A STOCHASTIC ANALYSIS OF INTERNAL MOBILITY WITH POPULATION PROJECTIONS FOR THE STATE ECONOMIC AREAS OF TEXAS

By

GARY DUANE LAUVER

Bachelor of Science

California Polytechnic State University

San Luis Obispo, California

1974

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1977

A STOCHASTIC ANALYSIS OF INTERNAL MOBILITY WITH

POPULATION PROJECTIONS FOR THE STATE

ECONOMIC AREAS OF TEXAS

Thesis Approved:

Robert E. Norris
Thesis Adviser

K. D. Harries

J. F. Rooney, Jr.

Norman N. Durham
Dean of the Graduate College

PREFACE

This study examined recent migration trends within the state of Texas. The primary objective was to analyze the migration trends and predict the distributional consequences of such a process. A secondary objective was to test both the adequacy and applicability of the Markov chain technique as a tool for migration research.

This investigation, to a large degree, owes its existance to the geography graduate study program. This program has two significant attributes. First, its dedication to academic freedom and flexibility which allows the graduate student to pursue his own interests. Second, a diversified staff which in itself serves as a substantial resource to the graduate student.

I want to thank my committee chairman, Dr. Robert E. Norris, for his guidance and assistance throughout the duration of this project. Special gratitude is expressed to another committee member, Dr. Paul Hagle, for his advice and continued support during the course of my studies. Sincere appreciation is expressed to Professor James Stine for his advice on cartographic depiction of the data. Thanks go also to Dr. Michael S. Salkin and associate Meg Kletke of the Agricultural Economics department for their invaluable assistance on technical and methodological problems. Without all of them, this thesis would not have been possible.

Thanks are also due to Joyce Gazaway for final typing of the thesis and to Robert Pool for permitting me time off to make the many trips to Stillwater.

Finally, I would like to thank all my friends who gave encouragement quite freely throughout the years. Most notably, I would like to thank my best friend, Pam Bradshaw. She stuck with me through the "thick and thin" of the entire ordeal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

There is little need here to belabor the importance of internal migration in our national economic and social life. The past several decades have borne witness, through the many contributions to the literature of migration, to the concern which has been evident regarding the subject. To the student of population phenomena, the mobility of the people within the borders of the nation has presented a stimulating and provacative opportunity to observe one of the most vital currents of population dynamics. To the social planner and the social technician, this mobility has indicated an increasing complex of problems demanding solutions in the interest of individual and collective welfare. To certain observers of the contemporary scene, the high mobility of the American people appears in the light of a distinctive national characteristic, an index at once of the progress and problems, of the instability and disorganization as well as the future promise of our nation. In a recent bibliographic series of migration theory, Shaw (39) pointed out that:

> Migration, especially in the process of regional economic development, urbanization, and industrialization, is both an important cause and effect of social and economic change. Recognition of this fact is evident in developed and underdeveloped countries alike. Policy makers have become increasingly aware of the role of migration in balanced economic

> growth and innumerable social, psychological, ecological and political ramifications of present and projected patterns of population redistribution (p. 1).

Aside from the social and economic considerations of internal migration, the sheer magnitude of internal migration must be taken into account. Migration throughout the United States has shown a marked increase in every census year. It seems likely that migration is a phenomenon which will continue in the future to an even greater extent than in the past. In an advanced society such as the United States where births and deaths are tending to decline, migration will undoubtedly be the major component of population change. In a generic study of world population patterns, Trewartha (44) concluded that:

> . . . advanced societies are characterized by unusual mobility even though they are typically sedentary. In the United States, about one-quarter of the population does not live in their state of birth, and every year one out of five persons changes his residence. . . Human migration is in no sense weak in its importance to population studies. Indeed, it looms exceedingly large in any analysis of the population element of a developed country or region (pp. 136-137).

Given just these two aspects of migration (that is, the socio-economic importance and magnitude of internal migration), it seems that there exists a clear need for information relating to the extent, directions, and volume of migration in various areas of the United States. Indeed, the call for relevant research in the field of internal migration was noted as early as the 1930's (4) (18) (43) (48) (49), and has continued into the seventies (25) (39). To summarize the literature cited above, there are at least five main problems within the scope of internal migration studies which demand further research. These are (1) the volume of migration between various areas; (2) the reasons why people migrate; (3) control measures which can be directed toward migration; (4) the effects of migration on population growth; and (5) the social aspects of internal migration; these constitute the most pressing problems of internal migration, and should be the foci around which population research (at least, research on internal movements of the population) should be oriented.

With respect to this study, attention is focused on items 1 and 4: an analysis of internal migration in Texas, as revealed by recent census information; and the effect of migration on population growth as predicted by a Markov chain model. These two factors are considered within a subregional frame of reference.

Significance

In an early study, Browder (5) attempted to trace the main trends and to point out some of the larger research areas relevant to the population of Texas. The study lists three areas of needed research: first, general population studies of the broader aspects of population growth and composition with more intensive inquiry into extent; direction and causes of major trends; second, more specific studies directed toward such significant phases of the population as internal migration, differential mobility, problems involving migratory labor, etc.; and third, community studies of ethnic and cultural groups, boom towns and stranded communities, and other elements in a diversified population. The comprehensiveness of the above list implies that, during the early part of the twentieth century, relatively little attention had been given to population research in Texas. In relative terms, this same situation exists to some extent today. The implication is borne out when the attempt is made to compile a bibliography of population research for the state. The investigator is immediately struck by the paucity of published material, either on the broader aspects of population history and development, or on more specific points of composition, structure, and change. It is most unfortunate that such a lack of material should exist, for in many ways the population of Texas and the Southwest in general provides some of the most interesting areas of research in the contemporary scene. Not only are general research efforts missing, but there is nearly a total lack of published material by geographers.

It is difficult to state precisely why more attention has not been devoted to the population of Texas, although a number of factors probably contribute to the situation. Texas, although it has been a state for over a century, still retains considerable flavor of the frontier. The vast size and widely varying terrain, climatic, and cultural characteristics of the area have meant that settlement has not proceeded in a particularly orderly fashion. It was not, in fact, until the beginning of the trend toward urbanization in the state that the size and density of the population became such that systematic research seemed to be warranted. The factor of distance, separating the borders of the state by almost a thousand miles in each direction, has not been conducive to consideration of the population as an easily comprehended whole. The large number of counties (254) means that data compiled on a county basis are bulky and tedious to work with. Finally, and perhaps most significant of all, no single institution in the state has as yet provided a research organization geared to respond to the type of work most needed.

In addition to data published by the Bureau of the Census (available back to 1850), and data compiled by other federal, state, and county agencies, material relating to the population of Texas falls into three categories. These are, first, the various estimates of population and analysis of population for different periods as presented by earlier historians. While they furnish much information, particularly regarding distribution of the early population, they must be used with considerable reservation, since many of the estimates are derived from questionable sources. A second type of research includes isolated studies of special phases of the Texas population. Included here are the theses and dissertations written on population subjects and which repose on library shelves at the various colleges and universities; it is difficult to enumerate and evaluate these, since many are unpublished. It is safe to assume that these unpublished studies do not represent a highly significant body of analytical material. A third type of research on the population of the state is a number of "professional quality" studies published through the social science departments at the various state colleges and universities. In addition, the state of Texas, Department of Economic and Community Affairs, and the Rice Center for Urban Research publish a number of papers on the population of Texas. These projects have been directed chiefly toward specific local problems, largely those relating to the mobility of the urban population of the state.

Statement of the Problem

Migration is known to be both an important cause and effect of socio-economic change. Policy makers at all levels of government are becoming increasingly aware of the importance of migration to the well being of areas, whether they are small rural communities, middle sized towns, large metropolitan areas, multistate regions, or nations of the world. While there is an increasing awareness of the importance of migration, there is at the same time much to be learned about the migration process itself. If it were somehow possible to examine and understand past migration experiences and forecast future outcomes, it might be possible to initiate policy that will circumvent suboptimal outcomes in lieu of preferred or optimal outcomes.

However, before we can expect to develop policy aimed at producing optimal population distributions, we must first gain a better understanding of the migration process. For example, what are the volumes of migrants between various areas? What effect will migration have on the population growth characteristics of origin and destination areas? What will the future population distributions be, given a continued migration process? It is these types of questions that the present study attempts to address.

Specifically, the present study was conceived as a response to the need for migration research relating to the population of Texas. This study was an attempt to broaden the scope of research over an area wider than that offered by previous research. While there has been nothing particularly unusual or inexplicable about the situation as it has developed in Texas, practically nothing has been known about the direction, extent, or volume of the internal movement of population in the state. Further, no adequate geographic frame of reference (i.e., a subregional approach) has been developed for Texas. Hence, the present study was designed to meet the following objectives:

(1) select an adequate geographic base that would meet the needs of the present study as well as future research efforts of a similar nature,

(2) provide an analysis of past migration patterns for the entire state,

(3) examine the impact of migration on population growth for the subregions of Texas, and

(4) forecast future population distributions within the state, based on past migration patterns.

Subregional Approach

To meet the need for a geographic base less cumbersome than 254 counties, yet one which would embody the minimum requirements for a soundly-oriented socio-economic regional approach, State Economic Areas (SEA's) were employed. While admittedly this subregional scheme is not ideal, it appeared to offer the best solution to the problem of which geographic base to use in the absence of time and resources to work out a separate scheme for this study. Tested both by the application of social and economic indices (47), and through "common sense" methods of the observation of differences of people, economy, and general land use among the different parts of the state, the state economic areas offered the best available basis for the purpose. No pretense is made for the complete adequacy of the scheme; the development of a definitive subregional plan for Texas (and for the remainder of the United States) remains one of the outstanding immediate problems confronting the investigator and interpreter of social and economic life of a state.

It is hoped that within the near future such a plan, perhaps based on the work of other investigators, may be developed.

Methodology, Data, and Period of Time

The field of inquiry of the present study, namely, an analysis of recent internal migration and the prediction of future population distributions in Texas, having been determined; and the frame of reference--the subregional approach--decided upon, there remained the problems of research methodology, source of data, and period of time.

Methodologies related to the study of migration in particular and to the analysis of population change in general are numerous and widely varied. However, the concern of this study was to employ a methodology that was both somewhat original and relatively simple to execute. Given these limitations, the field of choice was drastically reduced. Thus, the method chosen for this study was a Markov chain model.

The overriding features of a Markov chain model are its utter simplicity in describing dynamic migration processes from readily obtained data, and its focus on the results. The Markov chain technique allows the estimation of several SEA characteristics that could not easily be obtained using other methods. For example, some of the characteristics of interest are mean stay time (average years of residence in SEA), stayer probabilities (a measure of immobility), and the fixed probability vectors (an indication of the long-run or equilibrium characteristics of the migration process). As Ginsberg (14) points out, Markovian models have many advantages over more conventional methods based on regression analysis, because of the ability to represent stochastic and substantive dependencies in flows through a system of regions over time. A more detailed account of the various properties of Markov chains, and the specific methodology employed in this study, is presented in a later chapter.

Migration data for this study were derived from a computer tape file made available by the U. S. Bureau of the Census. This same information is available in tabular form in a census bureau publication entitled Migration Between State Economic Areas (47). The tape option was chosen to permit rapid, easy processing and manipulation of the data on the universities computer facilities.

The data employed in this study represent the flows of migrants between the various SEA's of Texas through two periods of time, 1955-1960 and 1965-1970. Additional data, reflecting the number of inhabitants in each SEA, were necessary to project the 1975, 1980, and long-range SEA population distributions (45).

Overview

This study is composed of four chapters. Chapter I is the introductory chapter and contains sections relating to the general background and significance of the study, the statement of the problem, the subregional approach used in the study, and a brief explanation of the methodology, data, and temporal dimensions of the study. Chapter II is a review of certain literature pertinent to the study, primarily that relating to the application of stochastic models in movement research. Chapter III is concerned with the methodology employed in the study. Chapter IV is a summary of the results of the Markov chain analysis and contains the summary, conclusions, and implications of the study.

CHAPTER II

REVIEW OF SELECTED LITERATURE

Introduction

Stochastic models have been used in social research for more than two decades. This review of the literature is basically an account of those proceedings. It begins with a short summary of the development of stochastic models in the social sciences and proceeds to a review of selected literature dealing with specific applications as they relate to human migration. Basically, two types of stochastic models are discussed in this review. They are simple Markov chain models and the more elaborate semi-Markov chain models. Previous applications are summarized and their relative merits are discussed. This review of previous research suggests that: (1) the use of stochastic models in social research, and migration studies in particular, has been relatively limited, and (2) although much of the more recent research advocates the use of semi-Markovian models, their applications are severely limited because of inherent data requirements.

Markov Chain Models and Social Research

It is not uncommon for theoretical developments in abstract mathematics to find ultimate applications in practical problems. Markov chain theory, developed by the Russian mathematician A. A. Markov early in the twentieth century, is a prime example. Recognition of the possible usefulness of Markov chain theory in geographic, economic, and other social problems has come about only recently. During the past three decades there have been a wide variety of problems to which Markov chain theory has been applied.

The principal use that has been made in economics has been in the measurement of industry concentration. Early applications of this nature were made by Simon and Bonini (40), Adelman (1), and Hart and Prais (21). The Simon and Bonini report is a theoretical discussion of why a stochastic model should be more useful in studying industry concentrations through time as opposed to traditional methods used. The Adelman paper reports on an application of Markov chain theory to analyze the size distribution of firms in the U. S. steel industry and projects the eventual equilibrium size distribution according to Markov chain theory. The Hart and Prais paper deals with British industry concentration in a manner much like that used by Adelman.

In a later paper by Collins and Preston (10), the composition and size structure of the 100 largest firms in the U. S. over the period 1909-1958 were analyzed using a Markov chain model. Another study of this type of problem was presented in a paper by Ijira and Simon (22). This paper reconsiders the earlier paper by Simon and Bonini; it weakens some assumptions made there to make Markov theory apply and also suggests a different approach.

Another use of Markov chain theory in economics has been to study income distribution change over time. Salow (38) studied variations in the income distribution of wage-earners for the years 1938-1940. Using the equilibrium characteristics of regular Markov chains, Salow is able to draw long-run conclusions about the equilibrium distribution of wage income.

In yet another type of application, Smith (41) developed a Markov chain model of regional growth in gross income, where each region is assumed to have fixed propensities to spend in each other region. de Cani (11) has applied a related but different approach to the study of regional population growth. de Cani, however, did not use the typical Markov chain model but used a related method of birth-death processes involving differential and difference equations. Three stochastic models were advanced: (1) pure migration, (2) mixed birth, death and migration, and (3) predator-prey. de Cani's approach does not appear to be fruitful in that: (1) the generating function of the stochastic process could have been estimated more simply by constructing a transition matrix from empirical data in the pure migration model; (2) he was unable to derive the generating function of the process in the mixed model; and (3) in the predator-prey model, only the trend of the process was derived.

Another significant type of problem to which Markov chains have been applied is that of occupational and social mobility of the population. Prais (30) has studied intergenerational mobility of the British population among social classes as indicated by social groupings. Certain occupational groupings were used to indicate social status. A transition matrix was constructed indicating the probability that a given man's son would go into various occupational groups, given the father's occupational group (i.e., the probability that a farmer's son would become a farmer, a skilled laborer, an industrial worker, a lawyer etc.). The transition matrix was analyzed using a Markov chain model and the ultimate occupational structure was predicted.

A similar application was made much later by Clark (8). In this study, equally spaced class intervals of contract rent were used as indicators of social status. Using a Markov chain model to analyze transitions between classes of contract rent, Clark was able to make a prediction of the social class equilibrium distribution.

Blumen et al. (3) conducted a study of industrial labor mobility in the United States. Using social security records of individuals over a period of years, a transition matrix was constructed which estimated the probability of individuals moving from one type of occupation to another between two points in time. The mobility patterns of industrial workers were then analyzed using a Markov model.

In a study of a related but different problem, Rogoff (34) used data from two samples of applications for marriage licenses to analyze occupational structure change for Marion County, Indiana. Rogoff used the sample data to construct and analyze a transition matrix of the probabilities of the county changing its occupational structure.

Anderson (2), in a unique study of attitude change, used data from a panel survey of potential voters. One of the questions dealt with which party the respondent intended to vote for. The same question was asked of all individuals in six different months. By using the data from several pairs of months, Anderson was able to construct a transition matrix of attitude change. Using a Markov chain model, Anderson then made predictions of the eventual distribution of voter attitudes.

So far we have briefly reviewed a wide variety of problems to which Markov chain theory has been applied in the recent past. In addition to the applications mentioned here, there have been countless applications to problems in the "hard sciences" (i.e., mathematics, physics, engineering and others). Interest here is principally in application to social science problems, though. The following sections will focus on yet one more social science problem; that is, studies relating specifically to the application of Markov chain theory to human migration.

Markov Chain Models and Migration

Tarver and Gurley (42) were among the first to study internal migration using a Markov chain model as a basis for analysis. Their paper focused on the movement of both whites and non-whites between the nine census divisions of the U. S. Using the 1960 census data, they estimated the 1965, 1970, and long-run divisional population distribution. No attempt was made, however, to evaluate the accuracy of their projections. Several points of interest were discussed in this paper, though: first, the simplicity and conciseness of the Markov chain approach; second, the failure of the model to incorporate the birth and death process; and last, that uncertainty exists in the assumption of constant migration probabilities through time.

Rogers (31) has also noted the appealing simplicity of the Markov approach to migration studies. The Rogers paper is both a theoretical and an applied migration study. Rogers provides not only an example of a Markovian policy model applied to California migration, but also presents some arguments for the use of Markov models for migration analyses. The crux of Rogers argument is that migration is interrelated with a large number of factors--socio-economic, political, and psychological.

Further, that any attempt to incorporate all relevant variables in a forecasting model will result in an incomprehensible abstraction of organized complexity. The objective, then, is to reduce the observed migration data into summary form, which can be easily comprehended and which focuses on certain regularities in movement patterns. To this end, the Markov approach is well suited.

Rogers also noted the obvious weakness in assuming constant migration probabilities, and cautioned against the use of long-term projections. To this weakness, though, Rogers suggested that it should not be a major obstacle given the emergence of real-time information systems. In other words, there is no longer a need to depend on long-time forecasts; given the availability of continuously updated information, migration probabilities can be updated as needed and new forecasts made.

In a related study by Burford (7), using an entirely different approach, the transition probabilities were found to be approximately constant over a 20-year period. In this study, rates of net migration were computed for each county in eight southern states. The net migration rates were computed for three periods, 1930-1940, 1940-1950, and 1950-1960. The counties were then classified into ranges of net migration for all three periods. This approach yields forecasts which are probabilities that the county will have a migration rate within certain ranges, and does not yield a specific numerical estimate, nor does it describe specific flows of migrants. Although this study differs substantially in approach from other studies, the important feature is that it lends some credence to the assumption of stationary migration probabilities.

More recently, in a study of migration for the western U. S., Salkin et al. (37) provided additional support for the use of Markov chains in migration studies. The study presents a simple method of adding population growth attributed to natural increase to the estimates derived from a Markov chain model. Additionally, two procedures are provided to test the accuracy of the predictions. First, using a 1960 transition matrix, the 1970 population distribution was predicted and compared with 1970 census figures. The total percentage of error was 6%. Second, predictions were made for 1980 based on the 1970 transition matrix. The predictions were then compared to predictions made by the Census Bureau. The second test indicated an approximate 2% overall difference between predictions.

Later, Cleveland and Salkin (9) presented a similar study related to migration in the state of Oklahoma. In this study, two Markov chain models were employed. Model I focused on intrastate migration. Model II differed in that interstate migration was included. Two transition matrices using 1955-1960 and 1965-1970 data were calculated for each model. To test the accuracy of the models, 1965 and 1970 populations were projected on the basis of the 1960 transition matrices. All projections for 1965 were within 10% of the actual in Model I, with only two projections deviating by more than 5% from actual population. Model II projections were quite similar with only three deviating by more than 5%. Model I was used to project the 1975 and 1980 populations based on the 1970 transition matrix. Again, adjustments were made to allow for natural increase as in the previous Salkin paper. The 1975 and 1980 projections were compared with Oklahoma Employment Security Commission projections and were found to be reasonably similar.

A paper by Brown (6), on the use of Markov chains in movement research, critically examines both the strengths and weaknesses of the model. Brown points out that the main strengths of the model are: (1) that it focuses on the dynamic aspects of movement, (2) data are readily available, (3) several descriptive measures and provided, and (4) the parameters are easily estimated. On the other hand, Brown cautioned that the model suffers both from the inability to account for natural increase and the assumption of stationary transition probabilities. Brown summarizes, however, by suggesting that the weakness of the model should not be considered a devastating flaw, especially when it is used as a descriptive tool.

Semi-Markov Chains and Migration

In addition to the criticisms leveled against Markov chain models described in the previous section, there exists one more which has led to the development of semi-Markov chain models. Basically, the criticism relates to an implicit assumption that the population under study is relatively homogeneous with respect to the propensity to migrate. In other words, all members of a population are considered as potential migrants (at least to some degree). Blumen et al. (3) and Goodman (16, 17) were among the first to challenge the assumption of population homogeneity by suggesting that the population might be dichotomized into movers and stayers. Since then, numerous others have jumped aboard "the bandwagon", suggesting that the population might be further stratified by age, sex, occupational group, stage in the family life cycle, and duration of residence. This section discusses some of the more significant contributions relating to the semi-Markovian approach.

The mover-stayer approach was first suggested by Blumen et al. (3) in their study of worker movements among industry groups in the United States. In this study, they found the simple Markov chain model to be a poor predictor of industrial movements. Subsequently, they advanced the idea of disaggregating the population into movers and stayers. The mover stayer concept implies that a large portion of the migration in a region can be attributed to a small segment of total population (i.e., repeated movers). They also presented estimates of the mover transition matrix and the proportion of stayers in each industrial category; unfortunately, the estimates proved to be inconsistent.

Later, Goodman (16) introduced a paper describing a statistical approach to estimating the parameters of the mover stayer model. Goodman's approach yielded estimates that were more consistent than those presented in the earlier Blumen study. Goodman's approach, however, presumes the availability of panel data; that is, a series of observations through time involving the same individuals at each interval.

A second method aimed at the development of a semi-Markov model is termed the duration of residence approach. Basically, this approach disaggregates the population at risk into subsets that form a continuum of probabilities based on previous migration histories. The mover portion of the population is partitioned into groups having different ranges of residential duration. This approach is considered a logical extension of the mover-stayer approach.

Myers et al. (27) have suggested a means by which duration of residence can be integrated within the constant time framework used in traditional Markov chain models. The modified Markov process outlined by Myers et al. permits the transition matrices to change based on the duration of residence structure of the population. Migration histories obtained from 1,700 Seattle High School students permitted incidence of migration to be examined as a function of prior residence. The authors concluded that although the data were not ideal, they indicated a definite trend that supports the duration of residence model. In addition, they discussed three characteristics that data should possess for an adequate test of the model. First, the data should permit duration of residence to be assigned to each resident at the beginning of the migration interval. Second, a move should be sufficiently distant so that a migrant has less social ties to his new location than does an established resident. Third, the unit of time selected as a single duration unit should be short enough so that a resident of duration status one does indeed have significantly less social ties to his community than a resident of duration status three or four.

In a similar but more comprehensive study, Morrison (28) concluded that the probability of migrating declines as duration status increases. Additionally, Morrison's analysis indicated that yet another temporal variable, biological age, played a strong role in determining probabilities of migration. The exact form of the relationship differed from one age group to another suggesting that age was an interesting variable. It is interesting to note that the age and duration specific data used in this study were drawn from the Dutch population register; this tends to substantiate the fact that data meeting the requirement of the duration of residence model are quite limited.

McGinnis (26), in a recent paper on the status of stochastic models of migration, advanced some rather contradictory views regarding the "state of the art". The duration of residence model was viewed as being superior to the Markov chain model because it incorporates a better representation of migration history (i.e., residential duration and biological age). McGinnis summarized by suggesting avenues for improving the model which included the following: (1) conversion from a cohort to a general population model, and (2) inclusion of the birth death processes. McGinnis's first suggestion, however, seems inconsistent in light of the fact that the semi-Markov models were developed specifically to disaggregate the population into meaningful cohorts (i.e., mover-stayer, duration status, and age cohorts) which have been demonstrated to add predictive power to the model.

More recently, Ginsberg (15) has advanced models which incorporate additional population subgroups. For example mobility has been shown to vary with household type, income, race, ethnicity, and several attitudinal variables. Ginsberg demonstrates mathematically that these variables can be incorporated within the semi-Markov framework. To this he adds, however, "because of the complexity of even the simplest cases it would be impossible to construct a single, fully general, realistic, yet computationally feasible stochastic model" (15, p. 123). Ginsberg also pointed out that the development of stochastic models has been seriously constrained by the lack of suitable data with which to test the models.

Morrison (29) has recently suggested the development of a two-stage model. The first is based upon a mover-stayer continuum which accounts for stage in the life cycle, occupational constraints, and past migration history. The second stage, on the other hand, is an allocation mechanism that focuses on the competition between various destination regions for shares of available outmigrants. The allocation mechanism is based upon a regression model of differential attraction. This model incorporates such variables as unemployment, wage rates, size of civilian labor force and intervening distance. Morrison (29, p. 133) cautioned that "the potential forecasting capability of the model is entirely dependent upon the availability of suitable forecasts of unemployment and wage levels."

Summary of Literature Review

This review of literature is by no means an exhaustive work; it merely purports to sketch the development of stochastic models in the social sciences, and discuss some of the more relevant issues involved in the use of stochastic models of social and geographic mobility. Two general approaches were considered. First, the Markov chain approach, and second, the semi-Markov approach.

Stochastic models of social processes, although still at an infantile stage, are now recognized as an important analytical approach. This is borne out by the wide range of applications to which stochastic models have been tested.

Significant contributions have been made in the field of economics. For example, Simon and Bonini (40), Adelman (1), Hart and Prais (21), Collins and Preston (10), and Ijira and Simon (22) have all demonstrated the usefulness of Markov chains in the study of industry concentration. Salow (38) and Smith (41) both provide examples of how income distributions may be studied using Markov chain models.

Another area in which Markov chain analysis has proven to be useful is social and occupational mobility. Examples of such studies are intergenerational mobility of occupational groups by Prais (30), social class distribution by Clark (8), industrial labor mobility by Blumen et al. (3), and changing occupational structure by Rogoff (34).

Anderson (2) demonstrates the usefulness of Markov chain analysis in the study of attitudinal change. His study has opened up a unique avenue for predicting voter behavior.

In the field of migration analysis, several important contributions have been made with regard to the development of stochastic models. Two related but different approaches have surfaced in the literature. These are the Markov chain and semi-Markov chain approaches. Each approach has advantages and disadvantages which should be considered when discussing the two.

The Markov chain model has been shown to be a plausible approach for analyzing and predicting migration. Tarver and Gurley (42) demonstrated the simplicity and consciseness of the Markov chain approach. They pointed out, however, that uncertainty exists in assuming stationary migration probabilities over extended periods of time, and that natural increase is not accounted for.

Rogers (31) addressed the stationarity assumption by suggesting that there is little need to rely on long-range forecasts. In other words, short-range forecasts can be updated as needed given the emergence of real-time information systems.

More recently, Burford (7) and Cleveland and Salkin (9) have reported findings which tend to support the stationarity assumption. Additionally, Salkin et al. (37) and Cleveland and Salkin (9) have introduced a method for incorporating the effects of natural increase into the Markov chain predictions.

On the other hand, Brown (6) questioned the stationarity assumption but also pointed out that the strengths of the model should not be overlooked. Brown highlighted the strengths of the model as follows: (1) its focus on the dynamic aspects of movement, (2) data are readily available, (3) several descriptive measures are provided, and (4) the parameters are easily estimated.

The semi-Markov model has also been shown to be a reasonable approach to studies of migration. The principal difference between the Markov chain and semi-Markov approach lies in the treatment of the population. In the Markov chain approach, the population is presumed to be homogeneous with respect to mobility. In the semi-Markov approach, the population is treated as being heterogeneous with respect to mobility.

Blumen et al. (3) advanced the concept of disaggregating the population into movers and stayers. Later, Goodman (16) introduced a method of statistically estimating the parameters of the mover stayer model. The mover stayer model was suggested to have higher analytical and predictive power than the Markov chain model. Estimating the models' parameters, however, presumes the availability of panel data.

Myers et al. (27) developed a modified version of the mover stayer model which incorporates duration of residence into the transition structure. Their findings suggested that duration status would increase the predictive power of the model. They were unable to test the model, however, because the sample data were too limited to allow construction of transition matrices.

Morrison (28), using data from the Dutch population register, was able to test the duration of residence model. His findings suggested that not only does duration status play a strong role in determining migration probabilities but so also did biological age. McGinnis (26) has also suggested the superiority of the duration of residence model. His reasoning being that it incorporates a more realistic representation of migration history.

Recently, Ginsberg (15) has demonstrated mathematically that additional population subgroups can be incorporated into the semi-Markov model (i.e., household type, race, etc.). He points out, however, that the model soon becomes extremely complex and that suitable data are lacking to test the model.

Finally, Morrison (29) has developed the conceptual and mathematical framework for a two-stage model. The first stage is based on a mover stayer continuum. The second stage is an allocation mechanism which incorporates such variables as unemployment, wage rates, size of labor forces, and intervening distances. The potential of the model, however, hinges on the availability of suitable wage and unemployment forecasts.

The works of Myers, McGinnis, Morrison, and Ginsberg suggest the apparent superiority of the semi-Markov approach as stochastic models of migration. It should be emphasized, however, that the semi-Markov approach has its share of weaknesses. For example, data meeting the requirements of the semi-Markov approach are scarce, and the number of observations required increases in a staggering fashion as parameters are added to the model. Additionally, the issue of incorporating natural increase into the models has, as yet, not been addressed.

In the final analysis, one is not faced with a clear cut choice between the better of two approaches. More aptly, one is faced with a choice between the practical and the ideal. The Markov chain approach offers ease of operation at the expense of precision. The semi-Markov approach, on the other hand, offers increased precision but is difficult to operationalize.

CHAPTER III

METHODOLOGY

Introduction

The purpose of the chapter to follow is to present as concise and clear a description of Texas migration as the data will permit. The achievement of this end required the selection of an effective model that would yield meaningful descriptions and insightful conclusions about the migration process. If these descriptions are to be useful, they should impart to the reader an indication of the impact of migration on the individual SEA's of Texas and also provide comparative measures for different temporal periods.

Because the data employed are limited to gross migrant flows between areas, the Markov chain technique was selected. This technique allows the estimation of several SEA characteristics including:

(1) stayer probabilities (a measure of SEA immobility),

(2) mean stay time (average years of residence in SEA),

(3) fixed probability vectors (an indication of the equilibrium characteristics of the migration process), and

(4) predictions of future population distribution (an indication of the consequences of the migration processes).

The purposes of this chapter are to present a brief overview of Markov chain theory, the requisites for application of the theory, a discussion of the models used in the present study, and a brief definition of terms.

Markov Chain Theory

A stochastic process can be described as a sequence of events in which the outcome on each individual event in the sequence depends on some probability P. For systems obeying probabilistic laws, one may estimate the probability P, that the system will be in a given state at a given time K + 1 from knowledge of its state at an earlier time. If the probability P does not depend on the history of the system prior to the previous time period, K, we have a special type of stochastic process known as a Markov process. A Markov chain is a special case of a Markov process where both the state space and the time space are discrete (by convention the discrete spaces are also considered to have a finite set of points).

The Markov chain process is characterized by the transition matrix

$$P = \begin{bmatrix} p_{11} & p_{12} \cdots p_{1j} \cdots p_{1n} \\ p_{21} & p_{22} \cdots p_{2j} \cdots p_{2n} \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ p_{i1} & p_{i2} \cdots p_{ij} \cdots p_{in} \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ p_{n1} & p_{n2} \cdots p_{nj} \cdots p_{nn} \end{bmatrix} \qquad (1)$$

Here, p_{ij} represents the probability of the system being in state j during period K + 1 given that it was in state i during period K. If $p^{(0)} = p_1^{(0)}, p_2^{(0)}, p_3^{(0)}, \ldots p_i^{(0)}, \ldots p_n^{(0)}$ is the vector of probabilities of being in state 1, state 2, ... state i, or state n initially, and if $p^{(1)} = p_1^{(1)}, p_2^{(1)}, \ldots p_j^{(1)}, \ldots p_n^{(1)}$ is the vector of probabilities of being in state 1, state 2, ... state j, or state n in the next period of the process, then

$$p^{(1)} = p^{(0)}P. \tag{2}$$

Similarly,

$$p^{(2)} = p^{(1)}P = p^{(0)}P^{(2)}, \tag{3}$$

$$p^{(3)} = p^{(2)}P = p^{(0)}P^{(3)}, \tag{4}$$

.

.

.

$$p^{(K)} = p^{(K-1)}P = p^{(0)}P^{(K)}. \tag{5}$$

Hence, if in a given case a system behaves according to a Markov chain process, it is possible to determine the probabilities of being in any given state K periods in the future by applying equation (5). That is, it is only necessary to raise the square matrix P to the K^{th} power and multiply on the left by the initial probability vector.

It should be noted that since $p^{(0)}, p^{(1)}, \ldots p^{(K)}$ are all probability vectors with each of their elements representing probabilities of being in that particular state at the given period, the sum of the elements in each such vector must equal one. That is to say,

$$\sum_{j=1}^{n} p_j^{(K)} = 1 \text{ for all } K. \tag{6}$$

Similarly, since p_{ij} in the transition matrix (equation 1) represents the probability of making the transition from state i to state j for all i and j, each row in P is also a probability vector. Thus,

$$\sum_{j=1}^{n} p_{ij} = 1 \text{ for all } i. \tag{7}$$

Consider a given set S of states in a system. If it is possible in a Markov chain to reach such state in S from every other state (not necessarily in one time period) and if once a state in S is reached the system can reach every other state in S but can never leave S, then the set S is called an "ergodic set" of states. All other states in the chain are called "transient states". All Markov chains have at least one ergodic state but not all such chains have transient chains. It is possible that the entire chain may comprise a single ergodic set of states.

If a process leaves a transient set of states, it can never return to that set; while if it ever enters an ergodic set, it can never leave it. If an ergodic set contains only one element, then this is a single state which once entered can never be left. Such a state is called an "absorbing state". A given state S_i is absorbing if and only if $p_{ii} = 1$; i.e., the probability of entering state i in one period and remaining in that state in the next period is one. A Markov chain with at least one absorbing state is termed an "absorbing chain".

An ergodic chain is a "regular Markov chain" if the entire chain is made up of a single ergodic set such that for some power of P all of its elements are greater than zero. If it is possible to reach each state from every other state but only in a specified cycle of periods (greater than one), the chain is "cyclic".

The regular Markov chain is of particular importance in this study. If the transition matrix P is regular, then the powers (P^K) of P approach a probability matrix W as K approaches infinity. Each row of W is the same probability vector $w = (w_1, w_2, \ldots w_j, \ldots w_n)$, where all the components w_j are greater than zero. The vector w is known as the "fixed point" of P (fixed probability vector); w is a vector such that $wP = w$, and W is a matrix such that $pW = w$ for any arbitrary probability vector p. In particular, if $p^{(0)}$ is the initial probability vector then $p^{(K)} = p^{(0)}P^{(K)}$ approaches w as K approaches infinity. That is to say, after enough periods have passed, the system tends to approach an equilibrium such that the probability of being in state j is independent of the initial state probabilities. In most cases this equilibrium tends to be reached rather quickly.

Regular Markov chains have several more interesting and useful characteristics, two of which have significance in this study. The first are the stayer probabilities, which are an interpretation of the diagonal elements of the transition matrix. The diagonal elements represent the probability of not moving from the respective states during the corresponding periods (i.e., the p_{ii}). These probabilities represent immobility. The second characteristic is known as the mean stay time. Specifically, the mean stay time is the average number of time periods a process will stay in a given state given that it is already in that state. The mean stay time is computed as $1/(1 - p_{ii})$ where p_{ii} is the i^{th} diagonal element in the transition matrix.

The foregoing, oversimplified as it is, constitutes the rudiments of finite Markov chain theory. For a complete study and for the proofs of the equations, the reader is referred to Kemeny and Snell (24).

Requisites for Application of the Theory

In order to utilize the Markov approach in the study of migration let us consider as states of the process the Texas SEA's, and denote the set of outcomes by $S_1, S_2, \ldots S_n$, where S_1 = residence in SEA 1, S_2 = residence in SEA 2, and S_n = residence in the last SEA. The symbol $p_{ij}^{K=1}$ is used to denote the transition probability that outcome S_j will occur in period $K + 1$ given the outcome S_i occurred in period K. If we view migration in this fashion, the following conventions are required:

(1) Migration from any SEA to another SEA in a given time period is regarded as a stochastic event with some probability of occurrence.

(2) The probability of migration from SEA i to SEA j, summed for all j, will equal unity; that is, $\sum_{j=1}^{n} p_{ij} = 1$.

(3) The migration probabilities, p_{ij}, between two SEA's do not change over time; that is, do not depend on K.

(4) The initial starting distribution of population is known.

Given data m_{ij} indicating migration between pairs of SEA's over some interval of time, the transition probabilities p_{ij} are readily estimated as $p_{ij} = m_{ij}/\Sigma m_{ij}$. From the resulting transition matrix we may then estimate the stayer probabilities, the long run probabilities of migration (fixed probability fector), the average years of residence for given SEA's, and predict future population distributions by means of powers of the transition matrix.

The Models

Two Markov chain models were employed in this study. Model I was designed to focus on interSEA migration within the state of Texas; interstate migration was not considered. Eliminating the effects of interestate migration allowed the relative attractiveness of the Texas SEA's to be compared. Two transition matrices using 1955-1960 and 1965-1970 data were calculated for Model I; this permitted a check against recent changes in migration trends.

Model II differed from Model I in two respects. First, interstate migration was incorporated into the transition matrix. The remaining 49 states were grouped into one SEA-at-large and labeled Remainder of U. S. (RUS). Second, only the 1965 to 1970 transition matrix was calculated. The sole purpose of Model II was an attempt to increase the accuracy of the population projections.

In both models, the 1975 projections were adjusted for natural increase. This was accomplished by adding the 1965-1970 rates of natural increase to the model projections. To test the accuracy of both models, the 1975 projections were compared with the 1975 Census Bureau estimates.

Definition of Terms

In the field of migration research, many terms are used to describe mobility status. In some cases, a simple mover-stayer dichotomy is used. The Census Bureau, on the other hand, uses the following classification: (1) non-mover (same house), (2) mover (different house same county), (3) migrant (different county same SEA, different county different SEA, different county same state, etc.). In this study, a simple dichotomy was used. The following terms have specific meaning in this study:

(1) Migrant--a person who changes his SEA of residence during a five-year period.

(2) Migration probability--the probability of a person changing his SEA of residence during a five-year period.

(3) Stayer--a person who does not change his SEA of residence during a five-year period.

(4) Stayer probability--the probability of a person not changing his SEA of residence during a five-year period.

(5) Intrastate migrant--a person who changes his SEA of residence but not his state of residence.

(6) Interstate migrant--a person who changes both his SEA and state of residence.

CHAPTER IV

ANALYSIS AND CONCLUSIONS

Introduction

In this final chapter, the results of the Markov chain analysis as well as the summary and conclusions are presented. Interest is focused on two aspects of the results. First, an attempt is made to meaningfully describe the migration process and its effect on population growth of the subregions (SEAs) of Texas. Second, the Markov chain technique is assessed as a descriptive tool for migration research. Throughout this chapter, the limitations of the data should be kept in mind; that is, input to the Markov chain models consisted primarily of two variables--the initial distribution of SEA populations and the inter-SEA migration flows. A third variable, SEA net natural increase, was employed in one segment of the analysis to supplement the Markov chain projections.

As discussed earlier in Chapter III, it is the transition matrix of the Markov chain model that captures and embodies the structure of the migration process being modeled. All descriptive measures of the migration process are either extracted directly from the transition matrix, or, are derivatives of it. In this study, the migration flows between all possible pairs of the 31 SEAs of Texas are concisely represented by a 31 by 31 transition matrix (a second model, however, consisting of a 32 by 32 matrix is also employed). As simple and concise as the matrix representation is, it still can be confusing to the reader and interpreter of the data. The approach taken in the analysis, then, is to partition the transition matrix and present each measure separately. The analysis is presented under the following subheadings:

(1) stayer probabilities,

(2) mean stay times,

(3) fixed probability vectors,

(4) salient migration flows,

(5) SEA populations and projections, and

(6) summary of analysis.

Results of the Analysis

In Chapter III, two analytical models were described. Model I was designed to focus on migration within the state of Texas. Model II was designed, on the other hand, to take into account the flows of migrants into and out of the state of Texas from the remainder of the United States. The focus of the present study is on migration within the borders of Texas. Therefore, the first four sections of the analysis refer specifically to Model I. In the fifth section, results of both Model I and Model II are compared to illustrate the difference in predictive power when population projections are made.

Before the results of the analysis are discussed, it may prove useful to examine a map of the study area. The locations and spatial relationships among the SEAs of Texas are illustrated in Figure 1.

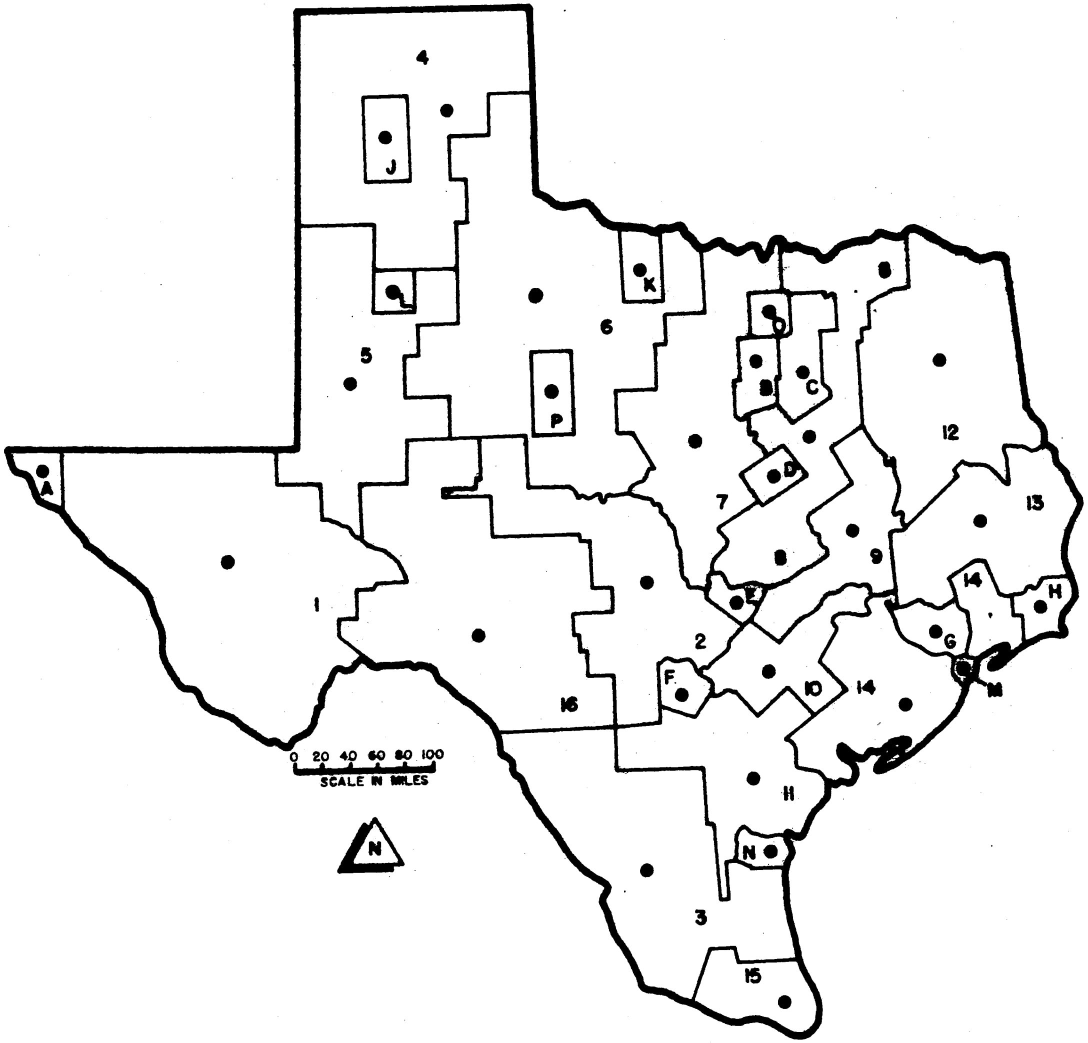

Figure 1. Map of Texas Showing Locations of SEAs

Stayer Probabilities

When applied to the study of migration, the diagonal elements of the transition matrix are referred to as stayer probabilities. That is, they represent the probability of not migrating (staying) from a given SEA. The stayer probabilities for all of the Texas SEAs are presented in Table I. The stayer probabilities are shown for two periods of time so that a temporal change in the migration process may be detected.

Overall, the data indicate a decrease in stayer probabilities over time. However, when the data are viewed with respect to metropolitan/nonmetropolitan status, opposite trends are apparent. Eleven of the 16 nonmetropolitan SEAs show an increase in stayer probabilities while all 15 of the metropolitan SEAs demonstrate a decline in stayer probabilities. The interpretation here is that the nonmetropolitan segment of the population became less mobile during the time periods shown, while at the same time the metropolitan counterpart became increasingly mobile. This finding corresponds with the general theory among demographers that the metropolitan segment of the population is more mobile than the rural segment.

The uniformity of the trend in mobility among the nonmetropolitan SEAs was not as definite as the metropolitan trend. There were five nonmetropolitan SEAs, which counter to the nonmetropolitan trend, showed increases in mobility (decreases in stayer probabilities). There is no apparent explanation for the deviation of these five nonmetropolitan SEAs. It is opinioned that there may be some significant economic differences between the five deviant SEAs and the remaining nonmetropolitan SEAs. However, substantiation of this idea is beyond the scope of this paper.

TABLE I

STAYER PROBABILITIES IN TEXAS SEAS

Metropolitan/ Nonmetropolitan Classification	SEA	1955-1960	1965-1970	Change
Nonmetropolitan	1	.7924	.7862	-.0062
	2	.8195	.8422	+.0227
	3	.8681	.8684	+.0003
	4	.8521	.8198	-.0323
	5	.8378	.7984	-.0394
	6	.8104	.8167	+.0063
	7	.8336	.8585	+.0249
	8	.8416	.8651	+.0235
	9	.8244	.8317	+.0073
	10	.8531	.8809	+.0278
	11	.8362	.8533	+.0171
	12	.8897	.9042	+.0145
	13	.8565	.8664	+.0099
	14	.8655	.8661	+.0006
	15	.9210	.9058	-.0152
	16	.8013	.7924	-.0089
Metropolitan	A	.9405	.9371	-.0034
	B	.8980	.8830	-.0150
	C	.9152	.8998	-.0154
	D	.8485	.8392	-.0083
	E	.8454	.8426	-.0028
	F	.9165	.9117	-.0048
	G	.9240	.9114	-.0126
	H	.9184	.8993	-.0191
	J	.8685	.8057	-.0628
	K	.8457	.8194	-.0263
	L	.8197	.7751	-.0446
	M	.8893	.8815	-.0078
	N	.8505	.8426	-.0079
	O	.7963	.7707	-.0256
	P	.7992	.7514	-.0478

Mean Stay Times

A second measure used to identify temporal changes in the migration process is termed the mean stay times. This measure is a product of the transition matrix and translates to the average number of years people reside in each of the Texas SEAs prior to migration. By comparing the columns in Table II, an indication of changes in the mean stay times for the Texas SEAs can be determined.

In general, the data in Table II indicate a downward trend in mean stay times. However, considering the nonmetropolitan and metropolitan SEAs separately yields opposing trends. On the average, the change in stay times for nonmetropolitan SEAs between census periods was a positive .175 years. The corresponding change for the metropolitan areas averaged out to a negative 1.1 years. This can be interpreted to mean that for the nonmetropolitan segment of the population the length of residence prior to migrating has increased while that for the metropolitan segment of the population has decreased. If we further compare the average rates of change between the nonmetropolitan and metropolitan populations, we find the metropolitan population increased their mobility at a rate of approximately six times that of the non-metropolitan population.

All 15 of the metropolitan SEAs experienced decreased stay times. The nonmetropolitan SEAs demonstrated 11 increases and five decreases in stay times. The five nonmetropolitan SEAs showing decreases in stay times correspond directly with the five SEAs in Table I which showed declining stayer probabilities.

TABLE II

MEAN STAY TIMES

Metropolitan/ Nonmetropolitan Classification	SEA	1955-1960 (1)	1965-1970 (2)	Change (3)
Nonmetropolitan	1	4.8	4.7	-0.1
	2	5.5	6.3	+0.8
	3	7.6	7.7	+0.1
	4	6.8	5.5	-1.3
	5	6.2	5.0	-1.2
	6	5.3	5.5	+0.2
	7	6.0	7.1	+1.1
	8	6.3	7.4	+1.1
	9	5.7	5.9	+0.2
	10	6.8	8.4	+1.6
	11	6.1	6.8	+0.7
	12	9.1	10.4	+1.3
	13	7.0	7.5	+0.5
	14	7.4	7.5	+0.1
	15	12.7	10.6	-2.1
	16	5.0	4.8	-0.2
Metropolitan	A	16.8	15.9	-0.9
	B	9.8	8.5	-1.3
	C	11.8	10.0	-1.8
	D	6.6	6.2	-0.4
	E	6.5	6.4	-0.7
	F	12.0	11.3	-0.7
	G	13.2	11.3	-1.9
	H	12.3	9.9	-2.4
	J	7.6	5.1	-2.5
	K	6.5	5.5	-1.0
	L	5.5	4.4	-1.1
	M	9.0	8.4	-0.6
	N	6.7	6.4	-0.3
	O	4.9	4.4	-0.5
	P	5.0	4.0	-1.0

Fixed Probability Vectors

A third useful measure derived from the transition matrix, referred to as the fixed probability vector, is used to characterize the equilibrium characteristics of the migration process. The elements of the vector represent the long run probability of migrating to each of the 31 SEAs in Texas, regardless of a person's SEA of residence in 1955 or 1965.

The fixed probability vectors for the two census periods are presented in Table III.

Examination of the vector for the first census period reveals that SEAs G, C, B, F, 12 and 5 are the six most popular SEAs in the state. Whereas, for the second census period, SEAs G, C, B, 12, F and 8 are the most popular SEAs. There appears to be a substantial amount of change in SEA popularity between the two census periods. Column 3 of the table indicates the absolute change between census periods. Overall, 18 of the SEAs have negative changes or loss of popularity. The remaining 13 SEAs have positive changes or gains in popularity. Singling out the nonmetropolitan SEAs, there is an even split between those that gained and those that lost popularity. Of the metropolitan SEAs, 10 have a loss of popularity with only five gaining in popularity. Of overriding consideration in viewing these SEA "performances" in the decline of metropolitan popularity and the increase in nonmetropolitan popularity. The 10-year span between the two census periods appears to mark the terminal shift of population as a function of rural to urban flow.

Up to this point in the analysis, the comparison of the descriptive measures for the two census periods has proven to be enlightening. In

TABLE III

FIXED PROBABILITY VECTORS

Metropolitan/ Nonmetropolitan Classification	SEA	1955-1960 (1)	1965-1970 (2)	Change (3)
Nonmetropolitan	1	.006173	.003057	-.003116
	2	.017283	.019522	+.002239
	3	.010458	.008373	-.002085
	4	.024220	.007315	-.016905
	5	.048299	.014817	-.033482
	6	.023351	.011997	-.011354
	7	.023142	.029026	+.005884
	8	.034111	.050560	+.016449
	9	.012167	.015063	+.002896
	10	.008840	.014195	+.005353
	11	.013023	.011793	-.001230
	12	.050218	.077391	+.027173
	13	.021000	.040560	+.019560
	14	.031851	.045157	+.013306
	15	.024837	.012091	-.016279
	16	.006028	.003000	-.003028
Metropolitan	A	.032566	.015533	-.017033
	B	.079632	.078144	-.001488
	C	.132505	.146357	+.013852
	D	.014882	.012696	-.002186
	E	.030125	.036043	+.005918
	F	.063556	.057589	-.005967
	G	.151009	.188501	+.037492
	H	.030984	.025053	-.005931
	J	.020968	.005904	-.015064
	K	.011884	.005246	-.006588
	L	.024795	.010485	-.014310
	M	.014526	.019753	+.005227
	N	.015942	.012839	-.003103
	O	.007657	.013990	+.008333
	P	.014018	.005948	-.008070

Table I we saw indications of an overall decrease in stayer probabilities which in turn translates to an increase in mobility. In Table II we viewed an overall intercensal decrease in mean stay times which also translate to increased mobility. Finally, in Table III we had some indication of structural change in the migration process itself; that is, long-standing metropolitan domination was beginning to diminish.

It is apparent from the above three tables that the migration transition structures between the two census periods are substantially different. It is also apparent that an attempt to project future SEA population distributions based on the 1955-1960 transition matrix would result in poor predictions. With the knowledge of recent changes of the migration process in mind, the remainder of the analysis will focus on the more recent transition matrix.

Salient Migration Flows

Rather than examine all 930 migration flows in the transition matrix, the analysis will be restricted to the more significant or salient migration flows. In order to identify the most significant flows, a selection criterion of $P_{ij} > .0125$ was employed. This means that only those pairs of SEAs having a migration probability greater than .0125 were considered to be significant flows. The results of this selection process are presented in Table IV and represent the largest 98 population flows in Texas. Although these flows comprise only 10 percent of the flows, they account for approximately 50 percent of the total migrants. It is these 98 salient flows that will most strongly dictate the future population distributions in Texas.

TABLE IV

SALIENT MIGRATION FLOWS
(P_{ij} > .0125)

SEA	to SEA	Migration Probability	SEA	to SEA	Migration Probability
1	5	.0723	14	G	.0535
	6	.0129	15	G	.0211
	A	.0180	16	2	.0274
2	E	.0130		5	.0229
	F	.0260		F	.0186
3	F	.0196	B	7	.0144
	G	.0147		C	.0252
	N	.0152		O	.0214
4	5	.0196	C	8	.0169
	6	.0127		12	.0159
	C	.0174		B	.0167
	J	.0319	D	8	.0204
	L	.0242		B	.0194
5	4	.0142		C	.0279
	B	.0193		E	.0135
	C	.0177		G	.0186
	G	.0175	E	8	.0136
	L	.0262		C	.0216
6	5	.0184		F	.0150
	7	.0163		G	.0342
	B	.0175	F	G	.0170
	C	.0171	G	13	.0149
	L	.0126		14	.0147
	P	.0156	H	13	.0221
7	8	.0140		G	.0339
	B	.0323	J	4	.0301
	C	.0151		B	.0186
8	C	.0344		C	.0273
9	C	.0164		G	.0211
	E	.0138		L	.0177
	G	.0438	K	6	.0186
10	14	.0184		7	.0126
	F	.0183		B	.0316
	G	.0215		C	.0322
11	14	.0176		G	.0148
	F	.0231	L	4	.0149
	G	.0189		5	.0263
	N	.0185		B	.0270
12	C	.0258		C	.0452
	G	.0171		G	.0195
13	12	.0154	M	14	.0134
	G	.0478		G	.0461
	H	.0202			

TABLE IV (Continued)

SEA to SEA		Migration Probability	SEA to SEA		Migration Probability
N	11	.0210	P	5	.0191
	C	.0146		6	.0286
	G	.0358		7	.0129
O	7	.0143		B	.0399
	B	.0332		C	.0355
	C	.0998		G	.0153
	G	.0126			

Examination of Table IV indicates that the four largest flows are from SEA O to SEA C, SEA 1 to SEA 5, SEA 14 to SEA G, and SEA 13 to SEA G. Further examination of the data reveal a multitude of flows and counterflows too numerous to detail here. For ease of presentation, the data are summarized in Figure 2.

The overriding trend portrayed in Figure 2 appears to be a migratory convergence on SEAs B, C, F and G. These metropolitan SEAs represent the larger urban areas of Texas including Fort Worth, Dallas, San Antonio and Houston respectively.

Figure 2 also highlights some areas of significant migratory outflow or divergence. In particular, SEAs 1, 3, 9, 10, 15, K, and M all show salient inflows of migrants. Moreover, these same SEAs show no salient outflows of migrants to counter their losses.

Some caution should be exercised in interpreting the data on salient flows for two reasons. First, the data only account for half of the migrants. The lesser migration flows, as insignificant as they may seem, can and do have substantial effects on the migration process

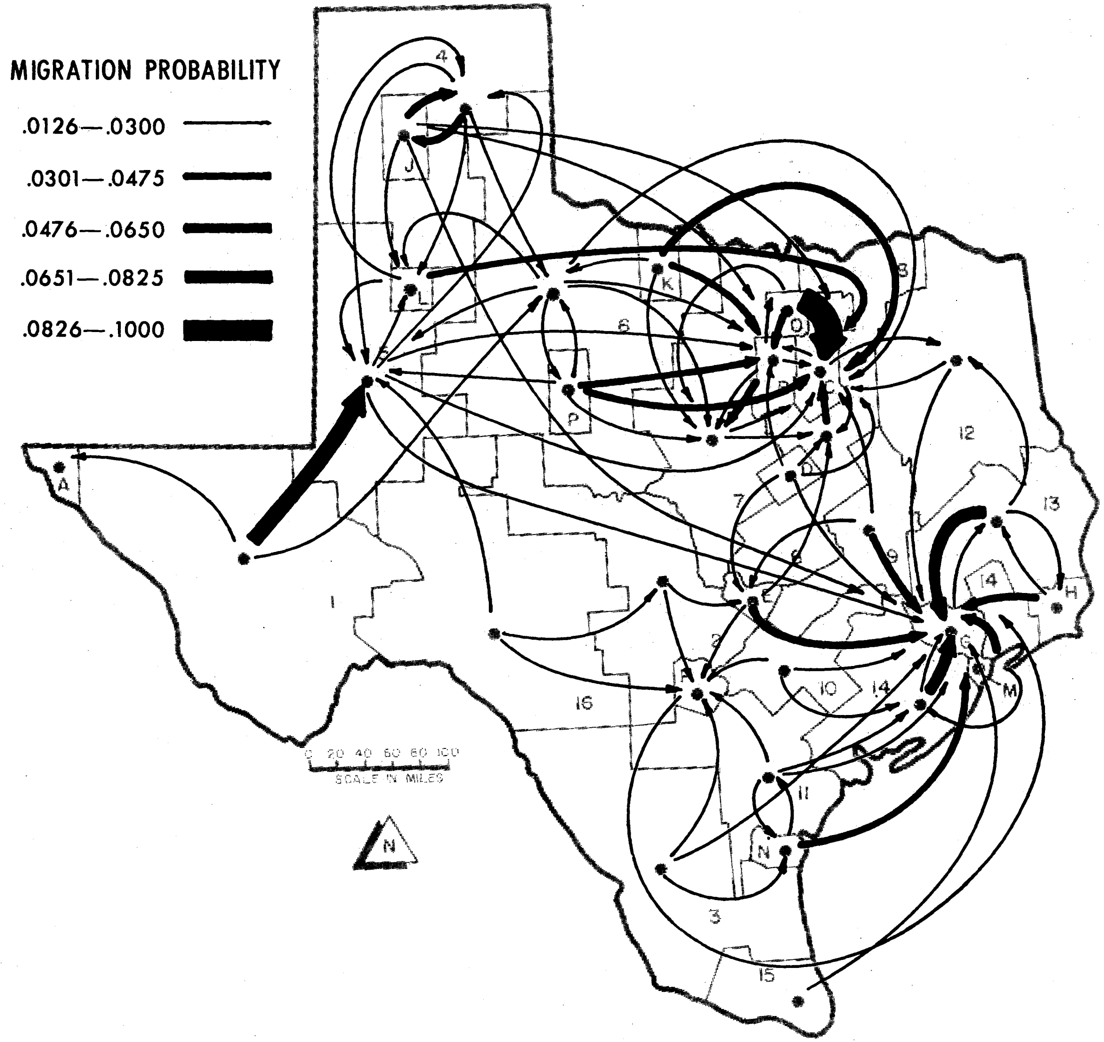

Figure 2. Salient Migration Flows

at hand. We have not presented all of them simply because of their sheer number. This does not imply that their additive effect is not important. Second, the salient flows presented above represent only the short-run migration process. As we have seen in Table III (fixed probability vectors), the long-run consequences of the migration process can be quite different than we might expect if we limit the analysis to a short-term view of the process.

SEA Populations and Projections

Beyond providing several meaningful measures of mobility, the Markov chain technique allows the estimation of future population distributions. In Table V, the presentation of the initial SEA populations is made, as well as a series of population projections based on two Markov chain models. Model I accounts only for the migratory flows within the state of Texas, while Model II accounts additionally for interstate flows between Texas and the remainder of the United States. Since the focus of the present study is concerned with intrastate flows of population, emphasis will be placed on the results of Model I. Model II results are presented for comparison and should, at least in theory, produce more accurate projections of the SEA populations. A series of maps (Figures 3, 4, 5 and 6) are included and correspond to columns 1, 3, 11 and 14 of Table V respectively.

The 1975 population projections without natural increase are detailed in columns 3 and 4 of Table V. Comparing the initial population distribution (column 1) with projected distributions permits examination of recent change. Model I projections indicate SEAs 2, 7, 8, 9, 10, 12, 13, 14, B, C, E, G and O will grow at the expense of the

TABLE V

SEA POPULATIONS FOR 1970 AND 1975 WITH PROJECTIONS TO 1975, 1980 AND THE LONG RUN

SEA	1970 Census Population (1)	1975 Census Estimate (2)	Projected 1975 Population Without Natural Increase: Model I (3)	Projected 1975 Population Without Natural Increase: Model II (4)
Nonmetropolitan				
1	63,377	62,500	60,667	59,789
2	218,838	245,100	224,075	224,524
3	197,754	210,400	187,637	187,032
4	210,256	209,800	194,737	191,952
5	344,677	351,300	318,627	317,954
6	232,403	235,600	221,488	219,838
7	263,873	269,600	274,314	295,064
8	505,267	556,400	508,586	528,290
9	147,113	167,300	148,795	148,935
10	125,502	130,800	129,517	132,799
11	208,127	213,400	200,673	200,141
12	672,361	722,400	684,325	689,156
13	249,102	313,000	270,207	271,070
14	400,795	447,900	410,229	412,192
15	337,473	406,000	320,970	309,973
16	79,989	89,000	72,581	74,046
Metropolitan				
A	359,291	414,700	349,354	347,399
B	762,086	795,700	778,793	823,966
C	1,441,253	1,543,600	1,456,951	1,543,091
D	147,553	156,700	145,883	142,484
E	295,516	359,400	313,328	322,188
F	830,460	910,400	820,198	860,305
G	1,741,912	1,963,600	1,768,652	1,857,765
H	317,572	314,500	307,941	311,110
J	144,396	152,000	136,199	130,188
K	126,322	128,400	115,986	128,067
L	179,295	196,700	176,170	173,700
M	169,812	182,000	173,225	179,574
N	237,544	247,600	226,548	229,129
O	75,663	101,100	97,105	99,646
P	113,959	119,100	106,025	108,117
Total	11,199,541	12,216,000	11,199,486	11,519,484

TABLE V (Continued)

SEA	Percent Error Model I (5)	Percent Error Model II (6)	Projected 1975 Population with Natural Increase Model I (7)	Projected 1975 Population with Natural Increase Model II (8)
Nonmetropolitan				
1	-2.9	-4.3	65,167	64,289
2	-8.6	-8.4	229,175	229,624
3	-10.8	-11.2	207,337	206,732
4	-7.2	-8.5	205,037	202,252
5	-9.3	-9.5	338,527	337,854
6	-6.0	-6.8	220,888	219,238
7	+1.7	+9.4	278,414	299,164
8	-8.6	-5.0	526,086	545,790
9	-11.2	-11.0	151,795	152,235
10	-1.0	+1.5	131,017	134,299
11	-5.9	-6.2	210,373	209,841
12	-5.3	-4.6	697,425	702,256
13	-13.7	-13.4	279,007	279,870
14	-8.4	-8.0	429,129	431,092
15	-20.9	-23.6	363,070	352,073
16	-18.4	-16.8	78,281	79,746
Metropolitan				
A	-15.7	-16.2	386,354	384,349
B	-2.1	+3.5	815,993	861,166
C	-5.6	0.0	1,546,851	1,632,991
D	-6.9	-9.1	149,483	146,084
E	-12.8	-10.3	315,828	324,688
F	-9.0	-5.5	881,598	921,705
G	-9.9	-5.3	1,889,252	1,978,365
H	-2.1	-1.1	319,641	322,810
J	-10.4	-14.3	143,199	137,188
K	-9.7	-0.3	122,086	134,167
L	-10.4	-11.7	188,870	186,400
M	-4.8	-1.3	180,325	186,674
N	-8.5	-7.5	245,948	248,529
O	-3.9	-1.4	101,305	103,846
P	-10.9	-9.2	111,125	113,217
Total	-8.3	-5.7	11,808,586	12,128,534

TABLE V (Continued)

SEA	Percent Error Model I (9)	Percent Error Model II (10)	Projected 1980 Population Without Natural Increase Model I (11)	Projected 1980 Population Without Natural Increase Model II (12)
Nonmetropolitan				
1	+4.3	+2.8	58,112	56,916
2	-6.5	-6.3	227,966	229,418
3	-1.4	-1.7	178,491	178,298
4	-2.3	-3.6	181,176	177,662
5	-3.6	-3.8	296,833	298,185
6	-6.2	-6.9	211,715	209,983
7	+3.2	+10.9	283,151	321,582
8	-5.4	-1.9	512,036	549,142
9	-9.3	-9.0	149,876	151,289
10	+0.2	+2.6	133,098	139,537
11	-1.4	-1.7	193,955	193,733
12	-3.5	-2.8	695,694	706,693
13	-10.8	-10.6	288,809	291,338
14	-4.2	-3.7	418,704	423,718
15	-10.6	-13.3	305,738	287,108
16	-12.0	-10.4	66,506	69,641
Metropolitan				
A	-6.8	-7.3	339,859	338,236
B	+2.5	+8.2	793,259	877,351
C	+0.2	+5.8	1,472,394	1,632,850
D	-4.6	-6.8	144,558	139,347
E	-12.1	-9.6	328,243	344,308
F	-3.2	+1.2	810,392	885,213
G	-3.8	+0.7	1,793,562	1,960,174
H	+1.6	+2.6	299,830	306,662
J	-5.8	-9.7	128,780	120,081
K	-4.9	-4.5	107,326	129,247
L	-4.0	-5.2	172,393	168,979
M	-0.9	+2.6	176,464	188,501
N	-0.7	+0.4	216,963	222,748
O	+0.2	+2.7	113,918	118,653
P	-6.7	-4.9	99,667	104,330
Total	-3.3	-0.7	11,199,468	11,820,923

TABLE V (Continued)

SEA	Percent Change 1970-1980 Without Natural Increase (Col 11-Col 1 / Col 1 x 100) (13)	Projected Long Run Population Without Natural Increase: Model I (14)	Projected Long Run Population Without Natural Increase: Model II (15)
Nonmetropolitan			
1	-8.3	34,239	51,405
2	+4.2	218,634	292,910
3	-9.7	93,776	152,450
4	-13.8	81,921	138,187
5	-13.9	165,940	265,817
6	-8.9	134,361	200,144
7	+7.3	325,077	518,903
8	+1.3	566,242	963,957
9	+1.9	168,697	211,904
10	+6.5	158,981	226,932
11	-6.8	132,081	190,227
12	+3.4	866,745	1,054,295
13	+15.9	454,250	542,727
14	+4.5	505,739	638,586
15	-9.4	135,413	190,722
16	-16.8	33,600	61,588
Metropolitan			
A	-5.4	173,958	314,615
B	+4.1	875,180	1,313,349
C	+2.2	1,639,128	2,430,953
D	-2.0	142,184	166,314
E	+11.1	403,661	514,561
F	-2.4	644,965	1,072,842
G	+3.0	2,111,119	2,984,308
H	-5.6	280,585	362,992
J	-10.8	66,121	100,305
K	-15.0	58,758	138,632
L	-3.8	117,428	167,906
M	+3.9	221,222	290,407
N	-8.7	143,794	223,233
O	+50.6	179,079	228,892
P	-12.5	66,617	107,466
Total	0.0	11,199,495	16,117,579

TABLE V (Continued)

SEA	Percent Change 1970-Long Run Without Natural Increase $(\frac{\text{Col 14-Col 1}}{\text{Col 1}} \times 100)$ (16)
Nonmetropolitan	
1	-45.9
2	-0.1
3	-52.6
4	-61.0
5	-51.8
6	-42.2
7	+23.2
8	+12.1
9	+14.7
10	+26.7
11	-36.5
12	+28.9
13	+82.3
14	+26.2
15	-59.8
16	-57.9
Metropolitan	
A	-51.6
B	+14.8
C	+13.7
D	-3.6
E	+36.6
F	-22.3
G	+21.2
H	-11.6
J	-54.2
K	-53.5
L	-34.5
M	+30.3
N	-39.5
O	+136.7
P	-41.5
Total	0.0

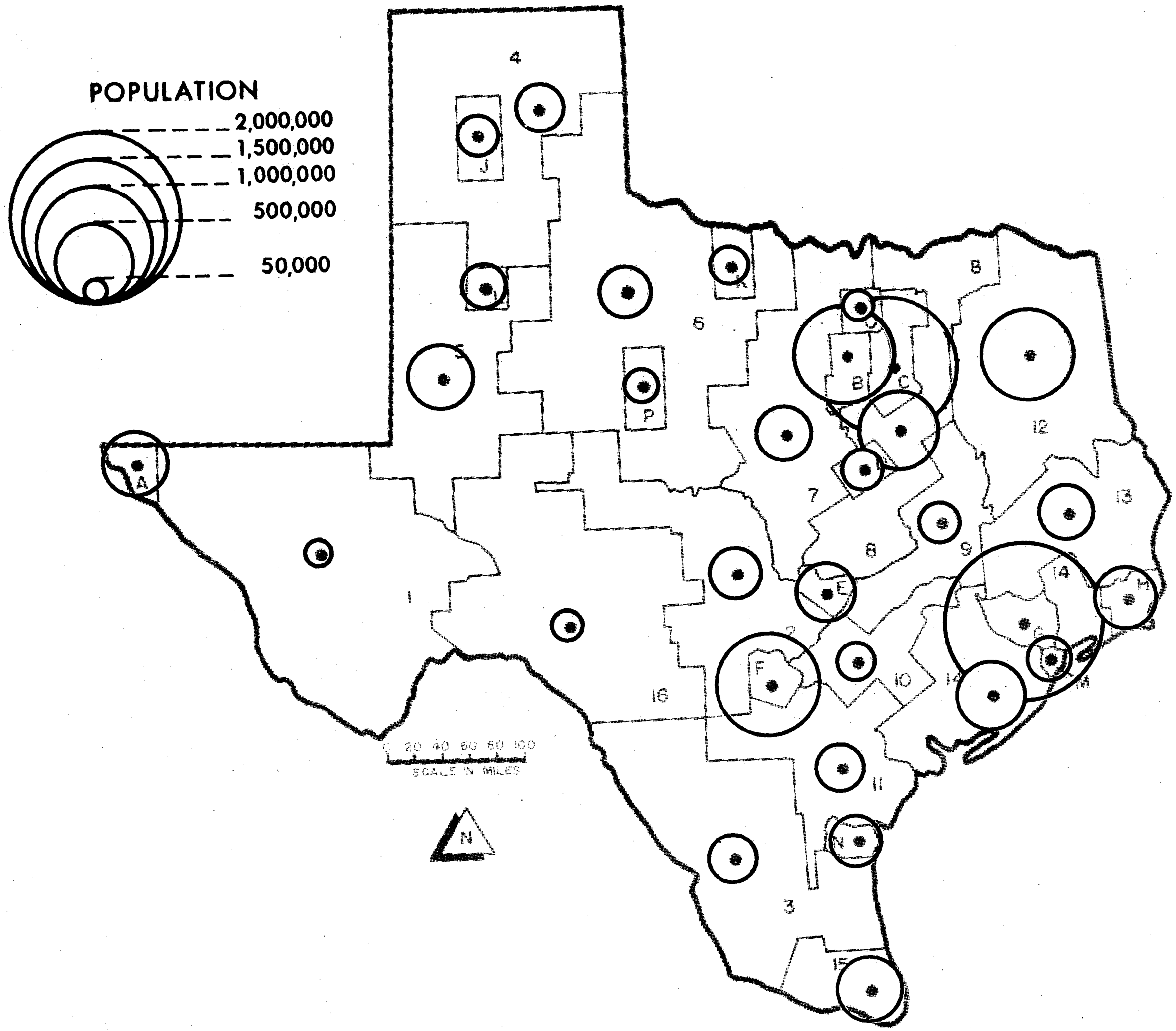

Figure 3. The 1970 Census Population Distribution

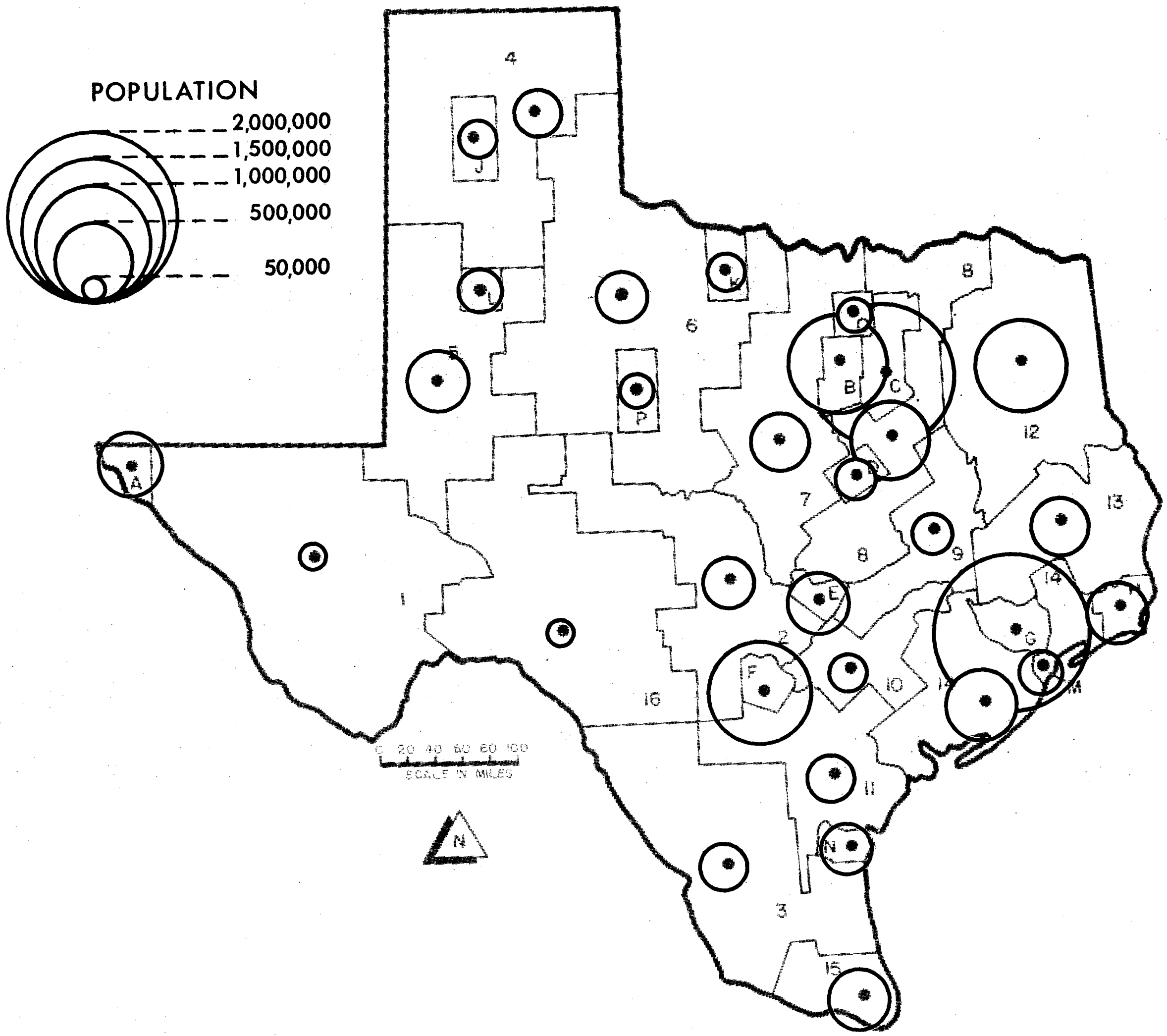

Figure 4. Projected 1975 Population Distribution

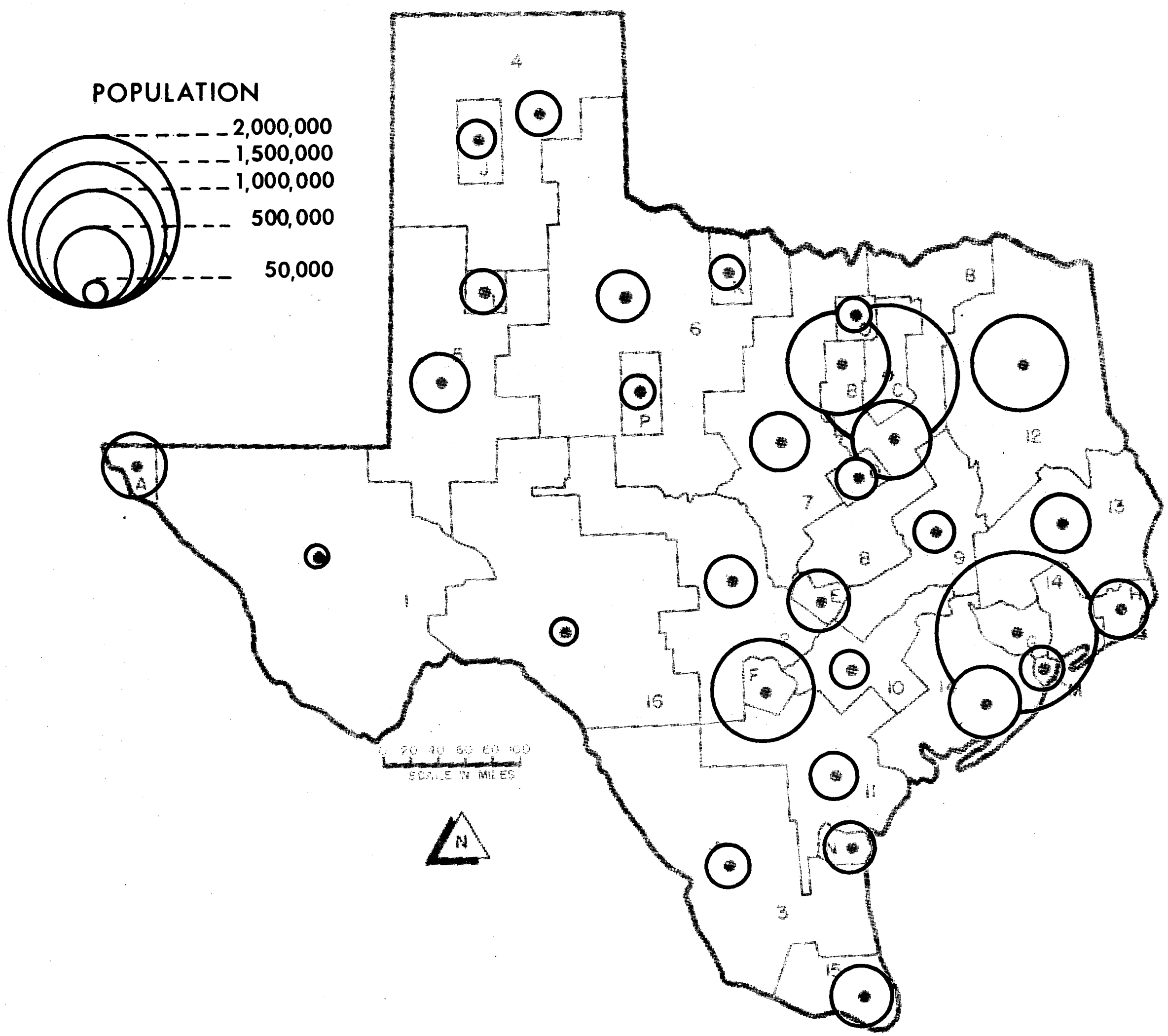

Figure 5. Projected 1980 Population Distribution

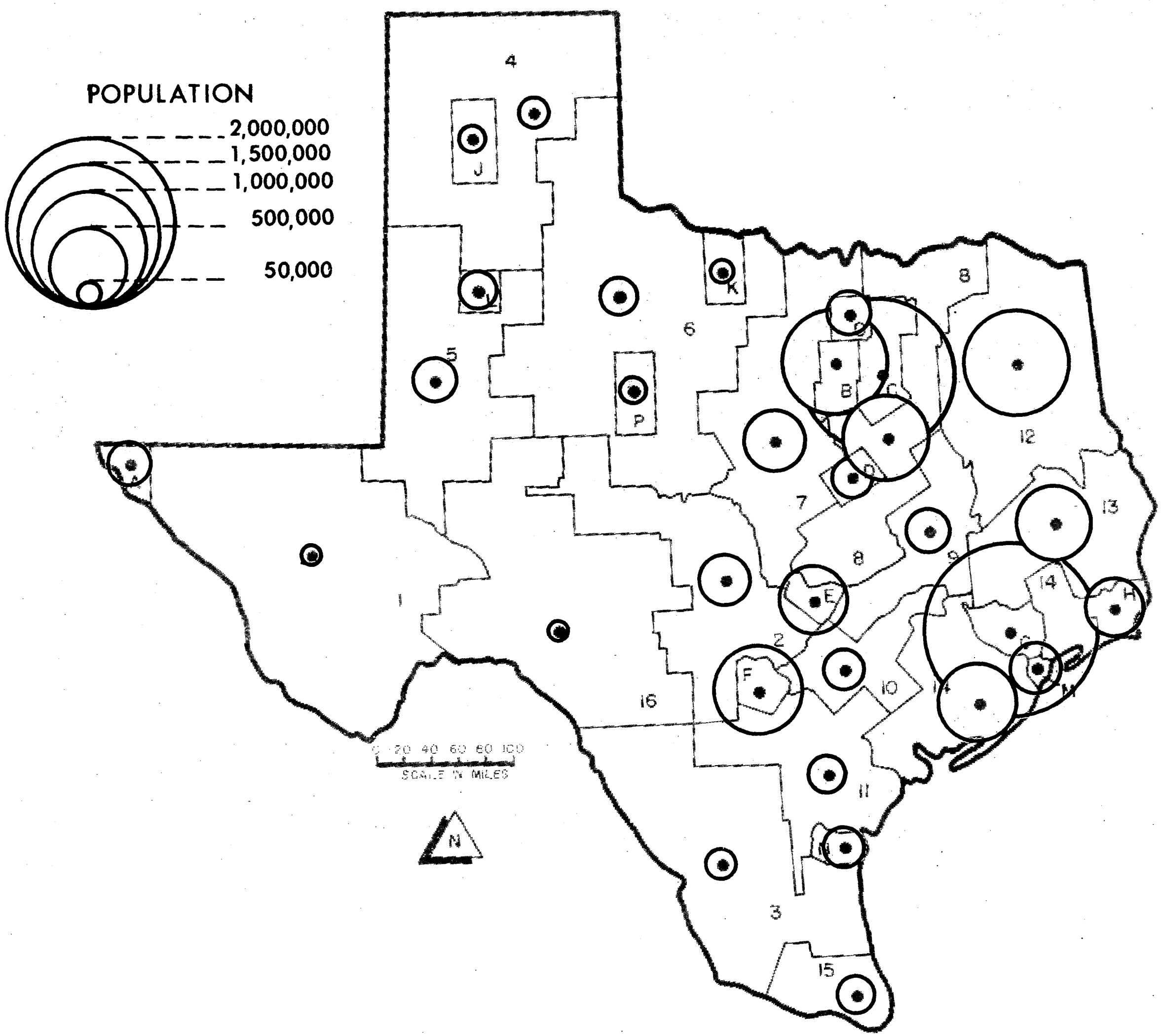

Figure 6. Projected Long-Run Population Distribution

remaining SEAs. Model II projections indicate two additional SEAs (F and K) will be added to the list of gainers. The differences between Model I and Model II are attributed to the influence of interstate migration. Figures 3 and 4 highlight the 1970 and projected 1975 population distributions, based on Model I.

Columns 5 and 6 of Table V list the percent error or deviation between the 1975 census estimate (column 2) and Model I and Model II projections respectively. There is a considerable range of error in both models. On the average, Model I underestimated the SEA populations by 9.1 percent. The corresponding figure for Model II is 7.1 percent underestimation. We must keep in mind, however, that the census estimates (column 2) reflect both net natural increase and net migration. Model I and Model II projections for this same year are based solely on net migration. Therefore, adjustments to the projections were made on the basis of previous rates of net natural increase (columns 7 and 8).

The 1975 projections adjusted for natural increase show a substantially different set of SEAs that are predicted to gain population. Model I projections indicate all SEAs with the exception of 4, 5, 6, 16, I, K and P will gain population. Model II projections indicate approximately the same pattern but add one more SEA (D) to the list of losers.

Columns 9 and 10 of Table V show the percent error between adjusted projections and the 1975 census estimates. Again, the range of error for both models is considerable. In most cases, however, the percent error for the adjusted projections are substantially smaller than the unadjusted projections. In fact, the average error for Model I has dropped to 3.4 percent underestimation and the average error for

Model II has declined to 2.4 percent underestimation. Overall, the adjusted projections are quite reasonable considering the simplicity of the basic model. Model II, in general, produces superior estimates over Model I. Each model should, however, be viewed in light of its intended use. That is, Model I is intended to focus on intrastate movement alone. Model II, on the other hand, is intended to provide more accurate projections.

The projected 1980 populations are presented in columns 11 and 12 of Table V. Comparable 1980 census projections were unavailable. Therefore, no attempt was made to test the accuracy of the projections or to adjust them for natural increase. Instead, attention is focused on the projected redistribution of population. Comparison of the initial distribution (column 1) with the projected 1980 distribution (columns 11 and 12) allows a short-run glimpse of the distributional consequences of the migration process being modeled.

The same basic pattern of gainers and losers noted in the 1975 projections is apparent in the 1980 projections. However, the impact of migration on the populations of the SEAs becomes more apparent. If the SEAs are grouped by metropolitan/nonmetropolitan status, we find that in 1970 38.0 percent of the population was residing in non-metropolitan SEAs and 68.0 percent of the population was residing in metropolitan SEAs. By 1980, the proportions are projected to be only marginally different, with 37.5 percent residing in nonmetropolitan areas. On the surface, it would appear the traditional rural to urban flow is still in effect. The broadness of the metropolitan/non-metropolitan classification, however, tends to mask the true exchange of migrants.

In column 13 of Table V, the relative population changes are presented between 1970 (column 1) and 1980 (column 11) exclusive of natural increase. Examining the nonmetropolitan SEAs there is an even split between areas that gained and areas that lost. The metropolitan SEAs totaled six gains and nine losses. When the population changes for the individual SEAs are examined, it is apparent that it is not a simple case of declining nonmetropolitan areas and growing metropolitan areas. More aptly, it is a case of selective growth and decline of both metropolitan and nonmetropolitan areas. Figures 3 and 5 illustrate the projected changes between 1970 and 1980. Some of the more significant changes shown on these maps are SEA O with a 50.6 percent increase, SEA 16 with a 16.8 percent decrease, SEA 13 with a 15.9 percent increase, SEA K with a 15.0 percent decrease and SEAs 4 and 5 with 13.8 and 13.9 percent decreases respectively.

Model II projections (column 12 of Table V) show basically the same set of gainers and losers as Model I. There are, however, substantial differences in the magnitudes of gains and losses. These differences stem from the interstate migration flow introduced in Model II. Furthermore, the state total for columns 1 and 12 indicate an overall increase in population. This would seem to indicate that Texas as a whole will gain population through net interstate immigration.

Columns 14 and 15 of Table V list the long run projections for Models I and II respectively. The long run, in this case, translates roughly to 350 years beyond the base year 1970. The long run projections should be interpreted with caution because of the marginal likelihood of a human process continuing for such a great length of time. The long run projections do, however, provide an indication of what would result if the process did continue unabated. Summarizing column 14, we find that in the long run 36.4 percent of the population is projected to reside in nonmetropolitan SEAs with the remaining 63.6 percent in metropolitan SEAs. Within the nonmetropolitan group, however, we find seven SEAs predicted to gain and nine to lose population. The corresponding figures for metropolitan SEAs are six gains and nine losses. Figure 6 illustrates the projected long-run distribution of population.

Column 15 of Table V lists long-run projections based on Model II. In general, the same pattern of gainers and losers are predicted by Model II as were predicted by Model I. The difference being five SEAs (SEA 2, SEA D, SEA F, SEA H and SEA K) added to the list of gainers. This can be interpreted to mean that net interstate immigration is substantial in these five areas. Again, the growth in the column total is worth noting; the projected state total indicates a net interstate immigration of substantial volume (4.9 million).

Column 16 and Figures 3 and 6 detail the relative projected population changes between 1970 and the long run based on Model I. The two areas showing the largest relative increases are SEAs O and 13. The areas with the two largest losses are SEAs 4 and 15. Also notable are SEAs 2 and D with minimal projected population change. These two areas appear to be stable with regard to net intrastate migration.

Summary of Analysis

The Markov chain technique employed in this study performed quite well and, in general, appeared to be a useful tool for the analysis of migration and prediction of future population distributions. Two indicators of the power of the Markov chain technique are the number of meaningful descriptive measures provided and the accuracy of the population projections.

The stayer probabilities permitted simultaneous examination of mobility, immobility and temporal change in mobility of the study population. Mean stay times allowed the estimation of the average years of residence in each SEA and also changes in residency through time. The fixed probability vector permitted examination of the long run characteristics of the migration process and provide a measure of the relative attractiveness of each SEA and changes in attractiveness through time. The salient migration flows represented but a small sample of the total inter-SEA migrant flows contained in the transition matrix. The salient migration flows permitted isolation of the largest and most significant inter-SEA flows. Finally, the Markov chain technique allowed the estimation of future population distributions. The projections permitted a "motion picture" view of the consequences of the migration process being studied, each frame being a different point in time.

Regarding the accuracy of the projections, the Markov chain technique proved to be quite satisfactory. Using the simpler of two models (Model I), the average error was within 9.1 percent of the "actual" population. Model II, the more elaborate and intuitively appealing model, produced an average error within 7.1 percent of the "actual" population. It was found that, by adjusting the projections for natural increase, the average error was reduced to 3.4 percent and 2.4 percent underestimation for Models I and II respectively. It should also be noted that the "benchmark" for which the percent errors were calculated are no more than projections themselves. That is, the 1975 census estimates are projections based on updates of the 1970 census of population, and as such, are subject to error too. The projections derived from the Markov chain models may have been better or worse depending on the accuracy of the census estimates. Since the 1975 census estimates were the only available measures of the "actual" SEA populations, they were assumed for all practical purposes to be correct.

Listed below is a summary of findings resulting from the analysis:

(1) For the state as a whole, the population has become increasingly mobile.

(2) The nonmetropolitan and metropolitan segments of the population exhibited opposite mobility trends. The nonmetropolitan segment lost mobility while the metropolitan segment gained mobility.

(3) Overall, the population of the state experienced a reduction in average years of residence.

(4) The nonmetropolitan and metropolitan segments of the population exhibited opposing trends of residency. The nonmetropolitan segment showed an increasing length of residency while the metropolitan segment showed a decreasing length of residency.

(5) For the state as a whole, Texas is predicted to be a popular destination for interstate migrants.

(6) Considering only intrastate migration, some of the most popular areas in the state in the long-run are predicted to be SEAs 0 and 12 (northeast), SEA 13 (east), SEA E (east

central), SEA M (southeast), and SEA 10 (south central).

(7) Isolation of salient migration flows yielded 98 individual flows. Although these flows represent only 10 percent of the total flows, they accounted for approximately 50 percent of all migrants.

(8) The traditional flow of migrants from rural to urban areas is predicted to diminish in the long-run future. There appears to be a new dynamic surfacing in which traditional flows of rural to urban migrants are being augmented by counterflows back to the rural areas.

Summary and Conclusions

It was noted in Chapter I that practically nothing has been known about the direction, extent, or volume of the internal movement of population in Texas. Further, no adequate frame of reference (i.e., a subregional approach) has been developed for Texas. Thus, the present study was designed to meet the following criteria:

(1) select an adequate geographic base that would meet the needs of the present study as well as future research efforts of a similar nature,

(2) provide an analysis of past migration patterns for the entire state,

(3) examine the impact of migration on population growth for the subregions of Texas, and

(4) forecast future population distributions within the state, based on past migration patterns.

Chapter II, the review of literature, outlined the use of stochastic models in social research. It was noted that recognition of the possible usefulness of Markov chain theory in geographic, economic and other social problems has come about only recently. Principal areas in which Markov chain theory had been applied are industrial concentration, income distribution, and occupational and social mobility.

In the field of migration analysis, two related but different approaches surfaced in the literature. These are the Markov chain and semi-Markov chain approaches. Each approach was found to have specific advantages and disadvantages. It was suggested that although much of the more recent literature advocates the use of semi-Markovian models, their applications are severely limited because of inherent data requirements. Finally, it was suggested that the use of stochastic models for migration research has been relatively limited.

Chapter III provided an overview of the Markov chain theory, the requisites for application of the theory to migration, and a discussion of the models employed in the present study. Briefly, the two models advanced in this study were designed to meet separate objectives. Model I was designed to focus on intrastate migration, with no allowances made for interstate migration. Although this design is somewhat unrealistic, it does permit the effect of intrastate migration on population growth to be isolated. Model II was designed to account for both inter and intrastate migration in the hopes of improving the accuracy of the population projections. Finally, a method of adjusting the projections for natural increase and testing the accuracy of the models was described.

In Chapter IV, the results of the analysis were presented. It was found that the state as a whole experienced a recent increase of mobility. Additionally, the population of Texas has shown a decrease in the average length of residency. Isolation of salient migration flows yielded 98 individual flows which accounted for approximately 50 percent of all migrants. Focus on intrastate migration revealed several popular SEAs (O, 13, E, M, 12 and 10) all of which are concentrated in the eastern half of the state. Texas was predicted to be a popular destination for interstate migrants. Further, there appeared to be a new dynamic surfacing in which long-standing flows of rural to urban migration are being augmented by counterflows back to the rural areas.

The Markov chain technique employed in this study performed surprisingly well, and generally appeared to be a powerful tool for the analysis of migration. Specifically, the technique provided a number of useful measures including stayer probabilities, mean stay times, fixed probability vectors, salient migration flows, and a series of projections. All of the above measures added insight into the migration process. Additionally, the projections were found to be reasonably accurate. In general, Model II provided superior projections. However, both models showed improved projections when adjusted for natural increase.

In the introductory chapter of this study it was noted that a subregional scheme has not been developed for Texas. The geographic framework selected for this study was State Economic Areas. Overall the SEAs proved to be adequate area units with the following exceptions:

(1) They did not, in all cases, represent continuous areas; witness SEA 14.

(2) Although considerable work was spent in their design and delineation, it is doubtful that after 20 years they still represent homogeneous areas.

It is suggested that a fertile avenue of future research might still be the delineation of a meaningful subregional scheme for Texas. Conceivably this might entail an overhaul of the existing SEAs or the development of an entirely new set of subregions.

In addition to the development of a subregional scheme, the present study has underscored a second area of needed research relating to the Markov chain technique itself. Specifically, a method is needed that will integrate both the birth and death process and the migration process into the Markov chain framework.

BIBLIOGRAPHY

1. Adelman, Irma. "A Stochastic Analysis of the Size Distribution of Firms." Journal of American Statistical Association, Vol. 53, No. 284 (1958), pp. 893-904.

2. Anderson, T. W. "Probability Models for Analyzing Time Changes in Attitude." In Paul F. Lazarsfeld (ed.), Mathematical Thinking in the Social Sciences. Glenco, Ill.: Free Press, 1954.

3. Blumen, et al. The Industrial Mobility of Labor as a Probability Process. Ithica: Cornell University, 1955.

4. Bogue, D. J. "Internal Migration." In P. M. Hauser and O. D. Duncan (eds.), The Study of Populations: An Inventory and Appraisal. Chicago: University of Chicago Press, 1959.

5. Browder, W. G. "The Population of Texas, 1900-1940: A Preliminary Survey." (Unpub. M.S. thesis, University of North Carolina, 1941.)

6. Brown, L. A. "On the Use of Markov Chains in Movement Research." Economic Geography, Vol. 46 (1970), pp. 393-403.

7. Burford, Roger. "Probability Projections of Rates of Net Migration for Southern Counties and Other Applications of Markov Chains." Louisiana Business Bulletin, Vol. 25, No. 1 (July, 1966).

8. Clark, W. "Markov Chain Analysis in Geography: An Application to the Movement of Rental Housing Areas." Ann. Assoc. Am. Geogr., Vol. 55 (1965), pp. 351-359.

9. Cleveland, O. A. and M. Salkin. "Prediction of the Distribution of Future Residents in Oklahoma." Growth and Change, Vol. 6, No. 4 (1975), pp. 32-36.

10. Collins, N. and L. Preston. "The Size Structure of the Largest Industrial Firms, 1909-1958." American Economic Review, Vol. LI, No. 5 (1961), pp. 986-1011.

11. de Cani, J. S. "On the Construction of Stochastic Models of Population Growth and Migration." Journal of Regional Science, Vol. 3, No. 2 (1961), pp. 1-13.

12. Dorn, Harold. "Pitfalls in Population Forecasts and Projections." Journal of the American Statistical Association, Vol. 45 (1950), pp. 311-334.

13. Duncan, Otis D. "Social Forecasting--The State of the Art." The Public Interest, No. 17 (1969), pp. 88-118.

14. Ginsberg, R. "Critique of Probabilistic Models: Application of the Semi-Markov Model to Migration." Journal of Mathematical Sociology, Vol. 2 (1972), pp. 63-82.

15. Ginsberg, R. B. "Stochastic Models of Residential and Geographic Mobility for Heterogeneous Populations." Environment and Planning, Vol. 5 (1973), pp. 113-124.

16. Goodman, L. A. "Statistical Models for the Mover-Stayer Model." Journal of American Statistical Association, Vol. 56 (1961), pp. 841-868.

17. Goodman, L. O. "Statistical Methods for Analyzing Processes of Change." American Journal of Sociology, Vol. 68 (1962), pp. 57-78.

18. Goodrich, Carter et al. Migration and Economic Opportunity. Philadelphia: University of Pennsylvania Press, 1938.

19. Haenszel, W. "Concept, Measurement, and Data in Migration Analysis." Demography, Vol. 4, No. 1 (1955), pp. 253-261.

20. Hajnal, John. "The Prospects for Population Forecasts." Journal of the American Statistical Association, Vol. 50 (1955), pp. 309-322.

21. Hart, P. and S. J. Prais. "Analysis of Business Concentration, A Statistical Approach." Journal of the Royal Statistical Society, Series A, Vol. 119 (1956), pp. 150-191.

22. Ijira, Y. and H. Simon. "Business Firm Growth and Size." American Economic Review, Vol. LIV, No. 2 (1964), pp. 77-89.

23. Jordan, T. G. "Population Origins in Texas, 1850." Geographical Review, Vol. 59 (1969).

24. Kemeny, John G. and J. Laurie Shell. Finite Markov Chains. Princeton, N. J.: Van Norstrand Co., 1960.

25. Lee, E. S. "A Theory of Migration." Demography, Vol. 3 (1966), pp. 47-57.

26. McGinnis, Robert. "A Stochastic Model of Social Mobility." American Sociological Review, Vol. 33 (1968), pp. 712-722.

27. Meyers, G. C., et al. "The Duration of Residence Approach to a Dynamic Stochastic Model of Internal Migration: A Test of the Axiom of Cumulative Inertia." Eugenics Quarterly, Vol. 14, No. 2 (1967), pp. 121-126.

28. Morrison, P. A. "Duration of Residence and Prospective Migration: The Evaluation of a Stochastic Model." Demography, Vol. 4 (1967), pp. 553-561.

29. Morrison, P. A. "Theoretical Issues in the Design of Population Mobility Models." Environment and Planning, Vol. 5 (1973), pp. 125-134.

30. Prais, J. "Measuring Social Mobility." Journal of the Royal Statistical Society, Series A, Vol. 118 (1955), pp. 55-66.

31. Rogers, Andre. "A Markovian Policy Model of Interregional Migration." Regional Science Association, Vol. 17 (1966), pp. 205-224.

32. ____________ and Robert Miller. "Estimating a Matrix Population Growth Operator from Distributional Time Series." Annals, A.A.G., Vol. 57 (1967), pp. 751-756.

33. ____________. Matrix Analysis of Interregional Population Growth and Distribution. University of California Press, 1968.

34. Rogoff, N. Recent Trend in Occupational Mobility. Glencoe, Illinois: Free Press, 1953.

35. Roseman, Curtis. "Channelization of Migration Flows from Rural South to the Industrial Midwest." Proceedings, A.A.G., Vol. 19, No. 3 (1971), pp. 140-145.

36. Roseman, Curtis. "Migration as a Spatial and Temporal Process." Annals, A.A.G., Vol. 61 (1971), pp. 589-598.

37. Salkin, M. S., et al. "Population Predictions for Western United States: A Markov Chain Approach." Journal of Regional Science, Vol. 15, No. 1 (1975), pp. 53-60.

38. Salow, R. "Some Long-Run Aspects of the Distribution of Wage Incomes." Econometrica, Vol. 19, No. 3 (1951), pp. 333-334.

39. Shaw, Paul. Migration Theory and Fact. Bibliography Series Number Five, Regional Science Research Institute, 1975.

40. Simon, H. A. and C. P. Bonini. "The Size Distribution of Business Firms." American Economic Review, Vol. XLVIII, No. 4 (1958), pp. 607-617.

41. Smith, P. "Markov Chains, Exchange Matrices, and Regional Development." Journal of Regional Science, Vol. 3, No. 1 (1961), pp. 27-36.

42. Tarver, J. D. and R. Gurley. "A Stochastic Analysis of Geographic Mobility and Population Projections of the Census Division in the U.S." Demography, Vol. 4 (1965), pp. 134-139.

43. Thomas, Dorothy S. Research Memorandum on Migration Differentials (Bulletin 43). New York: Social Science Research Council, 1938.

44. Trewartha, Glenn T. A Geography of Populations: World Patterns. New York: John Wiley and Sons, 1969.

45. U. S. Bureau of the Census. Population Estimates and Projections, Current Population Reports. Series p-25, No. 637, 1976.

46. U. S. Bureau of the Census. County and City Data Book. Washington, D. C.: U. S. Government Printing Office, 1972.

47. U. S. Bureau of the Census. U. S. Census of Population, Subject Reports Mobility for State Economic Areas (Final Report PC (2)-2E), 1972, and (Final Report PC (2)-2B), 1963. Washington, D. C.: U. S. Government Printing Office.

48. Vance, Rupart. Population Redistribution in the United States (Bulletin 42). New York: Social Science Research Council, 1938.

49. Whelpton, P. K. Needed Population Research. Lancaster, Pennsylvania, 1938.

VITA

Gary Duane Lauver

Candidate for the Degree of

Master of Science

Thesis: A STOCHASTIC ANALYSIS OF INTERNAL MOBILITY WITH POPULATION PROJECTIONS FOR THE STATE ECONOMIC AREAS OF TEXAS

Major Field: Geography

Biographical:

Personal Data: Born in Fort Wayne, Indiana, October 11, 1951, the son of Mr. and Mrs. Hugh O. Lauver.

Education: Graduated from Cabrillo High School, Lompoc, California, June, 1969; received the Associate of Arts degree from Columbia College at Columbia, California, with a major in liberal arts in June, 1972; received the Bachelor of Science degree from California Polytechnic State University at San Luis Obispo with a major in natural resource management in December, 1974; completed the requirements for the Master of Science degree at Oklahoma State University in December, 1977.

Professional Experience: Park technician, Monterey County Parks, spring and summer, 1974; graduate research assistant, Department of Geography, Oklahoma State University, fall and spring, 1975; field supervisor, Choctaw Indian Census, summer, 1975; administrative aid, Division of Oklahoma State Parks, fall, 1976; planner, Tulsa Metropolitan Area Planning Commission, 1976-1977.

Professional Organizations: Member of Association of American Geographers, American Institute of Planners, Regional Science Association, and Urban and Regional Information Systems Association.