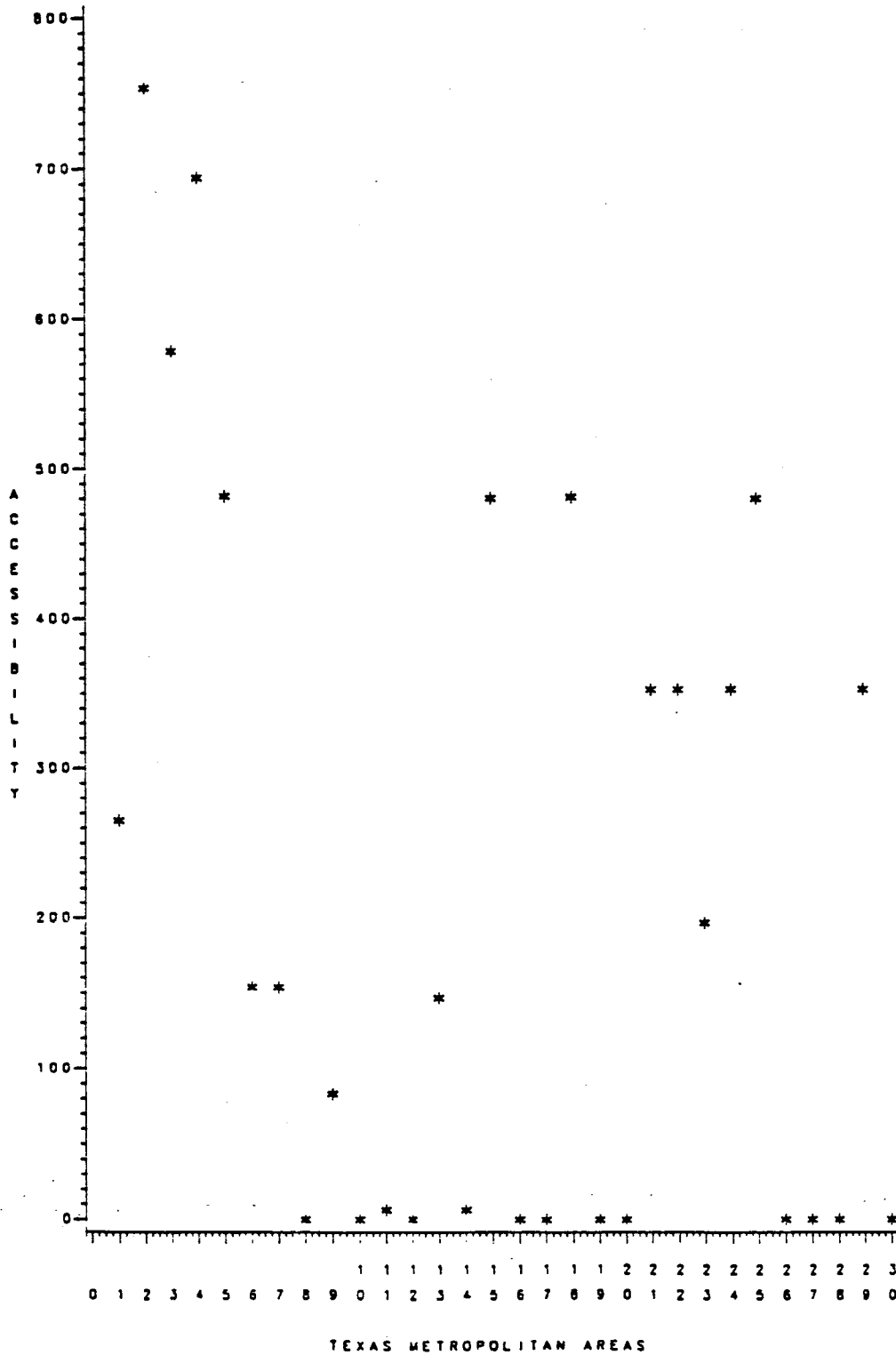


Figure 14

ACCESSIBILITY OF TEXAS CITIES FROM THE FHWA SYSTEM

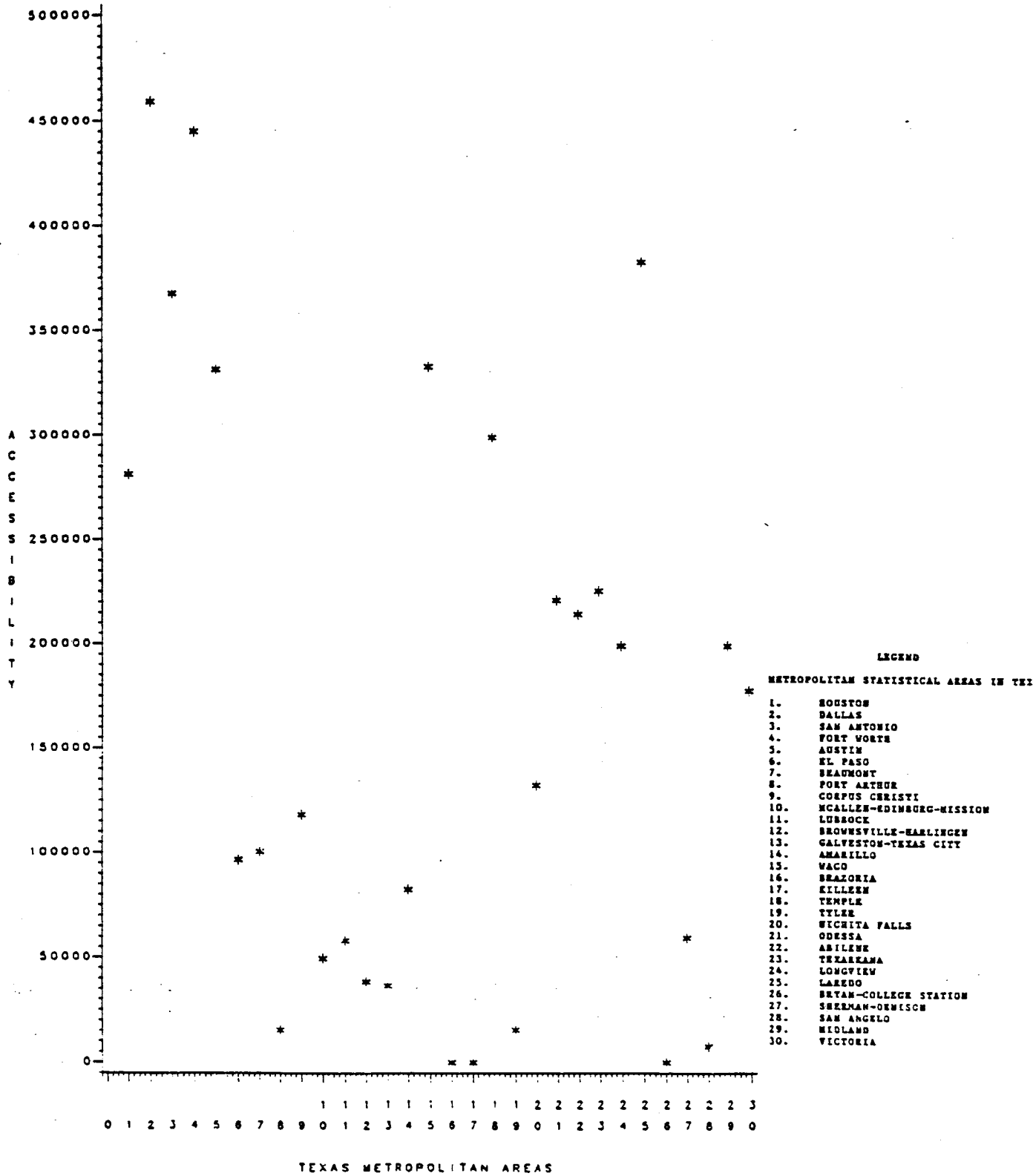
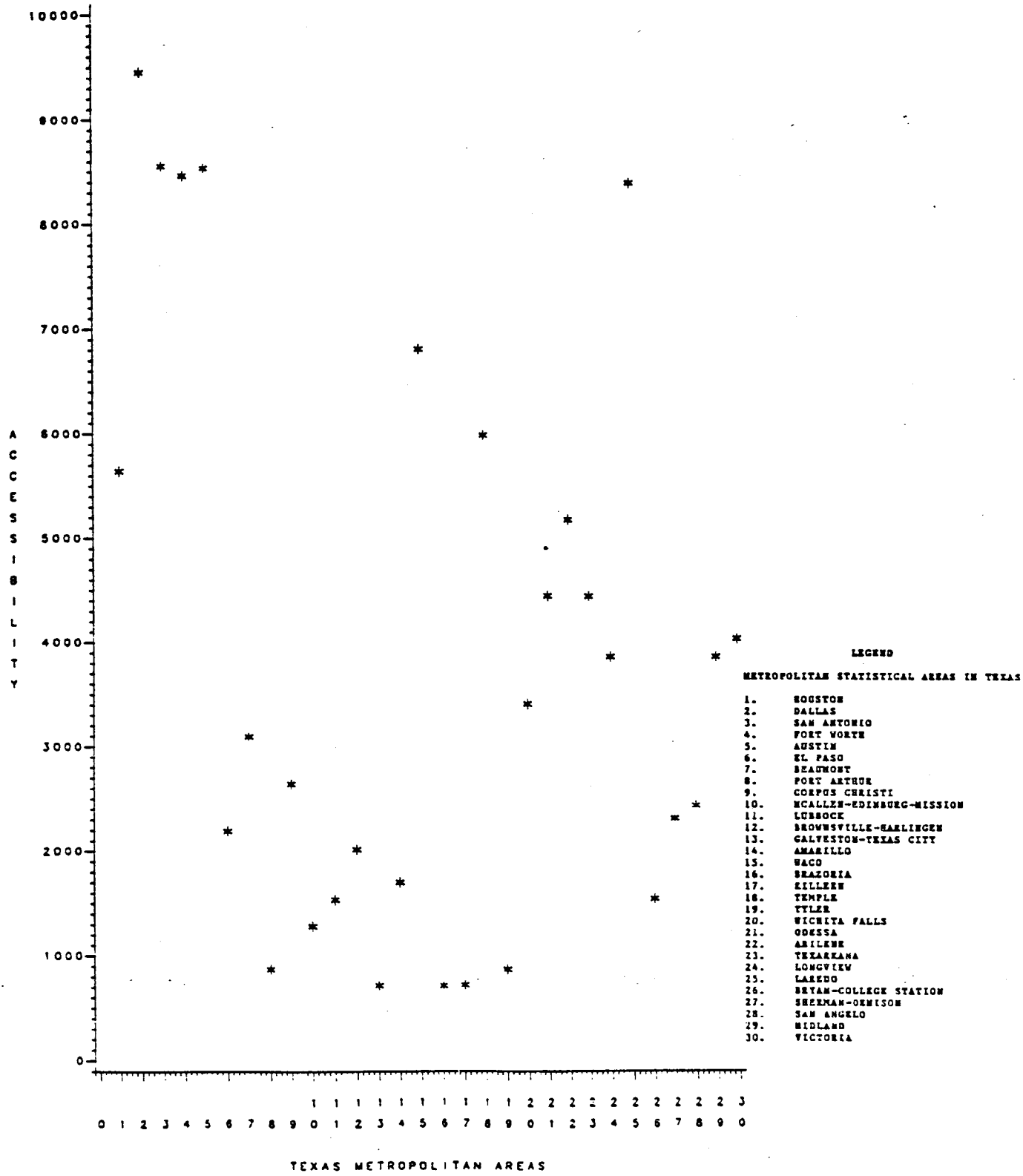


Figure 15

ACCESSIBILITY OF TEXAS CITIES FROM THE TOTAL FAP SYSTEM



Network Efficiency

For comparative purposes a measure of coverage efficiency was calculated for each level of the hierarchy. The coverage efficiency index measures the extent of demand that is not accessible to a facility. Thus, it can be viewed as an indicator of the amount of demand that is served. Demand is represented by the factor 1 and factor 3 scores that were calculated in the demand surface analysis.

To simplify the analysis the centroid for each county was used to represent the demand. Choosing the centroid to represent aggregate county data is an objective and equitable solution when demand must be defined in discrete space. Graphics software was developed to measure distances from each centroid to the closest branch of the network. The allocation of demand to the facility is based on weighted distance. Because demand from certain counties is greater, it would be more realistic to multiply straight line distance to the facility by some scalar (i.e., factor scores) in order to ensure that those centers with the greatest demand are made accessible to the network. The 254 weighted distances are aggregated to give an index of efficiency that can be compared for all levels of the hierarchy. In the previous section, the demand surface analysis has shown that the majority of counties all classified with a cluster that was labeled average. These counties are thus associated with negative or very low factor scores. Furthermore, factor scores are standardized coefficients with a mean of zero, and standard deviation of one; and therefore, most counties are associated with a negative factor score. This implies that when the efficiency index is negative the large demand centers are served. Thus, it is mostly the low demand areas that do not have access. When the Efficiency Index is zero, then all demand points are served, since the distance function for all counties would equal zero.

The coverage efficiency index is calculated by:

$$E = \frac{\sum_{i=1}^{254} w_i d_{ij}}{254}$$

3.3

Where: CEI - is the coverage efficiency index
 w_i - is the weighting scalar (factor scores), and
 d_{ij} - is the distance (in miles) from centroid i to facility j .

Table 16 summarizes the coverage efficiency index for the 4 networks.

Table 16: COVERAGE EFFICIENCY INDEX

	<u>Texas Triangle</u>	<u>Interstate System</u>	<u>Federal Defined System</u>	<u>Total Network</u>
Factor 1	-13.10	-4.08	-1.26	-0.64
Factor 3	-50.49	-7.52	-1.05	-0.18

The relatively high (in absolute terms), index for the Texas Triangle network indicates that a large portion of the counties that do not have high factor 1 and factor 3 scores are not accessible to that network. In contrast, the very low indexes for the Total network suggest that this is more equitable coverage pattern, since relatively more counties are accessible to the Total network, regardless of the amount of demand they generate.

The coverage efficiency index is a weighted measure representing relative highway coverage. This index does not infer actual miles from counties to a road segment. To acquire a measure of accessibility based on miles, the unweighted straight line distances from county centroids to the nearest facility were used to define the accessibility of counties to a network. For each network, the mean distance and standard deviation were calculated in order to obtain some measure of average access to the network. (Table 3.3). Together,

the mean and standard deviation are used to outline accessibility zones around highway segments.

Table 17: MEAN DISTANCE AND STANDARD DEVIATIONS FOR ALL COUNTIES
(in miles)

	<u>Mean</u>	<u>Standard Deviation</u>
Texas Triangle	129.03	105.00
Interstate System	33.02	26.17
FHWA Defined System	10.62	9.23
Total Network	5.48	5.09

Based on the statistics reported in Table 17 one can infer that 84 percent of the counties, that is, all counties located within one standard deviation from the mean distance from a facility, are within 234 miles of the Texas Triangle, 60 miles of the Interstate network, 20 miles of the FHWA defined network and within 11 miles of the Total FAP and Interstate network. Texas a state that is spatially economic extensive needs ot provide comprehensive access to all areas of the State. Judging from the means, standard deviations, and coverage efficiency index it is clear that neither the Texas Triangle nor the Interstate System can provide the full extent of coverage that is needed by the State. Specifically, the Texas Triangle and the Interstate system would render 41 counties outside of an accessibility zone that is 234 or 60 miles away from a facility. However, accessibility zones restricted to 20 or 11 miles would provide a workable solution to the access problem.

In order to emphasize the extent of coverage with respect of the demand counties, the mean and standard deviation were calculated for only those counties that are strongly correlated to factor 1 and/or factor 3. (Table 18). The high demand counties were identified as those that have upper quartile factor scores.

Table 18: MEAN DISTANCE AND STANDARD DEVIATIONS FOR COUNTIES WITH HIGH FACTOR SCORES (in miles)

	Texas Triangle	Interstate System	FHWA Defined	Total Network
Factor 1				
Mean	109.38	29.60	5.36	1.49
Standard Deviation	143.98	37.94	7.74	0.76
Factor 3				
Mean	49.98	20.33	10.33	6.15
Standard Deviation	57.44	17.12	8.77	5.63

It is clear that those counties associated with factor 1 have considerable closer access to the total network. Specifically 84 percent are within 5 miles to the closest facility. In contrast, 84% are within 13 miles of the FHWA specified network. The counties labeled as the Growth counties are, on average, five miles further away from a facility, when comparing the FHWA network to the Total network. Eighty-four percent are within 20 miles of the FHWA designated network and 12 miles of the Total FAP and Interstate network. However, for the Total network the discrepancy between access from the Growth and Size Counties is considerably larger. Eighty-four percent of the Size Counties are within 2.5 miles of a facility. Also, 84 percent of the Growth Counties are within 12 miles of a facility. This characteristic suggests that the Total network provides excellent coverage to those counties that are strongly correlated to the size factor. In contrast, the FHWA network provides relatively equal coverage to both the Size counties and the Growth counties that is 84 percent of the factor 1 counties are within 13.1 miles of a highway segment, and 84 percent of the factor 3 counties are within 19.1 miles.

The 16 percent of counties not adequately served by the FHWA and Total networks need closer examination. Four high growth counties, [Brazoria, Brazos, Hemphill and Llano], are not within 20 miles of a facility. Similarly, four

counties that make up the 16 percent that are not within one standard deviation of the mean distance from the Total network. They are Aransas, Bandera, Llano, and Zapata. This analysis has determined that these counties are potential high demand centers and thus statewide access policy needs to reflect their particular access needs.

In summary it is evident that the networks comprising the Texas Triangle and the Interstates provide relatively more access to the high growth counties. As the network coverage expands, more counties with a large demographic/economic base are reached, and only in relative terms, fewer Growth counties are not sufficiently covered.

Conclusions

Statistical analysis and computer assisted measurement techniques were used to develop a measure of access to a network of roads. A hierarchy of four networks were evaluated in terms of how much demand each has the potential to serve. Several characteristics were identified:

- The Texas Triangle and the Interstate network provide relatively better access to the high growth counties.
- Based on the Coverage Efficiency Index that was developed in this study, the Texas Triangle and the Interstate network cannot alone, provide equitable coverage to all demand centers in the State.
- The FHWA network and the Total network provide relatively better access to the counties that have a larger demographic/economic base.
- On average, all counties are within:
 - 129 miles of the Texas Triangle,
 - 33 miles of the Interstate network,
 - 10.6 miles of the FHWA network, and
 - 5.5 miles of the Total FAP and Interstate network.

These statistics, coupled with the knowledge of the growth trends for the State, are the tools to aid in solving problems of how much access can be afforded to the larger commercial vehicles. A statistically valid computerized procedure for doing "what if" or scenario analysis for defining access policies was outlined. This procedure can be applied to similar analyses at a micro scale, for example, at the planning region level or the SDHPT district level. The district level is of particular interest, since data can be collected for census blocks in order to measure required access from highway facilities to terminals and other related land use activities.

Research in this area is responding to problems brought about by the introduction of new technology by the trucking industry. This study can be compared to those that followed the completion of the Interstate highway system. Findings from such studies have revealed that economic and demographic growth can be attributed to the presence of an Interstate, despite the fact that the new Interstate network closely resembled the geographic patterns of the then current highway network. At that time, the Interstate represented an innovation that reduced the friction of distance. It is believed that a network of highways that will incorporate the design elements necessary to safely serve the new breed of larger/heavier commercial vehicles will encourage similar economic and demographic changes.

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