Lifecycle Stage, Automobility Cohort and Travel: Probing into Structural Change in Urban Travel

Doctoral Dissertation

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This dissertation is dedicated to Professor Ryuichi Kitamura.

Abstract

The mobility of urban residents has been expanding over time. Kitamura and susilo (2005) have shown that this expansion stems more from structural change (i.e. change in the relationship between travel behavior and demographic factors), than from change in demographic and socio-economic characteristics (for example, attributes of the individuals and households, such as, more women employed, the household size shrinking, and the resident population aging) of urban residents. Urry (2005) went to conjecture that this structural change is due to increasingly prevailing automobility, i.e., conversion of social and economic system and way of life to adapt to the ownership and use of the automobile. In this study, this conjecture is explored by examining automobility characteristics across lifecycle stages and across automobility cohorts over time. The level of automobility is operationally defined in this study in terms of: automobile ownership, total auto travel time, modal split, and the fraction of trip attraction in traditional central city in the study area. The Kyoto-Osaka-Kobe (Keihanshin) metropolitan area of Japan is the study area of this effort.

Intra-household interaction has dominant influences on household members' activity and travel, and also it is closely associated with lifecycle stage. Lifecycle stage factor is introduced into the analytical scope of this study and regarded as a main factor through this research. Nine stages of household lifecycle are formulated according to the classification scheme of the family lifecycle stage. The classification scheme utilizes the criteria, which generally are age and marital status of household head, presence and age of children of head, presence of other relatives and non-relatives. On the other side, changing the built environment affects urban residents' travel behavior to a large extent. This study explores how automobility characteristics and travel activity behavior changed across lifecycle stages within different residential areas over time using statistical analyses. The results confirm that the residence area rather than lifecycle stage is a significant explainer for automobile ownership and automobile use. It further

suggests that even within each lifecycle stage, change in the automobile use over time is suppressed in commercial and mixed commercial/residential areas. However, the fraction of automobile trips for suburbs, unurbanized areas, and autonomous areas increased over time in the range of 0 to 4 times depending on the lifecycle stage. Younger childless couple stage and all adults' stage are more auto-oriented in suburbs, unurbanized area, and autonomous areas, and this trend becomes stronger as automobility progresses. No significant differences were observed in the numbers of trips for households of the same lifecycle stage across different residential areas, suggesting that similarly active lifestyles exist. The results suggest that household members' age is also a strong explainer for the fraction of auto trips and total auto travel time, through a four variable ANOVA analysis, including lifecycle stage, residence area, time, and age effect.

It has been pointed out that the elderly of these days behave differently than the elderly grew up with the automobile and have been using it ever since their habit forming ages. Thus another important factor introduced into this research is automobility cohort which is defined by grouping individuals who turn 20 years old during the time period indicated. Each time period is chosen with respect to the level of automobility. The following five cohorts are developed for the study area and used in the analysis: pre-war (up to 1945), pre-motorization (1946-1960), initial growth (1961-1970), mass-ownership (1971-1980), and multi-car ownership (1980-). Using the repeated cross-sectional data of Kyoto-Osaka-Kobe metropolitan area in 1970, 1980, 1990, and 2000, this study has attempted to offer a possible explanation of the increases in automobility characteristics by examining automobility characteristics of automobility cohorts. In addition, time effects and age effects are introduced into the analysis as in standard cohort analysis. It focused on statistical age-period-cohort analysis using the popular multiple classification APC model. The identifiability problem attendant with the use of APC model was discussed with repeated cross-sectional data. An interesting finding is shown that pre-war and pre-motorization cohorts show little, roughly 6%, increase on the fraction of auto trips and nearly unchanged on total auto travel time over 1970 through 2000, although their household automobile ownership has increased more than 2 times. Initial growth, mass-ownership, and multi-car ownership cohorts show a great growth of automobile ownership, the fraction of auto trips, and auto travel time from 1970 to 2000, but a little surprising result is that mass-ownership cohorts, not multi-car ownership cohorts, show the largest increases to rely on auto use over 1970 through 2000. The above results confirm that each cohort having certain automobility traits that are unique, especially in terms of auto use. The standard age-period-cohort analysis confirms that automobility cohort effect do exist, unfortunately, automobility cohort effect is not an important explainer for automobility characteristics, while time effect plays an important part in automobile ownership choice, and age effect mainly determines automobile use. An attempt at APC-RA model illustrate that residence area rather than time effect have the strongest impact on automobile ownership, and age effect is still a significant explainer for the fraction of auto trips and auto travel time. This result is different with the results of age-period-cohort analysis, which further emphasize that residence area is a significant explainer for household automobile ownership in the Kyoto-Osaka-Kobe metropolitan area from 1970 to 2000.

Significant changes in demographic and socio-economic characteristics of urban resident have taken place over the past several decades. Most notable are: aging of the population and resulting increases in retired, non-employed individuals; decreasing household size caused by increasing fractions of single individuals and couples with fewer children; increased labor force participation by women; general increased in income; and increasing auto ownership and auto dependence. The overall effects on travel of these changes are complex and future trends are not immediately obvious, partly because some of the changes have opposite, cancelling effects on travel, and partly because these changes themselves are not independent but closely linked to each other. Prevailing tendencies in travel, however, have been expansion—urban residents' travel has continuously expanded over time in terms of total travel time (or distance), auto use, energy consumption, and the spatial extension of their action space. Will these trends continue into the future? Or will the trend change due to the aging of the urban population? Or are there other factors at work? If so, what are the magnitudes of demographic effects relative to theirs? The focus of this study is on auto travel. The analysis examines how auto travel has changed over time with changing demographics, residential location, and metropolitan structure. Simultaneous equations model systems are developed at the household level, with auto ownership, fraction of auto trips and total auto travel time as its dependent (or endogenous) variables. Their automobility characteristics are characterized and behavioral distinction identified through examination of the models' coefficient estimates. Using the repeated household travel survey results, the stability over time of the simultaneous equation system is statistically examined, and thereby the effects of demographics changes are separated from those of structural change. Using the results, it is shown how much of the change in urban auto travel is due to changes in demographics and how much is due to structural change. The statistical analyses have offered strong evidence that urban residents' auto use have been expanding. The results have further indicated that this expansion has been caused primarily by changes in the structural relationships even mixed changes in demographic factors have had opposite, cancelling effects on auto travel. In addition, the resultant model system is applied in a scenario analysis to forecast possible changes in future auto travel that will follow hypothetical demographic changes in the metropolitan area.

To face the coming global energy crisis and air pollution issues, the above results with the findings of this study would suggest that significantly more sustainable behavior for society would be possible with more compact built environments that facilitate non-motorized and public transit travel. Unfortunately, it takes time, money, resources, and the political will to change the built environment and initial steps that educate the public such as voluntary travel behavior change may be necessary first steps on the move to more sustainable travel.

As a suggestion for future works, more statistical analysis on interaction effects of three variables or four variables ANOVA analysis, including lifecycle stage, residence area, time, and age effects, need to be considered. Also, the interaction effects of age-period-cohort analysis need us to pay more attention on the future work. The simultaneous equations model system is developed as an attempt to explore how much of the change in urban travel is due to changes in demographics and how much is due to structural change, more endogenous variable could be considered in the future research, such as, residential location, commute distance, and commute trip mode choice.

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This dissertation is dedicated to Professor Ryuichi Kitamura.

CONTENTS

List of Tables

List of Figures

Chapter 1
Introduction

Most analyses of urban activity and travel patterns are concerned with the behavior of each individual. The focus on life cycle stage is in part based on the understanding that interactions among household members affect each member's activity and travel. (Kitamura, R, 2001)

1.1 Background

The issue of accommodating household interdependencies has not received adequate attention in activity-based modeling studies until much recently. However, certain aspects of intra-household interactions such as task allocation have long been an area of research in fields such as sociology and economics, although the intent of these studies is not necessarily towards the determination of travel demand. Intra-household interaction has dominant influences on household members' activity and travel, and also it is closely associated with lifecycle stage. Lifecycle stage factor is introduced into the analytical scope of this study and regarded as a main factor through this research. The Kyoto-Osaka-Kobe (Keihanshin) metropolitan area of Japan is the study area of this effort.

As in most metropolitan areas of industrialized countries, metropolitan areas of Japan underwent substantial changes in the second half of the 20th century. With the rapid urbanization after the World War Ⅱ, the metropolitan areas expanded outwards with the suburbs absorbing much of the influx of population (Kitamura, 2005). Changing the built environment affects urban residents' travel behavior to a large extent. Differences between auto users and non-users[1] become more distinct and spatial segregation between them becomes more outstanding as automobility progresses, such as, auto users had a tendency to live in autonomous and suburbs areas, while most of non-users lived in commercial and mixed commercial/residential areas; auto users made more trip attraction in suburbs, while

[1] Auto user is defined as: at least one trip by automobile and non-user means no trip by automobile.

non-users made more trip attraction in central city (Sun, 2007). Also, the mobility of urban residents has been expanding over time. Kitamura and Susilo (2005) have shown that this expansion stems more from structural change (i.e., change in the relationship between travel behavior and demographic factors), than from change in demographic and socio-economic characteristics (for example, attributes of the individual and households, such as, more women employed, the household size shrinking, and the resident population aging) of urban residents. Urry (2005) went to conjecture that this structural change is due to increasingly prevailing automobility, i.e., conversion of social and economic system and way of life to adapt to the ownership and use of the automobile.

In this study, this conjecture is firstly explored by examining automobility characteristics across lifecycle stages over time. The level of automobility is operationally defined in this study in terms of: automobile ownership, total auto travel time, modal split, and the fraction of trip attraction in traditional central city in the study area. Nine stages of household lifecycle are formulated according to the classification scheme of the family lifecycle stage:

the younger single household,
the younger childless-couple household,
the pre-school children nuclear family household,
the primary school children nuclear family household,
the middle or high-school children nuclear family household,
the elder childless-couple household,
the elder single household,
the single-parent household,
other household.

The classification scheme utilizes the criteria, which generally are age and marital status of household head, presence and age of children of head, presence of other relatives and non-relatives.

Another important factor introduced into this research is *automobility cohort* which is defined by grouping individuals who turn 20 years old during the time period indicated. Each time period is chosen with respect to the level of automobility. It has been pointed out that the elderly of these days behave differently than the elderly of decades ago because the current generations of elderly grew up with the automobile and have been using it ever since their habit forming ages. The following five cohorts are developed for the study area and used in the analysis: pre-war (up to 1945), pre-motorization (1946-1960), initial growth (1961-1970), mass-ownership (1971-1980), and multi-car ownership (1980-). The structural change is due to increasingly prevailing automobility, which is explored by examining mobility characteristics of automobility cohorts. In addition, time effects and age effects are introduced into the analysis as in standard cohort analysis.

Simultaneous equations model systems are developed at the household level, with auto ownership, fraction of auto trips and total auto travel time as its dependent (or endogenous) variables. Their mobility characteristics are characterized and behavioral distinction identified through examination of the models' coefficient estimates. Using the repeated household travel survey results, the stability over time of the simultaneous equation system is statistically examined, and thereby the effects of demographic changes are separated from those of structural change. Using the results, it is shown how much of the change in urban auto travel is due to changes in demographics and how much is due to structural change. In addition, the resultant model system is applied in a scenario analysis to forecast possible changes in future auto travel that will follow hypothetical demographic changes in the metropolitan area.

1.2 The purpose of this study

This study focuses on the following objectives:

1. To investigate how the built environment may create environments where more sustainable travel is possible by considering the automobility characteristics across different developed areas and within distinct lifecycle stages.
2. To examine mobility traits of each automobility cohort.
3. To explore how much of the change in urban residents' auto travel is due to changes in demographics and how much is due to structural change.

With examining the automobility characteristics across lifecycle stage and automobility cohorts over time, and developing a simultaneous equations model to examines how auto travel has changed over time with changing demographics, residential location, and metropolitan structure, this study attempts to offer a possible explanation of the structural change underlying the substantial change in travel found in the Kyoto-Osaka-Kobe metropolitan areas between 1970 and 2000.

1.3 Research Hypotheses

Several hypotheses behind this study are:
Hypothesis 1: Lifecycle stage and auto use are closely associated and certain lifecycle stages are more auto-oriented. This tie becomes stronger as automobility progresses.

Hypothesis 2: As more and more services become auto-oriented with prevailing automobility, distinction in spatial behavior becomes clearer across lifecycle stages.

Hypothesis 3: Lifecycle stage is not the only effect which is associated with auto use, and residence area is another important effect. Lifecycle effects are suppressed by the residence area.

Hypothesis 4: Automobility cohorts do exist, with each cohort having certain mobility traits that are unique, especially in terms of auto use.

Hypothesis 5: Urban residents' travel has the tendency to expand over time, especially on auto travel, and this expansion has been caused primarily by changes in the structural relationships while changes in demographic factors have had relatively minor effects.

Through the examination of these hypotheses, this study attempts to offer a possible explanation of the structural change underlying the substantial change in travel found in the Kyoto-Osaka-Kobe metropolitan areas between 1970 and 2000.

1.4 Structure of the Dissertation

Chapter 1 introduces the background, objectives and hypotheses of this research.

Chapter 2 reviews the concept, history and analysis method of two important factors used in this research—lifecycle and cohort analysis. The theories and empirical research approaches of intra-household interaction are also discussed in this chapter.

Chapter 3 represents the database used in this study—the household based person-face and person-trip data of the Kyoto-Osaka-Kobe (Keihanshin, or Greater Osaka) metropolitan area of Japan in 1970, 1980, 1990 and 2000, and discusses the changes of automobility happened in this metropolitan area.

Chapter 4 examines the changes in automobility characteristics across lifecycle stages within different residential areas over time using statistical analyses. It is further investigated which factor explained the differences greater, the built environment or the lifecycle stage.

Chapter 5 Automobility cohort effects are introduced into the analysis because each household has cohort and period properties. Five automobility cohorts are developed for the study area and used in the analysis with time effects and age effects as in standard cohort analysis. Then statistical analyses with considering cohort effects and residence ara effects simultaneously are discussed.

Chapter 6 examines how auto travel has changed over time with changing demographics, residential location, and metropolitan structure. A simultaneous equations model system is developed at the household level, with auto ownership, fraction of auto trips, and total auto travel time as its endogenous variables. Using the repeated household travel survey results, the stability over time of the simultaneous equations system is statistically examined, and thereby the effects of demographic changes are separated from those of structural change.

Chapter 7 concludes the summaries of the main findings and recommendations of future research.

Figure 1.1 Outline of the Dissertation

Chapter 1 Introduction

Introduce the background, purpose, hypotheses and structure of this research.

Chapter 2 Literature Review

Review the concept, history and analysis method of two important factors used in this research—lifecycle and cohort analysis. The theories and empirical research approaches of intra-household interaction are also described in this chapter.

Chapter 3 Data Description

Represent the database used in this study—the person-trip data of the Kyoto-Osaka-Kobe metropolitan area of Japan in 1970, 1980, 1990 and 2000 were used in this study.

Chapter 4 Stability of automobility characteristics across lifecycle stages over time

This chapter explores how automobility characteristics and travel activity behavior changed across lifecycle stage over time by examine automobility characteristics and travel activity behavior of households according to their lifecycle stage. Because our environment affects our choices on travel behavior to a large extent, residential location is another important effect and is introduced into the analysis.

Chapter 5 Automobility cohort as a tool in the study of urban travel

A hypothesis behind this study is automobility cohorts do exist, with each cohort have certain mobility traits that are unique, especially in terms of auto use. A statistical age-period-cohort analysis is used to examine the above hypothesis. Since residence area is a significant explainer for automobility characteristics, it is worth to include residence area effect into the age-period-cohort analysis. This study attempts to offer a possible explanation of the increases in automobilty characteristics

Chapter 6 Determinants of urban travel: demographics vs. structural change

Explore how much of the change in urban travel is due to changes in demographics and how much is due to structural change. The analysis examines how auto travel has changed over time with changing demographics, residential location, and metropolitan structure. A simultaneous equations model system is developed at the household level.

Chapter 7 Conclusion and Future Works

- Conclusion: summaries of the main findings
- Recommendations of future research

Chapter 2
Literature Review

2.1 Introduction

This chapter offers a brief overview of previous studies and methods related to family lifecycle, cohort analysis, and intra-household interaction. The strengths and weaknesses of these concepts and methods in travel behavior, and need pay more attention on urban auto travels. However, some issues is these concepts and methods are still not unclearly. It will be minutely dissected in the following sections.

2.2 Family lifecycle

Within the social sciences, increasing recognition of human behavior as a life-long process of growth and change has provided a fresh perspective for observation and interpretation. This process of change over time is captured in the term life cycle, which describes the birth-to-death sequence of stages in the life of an individual or family. (Zimmerman, 1982)

The above word from Zimmerman(1982) can describe the lifecycle concept. The concept of lifecycle has been firstly used in the social sciences in the early period of 20th century, and then it has been introduced into travel behavior in the seventies of last century. The concept of lifecycle had been used mainly by economists and sociologists in models of society, the labor market, family expenditure and for demographic forecasting. In this section, we will retrospect the history of lifecycle concept, as well as it has been employed in the studies of travel behavior.

2.2.1 The family Lifecycle Concept in History

The earliest explicit discussion of family lifecycle concept which I studied is proposed by

Rowntree (1903), the study was an attempt to understand the pattern of poverty in late 19th-century and early 20th-century England. Regardless of the substance of this study, I focus on the family lifecycle concept employed in this study, which was divided into three parts: one of poverty when children are young, one of relative prosperity when the children grow up and become wage earners, and a second period of poverty in old age. The concept has been applied in the rural sociology analysis, as Loomis (1936) carried out an economic analysis of the family life cycle which emphasized the changes in the size and composition of rural family membership. Bigelow (1948) began to focus on the consumer economics and move to a considerably more elaborate set of stages of the cycles. Lansing (1957) attempted to utilize stage in the life cycle as an independent variable explaining some form of behavior; they tried to separate the effects of lifecycle stage from other effects, such as age. The result is consistent with social theory since the family lifecycle should be a better reflection than age of the individual's social role. They suggest that the life cycle should be adopted more widely as an independent variable to be used in place of or parallel to age. Hogan (1978) utilized the lifecycle stage as an analytic framework in the studies of satisfaction, with which to view behavior over time. In this research, lifecycle stage is not viewed as competing with other variables for explanatory variables, it signals a phase of life to which individuals adapt. The foregoing works treat the family life cycle as an independent variable used to explain various types of family phenomena or economic phenomena.

The treatment of the family life cycle as interaction process appears in another groups of studies. Glick (1947) used family life cycle as a clear factor in his comparisons of the 1890 and the 1940 American family based on U.S. Census data. They described a number of significant stages in the family cycle and have demonstrated that characteristics of the average family vary widely from one stage of the cycle to another. They continue to discuss that the existence of these wide variations should be kept in mind in comparing the characteristics of families in two or more areas or social classes. Then, in the later research (Glick, 1965) based the analysis on demographic data, he drew many interesting speculative conclusions concerning the changes which may occur in the interactive experiences of families because of their changing demographic character. Also, some studies consider the significance to the family life cycle approach, such as Duvall (1957) emphasized longitudinal analysis, rather than cross-sectional studies and demonstrated that such a method was feasible. In the family life cycle analysis, a major idea, that of individual "developmental task" was testified, this provided a very important impetus to the work. The studies mentioned above can be considered as the "primitive period" in the history of the family life cycle approach. However, the works propel life cycle analysis into a period of major progress will be discussed as follows.

Duvall (1962) devised the initial conceptualization of family developmental tasks and outlined those tasks for the first stage of the family life cycle. This research stimulated a number of family studies to expand further this approach. Rodgers (1962) attempted to put the conceptual approach to an empirical test. The intent of the empirical test was to demonstrate that this conceptual approach allowed for a number of alternative formulations of the idea of “family life cycle stages” depending upon the type of family behavior. From this, a developmental orientation including several interesting characteristics appeared in the developmental literature. Lopata (1966) reported on the life-cycle of the social role of the housewife. There are also some works about comparative data analysis based on the family life cycle. Morioka (1967) reported the work on life cycles with comparisons of Japanese, Chinese, and American forms. Some significant literature regarded with theoretical and empirical contributions of considerable substance, such as, Hill (1965) considered for both theoretical and methodological clarification, for empirical work in a number of settings, and especially for three generation family analysis. Rodgers (1973) argued that these developmental analyses may be viewed as concerned with the interactional or transactional arena of family behavior and discussed the distinction between interactional and transactional arena of family behavior.

These attempts to use the lifecycle concept in empirical research viewed households as the unit of analysis. The concept of a family lifecycle is based on the assumption that the nuclear family is the typical or ideal family structure. However, the nuclear family consisting of husband, wife and their children has been declining in recent decades, while the numbers of single-parent families and single-person households have increased rapidly. Trost (1977) argued that the lifecycle concept is not theoretically sound, because so many households do not follow the nuclear family cycle. Thus the idea of stages is an unrealistic one because many families will never pass all stages but will jump from one stage to a much later stage. However, it is possible to adapt alternative family structures to the lifecycle frame work (Murphy, 1979). The modernized family life cycle proposed in this study utilizes the age of household head, marital status, and to a less extent, children’s ages to determine the length of the stages. Recognition of divorce and remaining childless as options are its major distinguishing features and an explanation of life style and financial characteristics for each stage is given to clarify this conceptualization. Also, there is a problem among the practical issues in lifecycle analysis, which is identifying stages in the family lifecycle. Goode (1977) have put forward the classification of the lifecycle stage considering of marital status, age of household heads, presence and age of children, and there appears to be general agreement on this class of variables. A family matures lifecycle concept passes through a series of stages, within each of which it behaves in a different manner. The reason behind the classification of the lifecycle stage is that the different stages are defined in terms of the presence or absence of children of various ages, and so within each stage there will be different demands and constraints on adult behavior. However, Clarke (1983) noted that several other relevant variables, such as age of adult members of the household, economic activities, and household income, are likely to be correlated with lifecycle stage, and these rather than just the household structure may be the causes of some observed variations in behavior.

There also have other issues in life-cycle analysis. Each household has cohort and period properties. Glick (1965) used a cohort approach in developing direct measures of family lifecycle stages and revealed that the last child in the family tends to be spaced considerably later after marriage. Nelson (1972) pointed out that it is less attention in lifecycle studies is the difficulty of separating lifecycle effects from cohort and period effects. Hogan(1978) discussed the ability of men to order their life course events in a normative fashion varies by the unique history of the birth cohort into which they are born, and in particular by the military service and educational experiences characteristic of their cohort. They conclude that continued periodicity in the tendencies of birth cohorts to experience a normative ordering of events will depend on period trends in educational attainment, age at marriage, and the ease of entry into the labor force. Masnick (1980) indicate that female shows greater trends to labor force participation, and furthermore, suggest that younger cohorts of women will alter the travel of their households as they enter later lifecycle stages. Easterlin (1987) has argued that the baby boom cohort has experienced, because its size relative to earlier and later cohorts, and furthermore, the baby boom cohort will continue to experience a high degree of competition among its members over resources such as schools, jobs and housing, and society is unable to provide on a scale sufficient to meet its timetable of needs.

2.2.2 The Family Lifecycle Concept in Travel Behavior

With respect to travel, lifecycle stage was ignored in travel behavior analysis in the earlier time, but it has made enormous progress in the empirical studies of urban travel in the late seventies of last century. Heggie (1978) found evidence for the significance of family structure in an exploratory study of the reactions of Oxford residents to that city’s policy of car restraint. He found that many of the reported responses were the results of behavior which was strongly constrained by family circumstances – these constraints being of a different nature depending on the numbers and ages of the children in the family. Accordingly, he developed a classificatory system of lifecycle stages which appeared to provide reasonably homogeneous grouping of household types. He made five-fold classification of lifecycle stages:

Young adults, whether married or not, without children;
Families with dependent children, the youngest aged 12 years or less;
Families with dependent children, the youngest aged 13 years or more;
Families of adults, all of working age;
The elderly.

On the basis of unstructured interviews with households he was able to explain much observed in terms of the influences typical of the lifecycle group to which a particular household belonged. They furthermore conclude that stage in the family cycle is thus an important determinant both in travel needs and of their solution. It seems to be even more important than household income. This was a small scale qualitative survey and various empirical studies which have tested analytically the usefulness of the lifecycle variable will be described in the following studies.

Jones et al. (1980) used lifecycle stage as a key classificatory variable. They discussed that Lifecycle stage is a useful classificatory variable, partly because it is a composite concept; it probably subsumes a host of causal factors which act in combination to produce the consistently different between-group patterns of behavior that we observed. They used the eight stages in their analysis. The eight stages include:

A Younger (married) adults without children,
B Families with pre-school children, all children under 5;
C Families with pre-school children and young school children,
D Families with young school children,
E Families with older school children,
F Families of adults, all of working age,
G Older adults, no children in household,
H Retired persons, all persons 65 or over,

They are defined in terms of family structure and age (particularly age of youngest child), although clear distinctions between certain stages are difficult to make. Problems of overlap are partly due to the fact that some of the differences between stages are caused, not by membership of stages per se, but by factors which are indirectly linked with lifecycle; notably patterns of household employment, income and expenditure, and vehicle license ownership. It must be emphasized that these categories of family type were derived on the basis of interviews with households resident in small and medium sized U.K. provincial towns. They therefore reflect the traditional family and social structure of that type of community, and while their classification is technically an exhaustive one, the less conventional household types (e.g. extended multi-generation families, single persons, groups of unrelated persons, or single parent families) do not fit so happily into their schema.

Representative of American work in this area is that of Zimmerman (1982), who proposed more complex lifecycle systems specifically to deal with atypical households. The average daily trip frequency of American households was calculated, and the result was that total travel by households varied considerably over the lifecycle. From the socio-demographic descriptions, each household was categorized by stage in the family lifecycle. The classification scheme utilized the criteria generally found in studies of the family lifecycle: age and marital status of household head, presence and age of children of head, presence of other relatives and non-relatives. A set of five household types and their life-cycle stages were formulated:

the "typical" or nuclear family household,
the single-parent household,
the childless-couple household,
the single-person household,
the household of unrelated individuals.

Comparison of trip making by lifecycle stage for the five household types point to the presence of a lifecycle effect in travel, but the effect appears to consist of two separate components: household structure, such as the relationships among household members, and the age of household members. Over the lifecycle, a household's trip-making will be determined by the relative contribution of these two separate components. The household types without compositional changes over the life cycle, for example, childless couples, single persons, unrelated individuals, are subject to the age effect of adulthood alone. The travel by households which do experience compositional shifts, such as typical family life cycle, will reflect both structural complexities imposed by the presence of household members with different social statuses and roles, and the independent age effects of each household member. It is also discussed other factors potentially contributing to the observed lifecycle patterns. Finally, it is concluded that further efforts to deal with the complexities of the lifecycle concept in travel research will be worthwhile.

The term "lifecycle" implies a dynamic aspect and another group of researchers do effort on the dynamic aspects of lifecycle. Any one household passes through different stages in the lifecycle during its lifetime. A lifecycle framework has potential merit in forecasting travel demand and in impact analyses. Clarke et al. (1982) developed micro-analytic simulation models of travel behavior. They assess the implications for travel given various combinations of probabilities, through ageing a hypothetical population through various household types and lifecycle stages, and simulating the impact of demographic, socioeconomic, and location variables at each stage. They continue to (Clarke et al., 1983) provide a detailed discussion of lifecycle classifications and other questions which arise in the context of a lifecycle-based approach to studying travel behavior. They present a diagram of some of the more common transitions between lifecycle stages based on 4 basic processes (the formation of households, births, deaths and young adults leaving home), but ignoring effects such as child mortality, adoption, separation and divorce, etc. They conclude that members of households at the same stage in the lifecycle find their behavior subject to fairly predictable pressures and constraints, with the result that the variance of behavior between households within a stage tends to be less than the variance between stages. This leads to the fact that lifecycle stage is a useful parameter for explaining variations in behavior in both qualitative and quantitative contexts. They suggest that it is possibility of combining static and dynamic analyses of behavior by using lifecycle as a classificatory variable.

These studies related to lifecycle stage which we discussed above, point to the presence of a lifecycle effect in household travel behavior. However, some issues in the lifecycle analysis are still not unclearly discussed in these studies, and lifecycle is an effect more complex than generally assumed. Firstly, the diversity of lifecycle categorizations indicates divergent views on appropriate “break points” separating lifecycle stages in the case of travel research. For example, not only does the number of stages in the family life cycle vary from five to eight or to nine, but the ages of adults and children used to define the stages differ as well. Better theoretical justifications for the selection of lifecycle stages in travel research than have been made to date are necessary. Secondly, Lifecycle stage is correlated with other variables such as household size, family income, and vehicle ownership. This question has been rarely discussed in the previous studies. Thirdly, time has not been examined but merely inferred from the age specific patterns of behavior in the previous studies except for a few studies such as Wachs (1979). The data which these studies used are cross-sectional and do not reflect the experience of individuals or households over time and the lifecycle of each type of household was contemporaneous households. An assumption behind the analyses is that early-stage households will behave in similar fashion to later-stage households which exist today. Thus, these analyses allow for no cohort effect, whereas wachs (1979) suggest that the elderly of the “future” to be more mobile than the elderly of “today” based on the high mobility of today's younger cohorts (relative to that period). However, these studies still not consider lifecycle effect and cohort effect together in the analysis, and it will be advantage to the use of the lifecycle concept in travel research, if we think about the intermingling of lifecycle, cohort and period effects.

2.3 Cohort Analysis

Cohort analysis, which is a general strategy for examining data rather than a specific statistical technique, has become increasingly popular in the social sciences in the past few decades as an abundance of data appropriate for its application has become available. Its popularity results partly from its usefulness in addressing substantive issues relating to aging and social and cultural change, but many researchers apparently have become interested in cohort analysis primarily because it presents an unusually intriguing methodological challenge (Glenn, 1976). This section will discuss the concept, history, and method of cohort analysis used in the previous studies.

2.3.1 Cohort Concept

The term cohort originally referred to a Roman military unit, and we can find the definition in a common dictionary is "a group of people who share a common feature or aspect of behavior". In demography, a cohort is defined as those people within a geographically or otherwise delineated population who experienced the same significant life event within a given period of time. The given period of time may be of any length, for example, one day or 10 years. The cohorts used for social scientific research usually consist of people who experienced a common significant life event within a period of from one to 10 years. The significant life event is often using birth; in this case, the cohort is termed a birth cohort. There are also other cohorts, such as marriage cohorts, educational cohorts and cohorts defined by the birth of the first child. Mason (2001) summarized that a cohort is a set of individuals entering a system at the same time. Individuals in a cohort are presumed to have similarities due to shared experiences that differentiate them from other cohorts.

2.3.2 The History of Cohort Analysis

As we discussed above that a cohort is any group of individuals linked as a group in some way- usually by age. And cohort analysis is a method for investigating the changes in patterns of behavior or attitudes of such group. Cohort analysis refer to any study in which there are measures of some characteristic of one or more cohorts (birth or otherwise) at two or more points in time. Cohort analysis is a method of research developed by demographers. Then it has been adapted to the study of various attitudinal and behavioral phenomena and popularized by sociologists, political scientists, psychologists, educators and economists. However, the term *generation* is usually used till 1940. Such usage has not promoted clarity of communication, since "generation" has a distinctly different meaning in kinship terminology. Therefore, insofar as possible, such usage of the word should be avoided, but one must be aware of this meaning to understand much of the literature reporting cohort analyses.

A classic article by Kermack et al. (1934) illustrates an early use of cohort analysis. Such analyses follow successive generations of entrants through the life course. The object is to link the pattern of specified outcomes to the particular previous experience defined by membership of a generation. The outcome of interest was overall mortality at successive ages. Their significant discovery was to demonstrate the potentially large and continuing contribution of experience in the earliest years to rates of death throughout the lifetime of each generation. Then various studies of cohort analysis has been developed followed this earliest study. Frost (1939) has attempted to show similarly for males the mortality at successive ages in cohorts of ten years terminal and have noted that the age selection has been uniform in successive cohorts. Ryder (1964) argues convincingly for the utility of the cohort as a unit for the study of social and cultural change. This study presents a demographic approach to the study of social change and directs the attention of sociologists toward the study of time series of parameters for successive cohorts of various types, in contradistinction to conventional period-by-period analyses. It is suggested that sociologists would be well-advised to exploit the congruence of social change and cohort differentiation in dynamic analysis. Hobcraft et al. (1982) have reviewed the stage of the art of age-period-cohort analysis for demographic dependent variables. These analyses have appeared both in mortality and fertility studies. In the area of mortality, the conventional approach (the conventional linear model) to such analysis appears to be well suited to a wide range of applications and often yields plausible and useful results, while the conventional approach is much less suitable for the analysis of fertility, and the forms of analysis appropriate to age-period-cohort investigations of fertility will have to develop hand in hand with the theories of reproductive behavior, such as developing the cohort analysis when facing the cohort-inversion phenomenon, or continuously-accumulating cohort effects. Attanasio (1998) uses the analysis of the average cohort techniques to shed some light in the decline in personal saving rates in the United States in the 1980s. The paper identifies a "typical age profile” for saving rates.

The purpose of cohort analysis, other than in studies of mortality or fertility or saving rates, has been to investigate the effects of human aging and of its close correlates. Some cohort studies have been designed to estimate the effects of aging on aspects of political attitudes and behavior. Crittenden (1962) has been to investigate the effects of human aging and of its close correlates and estimate the effects of aging on aspects of political attitudes and behavior, such as party identification and voter turnout. Culter and Kaufman (1975) have dealt with the effects of aging on such variables as tolerance of ideological nonconformity. The general strategy in such studies has been to examine intracohort trends and to try, by various means, to decide to what extent the trends reflect influences associated with aging rather than period influences. The general strategy in these studies has been to examine intracohort trends and to decide to what extent the trends reflect influences associated with aging rather than period influences by various means. While the concern has been with the effects of aging on susceptibility to change, measured changes during given periods of time in cohorts at different age levels have been compared (see Glenn and Hefner, 1972). They have presented a more adequate set of cohort data on political party identification. The study covers a span of 24 years and includes data for seven dates which demarcate four-year intervals and concludes that aging process has been an important influence for republicanism, further on, aging cohorts have become more republican in a relative sense as a result of a secular trend away from republicanism in the total adult population. Cross-sectional method to study the effects of aging is also used, and a cohort study usually includes a number of cross-sectional comparisons. Furthermore, cross-sectional studies usually entail analyses over and above those which can be performed with data from the usual kind of cohort table. For example, Glenn (1975a) has compared persons of the same chronological age who were at different stages of the life cycle—retired persons versus those not retired; parents with children still at home versus parents whose children have left home.

In survey studies, panel research entails repeated interviews with the same respondents, whereas a sequence of cross-sectional surveys does not. Repeated interviews enable the panel analyst to study not only net change but also turnover. The trend analysis, on the other hand, is restricted to the study of net change. However, the analogue of a group of specific panel respondents in successive cross-sectional surveys is a “cohort”. Evan (1959) has examined a series of three cross-sectional polls to illustrate some operations of cohort analysis of opinion change. This analysis of internal change is possible by sub-classifying each cohort by relevant structural variables. This procedure makes it possible to tap an ever-growing body of poll and survey data of societal scope and it is enabled to explore opinion formation and change as it is affected by cultural and social structural differences.

It is introduced some studies for some purposes for which cohort analysis has been used, better techniques are available. For some purposes, cohort analysis is the best available means of investigation, or else it is a valuable supplement to other techniques. Furthermore, in the theories of aging, cohort analysis can lead to reasonable conclusions, and should not only be used in social scientific research.

2.3.3 The Method of Cohort Analysis

Cohort analysis usually begin with construction of a “standard” cohort table; that is, a table in which sets of cross-sectional data for the different dates are juxtaposed and in which the intervals between the points in time for which there are data correspond in years with the intervals used to delineate the birth cohorts. In such a table, intercohort comparisons can be made by reading down the columns; intracohort trends can be traced by reading diagonally down and to the right; and trends at each age level as the different cohorts replace one another can be traced by reading across the rows. Mason (2001) mentioned that cohort analysis seeks to explain an outcome through exploitation of differences between cohorts, as well as differences across two other temporal dimensions: age (time since system entry) and period (time when an outcome is measured). Therefore, an outcome can be classified into three kinds of effects according to the kinds of influences which produce them. One influence associated with aging are age effects, another influence associated with birth cohort or other cohort membership are cohort effects, and the last influence associated with each period of time are period effects.

Unfortunately, there is no straightforward way of identifying theses effects through examination or statistical analysis of the cohort table. Two of the age, cohort, and period effects are confounded with each other: age and cohort effects in the cross-sectional data in each column; age and period effects in each cohort diagonal; and cohort and period effects in each row. This confounded problem has been called the “identification problem” (Blalock 1966), which occurs when an independent variable in an analysis is a perfect function of two or more other variables of theoretical interest. In other words, there is linear dependency of one independent variable on two or more other variables which should be controlled or used as independent variables. In the cohort table, age is a perfect function of cohort membership and period of time, cohort membership is a perfect function of age and period, and period is a perfect function of age and cohort membership. Various cohort analysis methods have been developed for the identification of the three effects through statistical analysis as follows.

Greenberg et al. (1950) recognized the limitations of a descriptive analysis, and they proposed the use of a three-factor, analysis of variance-type model to quantify the "separate" effects of the categorized age, period, and cohort variables. They made an attempt to present a method of analyzing simultaneously some of the important factors affecting the incidence of syphilis in a group specific for race and sex. A mathematical model was constructed which took into account three important, measurable factors—age, date of birth and year under observation as follows:

$$Y_{xij} + 1 = X^{\beta_2} e^{\beta_0 X_0 + \beta_1 X + \sum_{i=1}^{7} \gamma_i X_i + \sum_{j=8}^{14} \delta_j X_j + \varepsilon_{Xij}}$$

Where, Y_{Xij} represent the observed rate occurring at age X, in the ith year, and in the jth date of birth cohort. The model allows Y_{Xij} to be zero only at zero age and at infinite age. To overcome this limitation, the model was constructed relating (Y_{Xij}+1) to the effects of interest. $\beta_0, \beta_1, \beta_2$ are parameters in a Pearson Type Ⅲ curve. γ_i are year effects and δ_j are data of birth or cohort effects. ε_{Xij} are random error. By taking logarithms, the right-hand side is expressible as a linear function of the parameters, and the mathematical model may be written as:

$$\log_e(Y_{Xij} + 1) = \beta_0 X_0 + \beta_1 X + \beta_2 \log_e X + \sum_{i=1}^{7} \gamma_i X_i + \sum_{j=8}^{14} \delta_j X_j + \varepsilon_{Xij}$$

The technique was illustrated by using data on syphilis incidence among Negro females in four counties during a seven-year period. Several instances were indicated where erroneous inferences were possible if the observed rates of syphilis incidence were analyzed separately for each factor instead of considering their effects simultaneously.

Mason et al. (1973) consider the identification problem for situations in which the dependent quantity is treated as a joint function of age, period, and cohort membership. They point out that the model

$$Y = \alpha + \beta_1 A + \beta_2 P + \beta_3 C + \varepsilon$$

In which observations are scored on Y, by their age for A, by the specific point of measurement for P, and by their year of birth for C, is not estimable if A, P, and C have been scaled such that A=P-C for all observations. Mason and associates go on to discuss the problem in cohort analysis that results from the logical relationship among age, historical period and birth cohort. The three effects are logically confounded with each other, and their joint use to predict a dependent variable is therefore problematic. They specify a multiple classification model as a general model for cohort analysis and indicate the assumptions necessary to estimate its age, period and cohort parameters. This model is shown as below:

$$Y_{ij} = \mu + \beta_i + \gamma_j + \delta_k + \varepsilon_{ij}$$

$$(i = 1, \dots, r; j = 1, \dots, s; k = 1, \dots, r + s - 1),$$

Where the effect of the i-th age group is given by β_i, the effect of the j-th period by γ_j and the effect of the k-th cohort by δ_k; where $\mu$is the grand mean of the dependent variable and where ε_{ij} is the random disturbance. As is well known it is impossible to obtain estimates for the coefficients of models because of the identification problem which is discussed above. Under the assumption that two categories of a dimension have the same effect on the dependent variable, or, any two ages, periods or cohorts have identical effects on the dependent variable, then three-way cohort analysis is feasible in the sense of yielding estimable differences between coefficients. The first assumption is not especially troublesome, since it is only a small distortion of reality. However, the technique also requires a much more troublesome assumption, which the age, cohort, and period effects do not interact. That is, age effects are the same for all cohorts and periods, cohort effects are the same for all ages and periods, and period effects are the same for all ages and cohorts. For many attitudinal and behavioral dependent variables, this assumption is not realistic. However, models in which at least two age groups, two periods or two birth cohorts are assumed to have identical effect parameters are estimable. Finally, they discussed that cohort analyses performed without prior knowledge or strong theoretical preconceptions about which parameters are identical are subject to errors of interpretation. The estimates derived from different cohort models can be quite distinct and the underlying effects in the data are known, can produce misleading results. Then they proposed that incorporating an additional equality constraint on a second dimension into the estimation of several alternative cohort models, along with estimating changes in the coefficient of determination when classifications are added to and removed from the total model, may provide some clues.

Fienberg et al. (1978) go on propose a basic logistic response model with the simultaneous effects of age, period, and cohort on a categorical response variable, which is based on the logarithm of the odds:

$$\log\left({}^{P_{ijk}}\!/_{1 - P_{ijk}} \right) = W + W_{1(i)} + W_{2(j)} + W_{3(i-j+J)}$$

$$(i = 1, \dots, I; j = 1, \dots, J; k = 1, \dots, K)$$

Where the subscripted parameters in the above model are deviations from W; that is,

$$\sum_{i} W_{1(i)} = \sum_{j} W_{2(j)} = \sum_{k} W_{3(k)} = 0$$

This model postulates simultaneous age, period, and cohort effects on the log odds of the probability of success. The model is directly analogous to the age-period-cohort model for quantitative response variates examined by Mason et al. (1973).

Glenn (1976) go on discuss the method of Mason et al. (1973) which they explicated the “identification problem” in cohort analysis with unprecedented clarity, sets forth a method, utilizing multiple classification analysis, for separating the effects confounded in cohort data. However, the authors caution that their method has limitation and do not claim that their method is a general solution to the age-period-cohort problem. Furthermore, Glenn emphasized that a mechanical, theoretical cohort analysis is a useless exercise and that statistical innovations alone will not solve the age-period-cohort problem. Cohort analysis should never be a mechanical exercise uninformed by theory and by evidence from outside the cohort table. He further on discussed that mechanical, theoretical cohort analyses are waste of time, and they are likely to lead to incorrect conclusions which may become widely accepted and which may influence policy decisions. Breslow et al. (1983) discuss three methods of cohort analysis for a statistical model wherein the explanatory or exposure variables act multiplicatively on age×calendar year specific death rates. The first method, which assumes that the baseline rates are known from national vital statistics, is a multiple regression analysis of the standardized mortality ratio. The second method is a variant of Cox’s proportional hazards analysis in which the baseline rates are treated as unknown nuisance parameters. The third method consists of case-control sampling from the risk sets formed in the course of applying Cox’s model. It requires substantially less computation than do the other two. The result is all three approaches yield roughly equivalent estimates and discuss the tradeoff between efficiency and bias in the selection of a particular method of analysis, also some practical issues that arise in the applications. Kupper et al. (1984) reviewed and critique the general area of age-period-cohort analysis and discussed and illustrated some of the important limitations of popular statistical modeling approaches for analyzing age-period-cohort data. They argued that any interpretations regarding patterns in age, period, and cohort effects based on the use of such modeling procedures must be made with a great deal of caution. They stressed that any statistical modeling of age-period-cohort data should be carried out in conjunction with a detailed descriptive analysis such as discussed by Glenn (1976). Mason et al. (2001) proposed that a hierarchical Bayes approach is a promising path for future technical development for the resolution of the identification problem. A hierarchical Bayes approach treats appropriately defined cohort, age, and period contrasts as randomly distributed and allows for their dependence on substantive measured variables. Models that include age, period, and cohort can also include interactions between these dimensions, but not all such interactions are identified. However, panel studies and cross-sectional studies with retrospective information provide the basis for a solution to the identification problem.

2.4 Intra-household Interaction

The field of activity-based travel-demand modeling has seen phenomenal interest in the past couple of decades. Several researchers have explored different facets of the problem of characterizing and modeling activity and travel patterns. Some of these studies have examined one or more aspects of activity participation behavior (such as activity generation, activity sequencing, and duration of activity episodes, location, and time-of-day) in great detail. Other studies have adopted a wider focus to develop comprehensive activity-based travel demand modeling systems. The following studies provide snap-shots of the state-of-the art in activity-based travel-demand modeling at different points in time over the past couple of decades: Damm (1983), Kitamura (1988), and Kitamura (1997). Despite this substantial overall interest in activity-based modeling, the issue of accommodating household interdependencies has not received adequate attention in activity-based modeling studies until much recently. However, certain aspects of intra-household interactions such as task allocation have long been an area of research in fields such as sociology and economics, although the intent of these studies is not necessarily towards the determination of travel demand.

Within the context of modeling short-term activity-travel demand, three keywords in intra-household interactions are of importance. These are tasks allocation, joint activity engagement and vehicle allocation. Task allocation means how the household members divide household tasks, for example, who escort children to and from school. Joint activity engagement, that is to say, household members are doing things together, for example, a family have dinner together outside. Vehicle allocation means that household members are sharing the use of common household vehicles, for example, which use and how to use a family car. The review of theories and empirical research approaches used in the intra-household interaction studies are as follows.

2.4.1 Theories of Household Interactions in Activity-Generation and Time-Use

The reviewed studies are broadly classified into (1) sociological theories of division of family work, (2) economic theory of household labor allocation and (3) integrated "socio-economic" theories of time use.

Sociological Theories on Division of Family Work

Sociologists are interested in understanding the overall functioning of the family and the roles and responsibilities of its members. Many studies in this field have investigated how the husbands and wives divide household tasks (child care, cooking, cleaning, shopping, paying bills, etc.) between themselves. Blair and Lichter (1991) identify three prominent theories that describe the division of household responsibilities (or family work) between the household heads. These are (1) the gender-role theory, (2) the time availability theory, and (3) the resource or power theory.

(1) The gender-role theory hypothesizes that men and women quite naturally have different functional roles to play in the household based on the biological differences between the two sexes. Further, women are also trained early in their lives to assume traditional "feminine" roles. The more the traditional sex-roles are ingrained in one or more of the family members, the greater is the wife's responsibility for family tasks. (2) The time availability theory hypothesizes that division of household chores simply reflects the time availability of the different family members for undertaking household chores. The time availability is often dictated by the employment status of the household members and their work durations. The member with more time can undertake household chores with greater ease than those operating under time pressures and, consequently, assume a greater share of household tasks. (3) The resource theory or the power theory hypothesizes that household task allocation is influenced by the bargaining power wielded by the different household members. This power of household members is derived by their relative contribution of resources and is often characterized by socio-economic factors like education, employment status, income, etc.. A powerful family member not only has a greater influence on the behavior of other members but also is less likely to be influenced by others.

In summary, there are at least three sociological theories seeking to explain the division of household tasks between the husband and wife. There is no clear evidence favoring any one theory over the others. At the same time, it appears quite possible that the family task-allocation is actually a consequence of all the different reasons put forth by these theories (i.e. gender roles, time constrains, and bargaining power or influence.

Economic Theory of Household Labor Allocation

In contrast to sociologists who have predominantly focused only on division of household chores between spouses, economists have examined the allocation of household labor to both household chores and the external market (i.e. working in return for wages).

In the economic theory of household labor allocation, households are treated as both consumers as well as producers. Households produce “basic commodities” by combining goods purchased in an external market and time investments by household members. The conversion of these inputs into commodities is described via “household production functions”, which forms a central idea in the economic theory (Becker, 1965; Becker 1981). The relative worth of the different bundles of basic commodities to the household is described using a utility function. Within this framework, the economic theory hypothesizes that rational households, when operating under monetary and time budget constrains, that limit the availability of inputs for household production, seek to maximize household’s utility (i.e. do what is best for the household as a whole). Consequently this theory implies that members invest time in external market (work) and home production (household tasks) based on their relative productivities in these two sectors. Wage rate is often used to describe productivity in market work while efficiency in producing home-goods describes productivity at home. In the overall, the economic theory implies considerable task specializations of one member in the external market and the other in home-productions to achieve efficiency. A key limitation of the economic theory is that it assumes task allocation is purely dictated by efficiency considerations and ignores the role of factors such as social norms, habits, and interpersonal “bargaining”.

Integrated “Socio-Economic” Theories of Time Use

The sociological theories focus on the division of household tasks and capture the “human nature” of the interactions (i.e. bargaining the power, impact of the social norms, personal ideologies, etc.). The economic theory, on the other hand, examines the time allocation between external markets and home, and captures the desire for achieving efficiency by making the best use of available monetary and time resources. Thus, each of these theories presents a partial description of the overall household time-use behavior. This theory describes efforts to integrate ideas from sociology and economics to develop theories for describing inter-personal interactions in the time-use decisions of household members.

Gliebe and Koppelman (2002) developed a theory of time-use that explicitly accommodates joint activity participation decisions of household heads in maintenance and leisure activities. The authors identify that joint activities are motivated by several considerations, including efficiency, altruism, and companionship, and develop a utility-theoretic representation for describing the time-use decisions in two adult households. The household's utility is assumed to be composed of individual's utility is defined as a function of individual's consumption., satisfaction derived from activity participation, altruistic benefits from the activity participation of other household members, and companionship derived from joint activity participation with the other household head. It follows from their model formulation that the proportion of daily time allocated to any activity by an individual is the proportion of daily utility derived from participating in that activity. Further, by explicitly imposing the constraint that the amount of joint time invested by one member in any activity is equal to the amount of joint time invested by the other member, Gliebe and Koppelman have derived the analytical model structure, which takes the proportional-shares form.

Studies undertaken by Zhang and colleagues [Zhang *et al.* (2001) and Zhang and Fujiwara (2004)] have also focused on developing a household utility-maximizing model of daily time use accommodating both independent and joint activity participation decisions of household heads in two adult households. As in the case of Glibe and Koppelman's theory, research by these authors also explicitly recognizes that the daily activity choices are a consequence of a group decision mechanism of the household members. Further, these studies have examined two different types of structures for the household utility functions, the multi-linear and the iso-elastic functions, each representing a different kind of group decision-making mechanism. As opposed Glibe and Koppleman's model, which focused on modeling the fraction of daily time invested in each activity type, the approach presented by Zhang and colleagues models time-use in terms of the total duration invested in each activity type. The analytical model structure takes the form of a system of seemingly unrelated regression equations.

2.4.2 Empirical Studies in Transportation

The empirical research efforts examining the impact of intra-household interactions in shaping the daily activity-travel patterns of individuals may be broadly classified into the following three categories based on the methodology used for analysis: (1) continuous choice modeling approaches, (2) discrete-choice and shares modeling approaches, and (3) exploratory analyses.

Continuous Choice Modeling Approaches

The continuous choice modeling approaches for the analysis of household interactions involve the joint modeling of multiple continuous-choice variables (for example, the activity durations of the husband and the wife). This joint estimation is accomplished either using the structural equations modeling (SEM) approach or the seemingly unrelated regressions (SUR) modeling approach.

Structural equations modeling (SEM) approaches

Structural equations models allow the simultaneous estimation of multiple equations with specified causal linkages among the different dependent variables. Most of the studies employing the SEM methodology have examined the linkages among the activity and travel decisions of the male and female heads of the household. The matrix of causal linkages and the correlations in the error terms are instrumental in capturing the relevant inter-dependencies.

Golob and McNally (1997) disaggregated the activity types and explored interpersonal interactions in the activity and travel durations of the male and female household heads for three categories: work, maintenance, and discretionary activities. The model system also accommodated the censored nature of duration, since several individuals may not participate at all in specific activity types. The models were estimated using a two-day activity-travel survey data from Portland. This study brings out important gender differences in the roles played by the household heads. Specifically, increasing the work duration of the male was found to increase the female's maintenance activity and travel durations. However, increasing the work duration of the female was not found to influence the male's maintenance activity duration or travel time.

The study presented above did not explicitly distinguish activities undertaken jointly by the household heads from activities pursued independently. In contrast, research undertaken by Fujii *et al.* (1999) examined individuals' preferences for joint versus independent activity engagement using reveled preference (RP) and stated preference (SP) data collected from the Osaka-Kobe metropolitan area in Japan. This study did not examine time-use by activity purpose; rather, it studied time use based on companion type and activity location, as determined in the following categories: in-home alone, in-home with family, in-home with others, out-of-home alone, out-of-home with family, and out-of-home with others. Some interesting results from this study include (1) workers who work long hours tend to engage more frequently in out-of-home activities with family members, and (2) persons with children prefer to spend more time in-home jointly with family.

Seemingly unrelated regressions (SUR) approaches

The seemingly unrelated regression models allow the estimation of two or more equations with a specified error correlation. Zhang *et al.* (2001) and Zhang and Fujiwara (2004) have applied the SUR approach in the context of modeling inter-dependent time-use decisions accommodating both independent and joint activity participations. These models are based on an underlying household utility maximizing model that explicitly accounts for the presence of two decision makers. Data from The Netherlands and from Japan have been used in the empirical analysis. While insightful in addressing the different possible decision making mechanisms that households might employ, a methodological limitation of these studies is that they do not account for the censored nature of the activity durations arising as a consequence of several individuals not participating in specific kinds of activities during the day.

Discrete Choice and Shares Modeling Approaches

Wen and Koppelman (1999, 2000) focused on modeling the household interactions impacting choices related to household maintenance activities, explicitly recognizing that maintenance activities are undertaken to serve household needs as opposed to individual needs. This study comprises two nested-logit model systems. The first model system models household maintenance stop generation, allocation of these stops to one of the household heads, and the allocation of the household automobiles for undertaking the generated maintenance stops. The second model system, conditional on choices related to number of maintenance stops and the allocation of these stops and autos, determines the tour generation for each household adult and the assignment of maintenance stops to these tours. Joint activity participation is not considered by this modeling system. The empirical results indicate that in single vehicle households, the vehicle is very likely to be assigned to the person undertaking maintenance stops. Further, the study also finds strong linkages among the various generation, allocation, and organization choices considered in the analysis.

The proportional shares model developed by Gliebe and Koppelman (2002) determines the proportion of time invested, independently and jointly, by each of the two household heads, in different types of activities (subsistence, maintenance, leisure, and home for independent participation and maintenance and leisure for joint participation). Thus, this modeling approach captures both the intra-personal and inter-personal trade-offs in activity participation decisions. The empirical model results indicate employed members have a proportionately greater impact on joint activity decision making, presumably due to their greater time constraints. Further, adults in households with children were found to be less likely to undertake joint maintenance and leisure activities. Availability of an automobile for personal use for each of the adults was found to increase independent non-work time investments of the household heads.

All the efforts described above (both discrete and continuous choice models) have focused on two-adult households and have limited their analysis to the interaction between the two household heads.

Exploratory Analyses

The studies reviewed in this section have not developed models of inter-dependent activity-travel choices of household members. Rather, these studies have focused on conducting exploratory analyses of the various linkages among the activity-travel patterns of household members.

Research by Kostyniuk and Kitamura (1983) compare the characteristics of joint and independent paths of household members. The path was defined as the complete space-time trajectory of the household members during the evening period. Data from the Detroit area was used in the analysis and several interesting and intuitive results are observed. Couples without children and couples who are both workers are found to have joint paths with contact point other than home, suggesting that these couples meet at some out-of-home and pursue activity-travel from that point jointly. Presence of children in the household and the availability of multiple automobiles favor independent paths for the husband and wife. Finally, the total out-of-home time was found to be longer when the evening activity-travel patterns of couples involved joint paths.

Kitamura (1983) has examined the serve-passenger activity participation behavior using data from the Detroit area. This study finds evidence for hypothesis that serve-passenger activities are undertaken within strict space-time constraints and consequently are not chained with other activity purposes. If at all chained, serve-passenger activities were found to be chained with flexible non-obligatory activity purposes. Quite intuitively, both workers and non-workers are found to be more likely to undertake serve-passenger activities when school-age children are present in the household. In the overall, this study highlights that the strict space-time fixities and interpersonal coupling constraints in undertaking serve-passenger activities impacts the overall travel behavior of individuals (especially non-workers).

2.4.3 Summary and Contributions of Current Research

There has been a phenomenal interest in the development of activity-based travel-demand models. Most of these models have accommodated household interdependencies by using household characteristics as explanatory variables in models describing choices of individuals. More recently, there has been increasing interest to explicitly capture the impact of household interactions in activity-travel decision-making. These studies indicate several ways in which the activity-travel patterns of household members are inter-linked.

2.5 Summary

These previous studies related to family lifecycle stage, cohort analysis, and intra-household interaction which we discussed above, indicates the presence and importance of these in household travel behavior. However, some issues in these studies related to these three concept and methods are still not unclearly, the potential contribution to knowledge of these methods and approaches will be realized more caution and sophistication among those who use it.

Chapter 3
Data Description

Person-trip data and their individual attributes data based on a household survey in the Kyoto-Osaka-Kobe (Keihanshin, Greater Osaka) metropolitan area of Japan in 1970, 1980, 1990 and 2000 were used in this study. The data structure is the repeated cross-sectional data collected over the last three decades.

Kyoto-Osaka-Kobe metropolitan area is the second most populated urban region after the Greater Tokyo Area in Japan, containing roughly 15% of Japan’s population. It has three core cities of Osaka, Kyoto, and Kobe. Osaka is the second largest city in Japan and is the center of commerce in the Kansai area; Kyoto was the ancient capital of Japan established in 794 AD; and Kobe is the maritime center of the area. It covers a total area of 7,800 square kilometers within a radius of about 50 to 60 km from the center of Osaka. With a population totaling about 17 million as of 2000, it is one of the largest metropolitan areas in the world. The area has very dense, mixed-use land developments, and has well-developed rail networks. The map of the Osaka metropolitan area is shown on Figure 3.1.

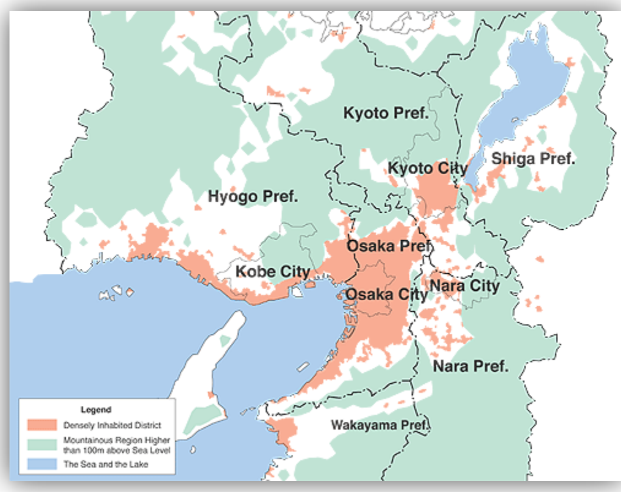


Figure 3.1 Map of the Kyoto-Osaka-Kobe metropolitan area

The repeated cross-sectional data collected over the last three decades of Kyoto-Osaka-Kobe metropolitan area contains:

- Socio-demographic characteristics of the observed individuals as well as their household attributes.
- The modal split, travel time, trip purpose, number of activities, and trip engagements of the observed persons on the observed day.
- Home and work zone locations of the observed individuals.

This household-based survey produced comparable data sets whose samples are large enough for a variety of analyses.

Like most metropolitan areas of industrialized countries, Kyoto-Osaka-Kobe metropolitan areas underwent substantial changes in the second half of the 20th century. With the rapid urbanization after the World War Ⅱ, metropolitan areas expand outwards with the suburbs absorbing much of the influx of population. Changes of automobility characteristics in the year of 1970, 1980, 1990 and 2000 are reported in Table 3.1. As we mentioned in the *Introduction Chapter*, the level of automobility is operationally defined in this study in terms of: household automobile ownership, driver's license holding, modal split, and the fraction of trip attraction in traditional central city in the study area. Here the traditional central city means the *commercial city* which defined by Fukui (2003), the classification of urban areas are based on a principal component analysis of attributes of the municipalities in the metropolitan area for 1970, 1980, 1990 and 2000. Automojbile modal means a trip made by vehicle.

Table 3.1 Automobility changes in the Kyoto-Osaka-Kobe metropolitan Area

	1970	**1980**	**1990**	**2000**
The average number of automobiles per household	0.38	0.73	0.94	1.06
Automobile ownership (more than 1 car)	26.9%	54.0%	65.6%	69.5%
Driver's license holding	21.1%	26.8%	41.5%	52.7%
Automobile modal	17.7%	20.9%	25.9%	33.9%
Trip attraction in traditional central city	9.2%	6.7%	9.1%	7.7%

The average number of the automobiles per household has gradually increased from 0.38 in 1970 to 1.06 in 2000. Especially automobile ownership of 2 and more cars, increased rapidly from 26.9% in 1970 to 69.5% in 2000, and over half percent households owns 2 or more cars since 1980. License holders also increased by decade, which 21.1% of person held auto license in 1970, while 52.7% in 2000. Fraction of auto trips has steadily increased from 17.7% in 1970 to 33.9% in 2000. However, trip attraction in traditional central city is nearly unchanged but a slight decrease from 9.2% in 1970, 6.7% in 1980, 9.1% in 1990, and 7.7% in 2000. These results are showing rapid progress in the automobility over 1970 through 2000 in the Kyoto-Osaka-Kobe metropolitan area.

The next several chapters offer a brief discuss of the changes in the Kyoto-Osaka-Kobe metropolitan area, especially on auto travel and describe the model system, discuss the methods adopted to examine stability in auto activity-travel based on these data.

Chapter 4
Stability of Automobility across Lifecycle Stages over Time

4.1 Introduction

Lifecycle stage is a useful classificatory variable, partly because it is a composite concept; it probably subsumes a host of causal factors which act in combination to produce the consistently different between-group patterns of behavior that we observed. (Jones et al., 1980)

The strengths and weaknesses of lifecycle concept in travel behavior have been discussed in many travel researches, and these studies point to the presence of a lifecycle effect in travel behavior, which discussed in detail in the Chapter 2. The following discussion gives a general overview of family lifecycle stage effect used in the studies of urban travel. Heggie (1978) found evidence for the significance of family structure in an exploratory study of the reactions of Oxford residents to that city's policy of car restraint. He found that many of the reported responses were the results of behavior which was strongly constrained by family circumstances – these constraints being of a different nature depending on the numbers and ages of the children in the family. Jones et al. (1980) used lifecycle stage as a key classificatory variable. Zimmerman (1982) showed differences in the average daily trip frequency across households of different lifecycle stages; e.g., single parents and nuclear families show increases in trip-making as the household head becomes older. Clarke et al. (1982) developed micro-analytic simulation models of travel behavior. They assess the implications for travel given various combinations of probabilities, through ageing a hypothetical population through various household types and lifecycle stages, and simulating the impact of demographic, socioeconomic, and location variables at each stage.

However, these studies have been argued that the application of the lifecycle concept in transportation planning is only beginning to be realized, and the concept has been used uncritically and too simplistically. Some issues in the lifecycle analysis are still not unclearly. Time has not been examined but merely inferred from the age specific patterns of behavior in the previous studies. The data which these studies used are cross-sectional and do not reflect the experience of individuals or households over time and the lifecycle of each type of household was contemporaneous households. An assumption behind the analyses is that early-stage households will behave in similar fashion to later-stage households which exist today. Thus, it will be advantage to the use of the lifecycle concept in travel research, if we think about the intermingling of lifecycle and period effects. An examination of time effects using longitudinal data may prove useful.

On the other side, our environment affects our choices on travel behavior to a large extent, especially on what mode we take. If our neighborhood has more convenient and fast public transport, we may not drive cars to work, shop and play. Changing the built environment has been suggested as a method to reduce automobile use (Litman, T.) and some studies have shown a difference in travel behavior between neighborhoods built prior to 1945 and those built after (Handy, 1996). Kitamura et al. (2003) examined the changes of travel mode choices with respect to the residence areas over time, they noted that modal split is practically unchanged in commercial cities and mixed commercial/residential cities, while an increase in the fraction of auto trips and a decline of the share of public transit are noticeable with new suburbs, and the auto trips are starting to dominate in urbanizing areas. However, lifecycle effect is not considered in this study. Sun & Kitamura (2007) attempted exploring the relationship among three factors – lifecycle stage, residence area and year – on travel behavior by examine mobility characteristics of households according to their lifecycle stage, but the fraction of auto trips is merely considered in the study.

This study explores how automobility characteristics and travel activity behavior changed across lifecycle stages within different residential areas over time using statistical analyses. Automobility characteristics, such as auto ownership, fraction of auto trips, and total auto travel time, mainly discussed in this study. It is further investigated which explained the differences greater, the built environment or the lifecycle stage. The study focuses on the following hypotheses.

- Lifecycle stage and auto use are closely associated and certain lifecycle stages are more auto-oriented. This tie becomes stronger as automobility progresses.
- As more and more services become auto-oriented with prevailing automobility, distinction in spatial behavior becomes clearer across lifecycle stages.
- Lifecycle stage is not the only effect which is associated with auto use, and residence area is another important effect. Lifecycle effects are suppressed by the residence area.

These hypotheses can be examined using the repeated cross-sectional data collected over the last three decades.

4.2 Identifying different residential areas

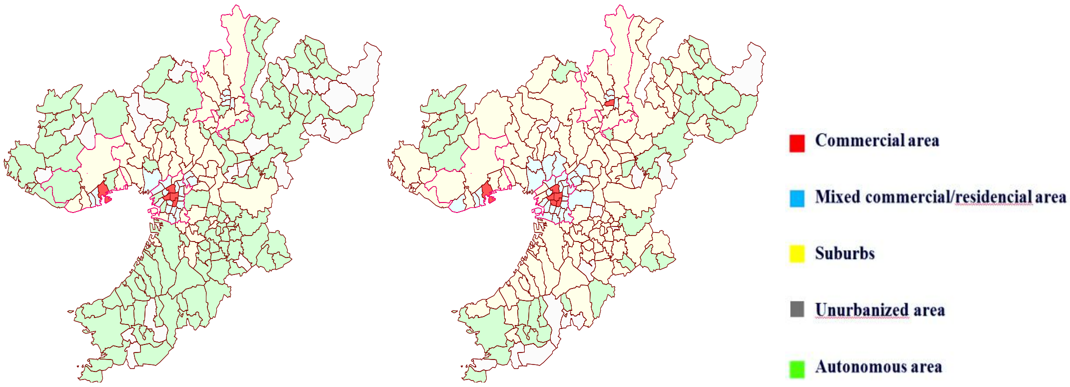
This section gives details about how the distinct residential areas were determined. The areas' boundaries were determined by political boundaries established by the Japanese government. A considerable amount of information about the residences' characteristics, the densities of both people and shops, along with the employment situation was used to identify the different residential areas. Residential areas are categorized into five classes (Fukui, 2003), which are based on a principal component analysis of attributes of the municipalities in the Keihanshin metropolitan area in 1970, 1980, 1990 and 2000. Five basic residential areas were identified: *commercial area mixed commercial/residential area, autonomous area, suburbs, and unurbanized area*. The basic definitions of each area are:

1) The *commercial area* is a municipality with remarkable high density and remarkable high employment ability, where the daytime population exceeds the nighttime population.
2) The *mixed commercial/residential area* has both commercial and residential developments, high density, and high employment ability, but the daytime population does not exceed the nighttime population.
3) The *autonomous area* is one with a small fraction of workers who commutes to outside the municipality, and it have employment ability without depending on the other area.
4) The *suburbs* are a municipality which is urbanized, and also it doesn't have employment ability and have to depend on the other area.

5) The *unurbanized area* is one where the ratio of daytime population to nighttime population is more than a half standard deviation below the metropolitan average, and with no concentration of commercial activities.

As is well acknowledged, the process of motorization transforms urban area; the area expands outwards and suburban roadside commercial development became prevalent, and employment, as well as population has gradually been decentralized in the Osaka metropolitan area. Figure 4.1 shows the changes of residence areas in the Osaka metropolitan area in 1970 through 2000 (Fukui, 2003).

Figure 4.1 Changes in the Osaka metropolitan area



1970 2000

4.3 Lifecycle Stages defined in this study

A person passes through different stages of growth from birth, infancy, childhood, adolescence, adulthood, and then get married, birth of the next generation… From the aspect of family, one household passes through different stages in the lifecycle. For a typical family, a path can be through the stage from younger single household, through the stage of young married couples without children, then with children, through the stage of elder couple with all the children leaving them, and through the elder single household. There are clearly many alternative paths which correspond to less conventional lifestyles, such as the single-parent household which one of the spouse leaving from the family or dying. As a household passes through different stages, whose travel behavior also changes as a result of its changing circumstances. According to the above processes of development of the family lifecycle stage, ten distinct stages of lifecycle are formulated as shown in Table 4.1.

Repeated household travel surveys in the Kyoto-Osaka-Kobe metropolitan area, conducted in 1970, 1980, 1990 and 2000, are used in this study. Since there is no information about marital status in this survey, the classification scheme utilizes the criteria, which are age and sex of household members, presence and age of youngest children, presence of other relatives and non-relatives. However, even with known the age and sex of each household members, we cannot judge which are spouses, or which are parent and children? Therefore, a few assumptions and definitions were supposed in this classification:

a. Age differences between spouses are under 22.
b. Childbearing age is 18 through 49.
c. Age of an adult is 18 and over.
d. Working age is 18 through 64.

Table 4.1 Descriptions and Definitions of lifecycle stages

Acronym		Descriptions	Definitions
A	Younger single	Younger single household	Age under 60
B	Younger childless couple	Younger childless-couple household	Oldest person under 60
C	Pre-school nuclear	Nuclear families with pre-school children	Youngest child under 6
D	Young school nuclear	Nuclear families with young school children	Youngest child 6 or over but under 12
E	Older school nuclear	Nuclear families with older school children	Youngest child 12 or over but under 18
F	All adults	Families of all adults	Nuclear families and single parent families with all members of working age
G	Older childless couple	Older childless-couple household	Oldest person 60 or over
H	Older single	Older single household	Age 60 or over
I	Single parent	Single-parent household	Youngest child under 18
J	Others	Other households	Families with three generation, other related persons and unrelated persons

The detailed flowchart of lifecycle stage classification scheme is shown in the Figure 4.2. This classification scheme is according to the criteria, which are judgments with household members, with the age of each household member, with adult members in one household, with sex of these adults, with age differences among these adults, and with the age of youngest child in one household. According to this classification scheme, ten distinct stages are classified. The program of lifecycle classification is on Appendix 4.1.

Figure 4.3 shows the lifecycle stage distribution in 1970 and 2000. Because age of children under 5 are not included into the survey, also because in some case not all the household members are included into the survey, some missing data happened which was named as “Lack of data” category in lifecycle classification. Compare with percent of households in 1970, we can see that younger single households and nuclear families decreased except pre-school nuclear families, while older single, older childless couple households increased largely in 2000 year. However, younger childless couple, all adults, single parent and other families are nearly unchanged in 2000. It was regret that there is no information about family members in 1980 and 1990 in the Kyoto-Osaka-Kobe metropolitan area. In order to know approximately curve trend, we suppose that all family members belong to each household are all included into this survey in 1980 and 1990.

We also re-calculate the percentage of numbers of each lifecycle stages with picking out the *Lack of data* in 1970 and 2000, and then we put the four years’ information into Figure 4.4. We can find that the results are showed similar trend comparing with the results in 1970, 1980 and 1990, while the results of 2000 year shows greatly different in curved profile compare with 1970, 1980 and 1990. We can see the change of lifecycle stage in 1970 through 2000; the younger single families are on the peak in 1970 while the older childless couple households are on the peak in 2000. This change in 2000 year with large decline of younger single and nuclear families, big growth of older childless couple and older single families imply Japan face aging population in 2000, and this aging population also changes the lifecycle stage. This aging of the population brought about by a combination of low fertility and high life expectancies (i.e. low mortality).

Japan's population is around 127 million, making it the world's tenth most populated country. Its size can be attributed to fast growth rates experienced during the late 19th and early 20th centuries. However, more recently Japan has been experiencing net population loss, due to falling birth rates and almost no net immigration. Japan is also noted for ethnic homogeneity, high population densities and for having one of the highest life expectancies in the world, at 81.25 years of age as of 2006[1]. But we still cannot explain why the percentage of the numbers of pre-school nuclear families is low in 1970 comparing with 2000. Perhaps the sample size of pre-school nuclear families is low in 1970.

Figure 4.3 Changes in lifecycle stage in 1970 and 2000

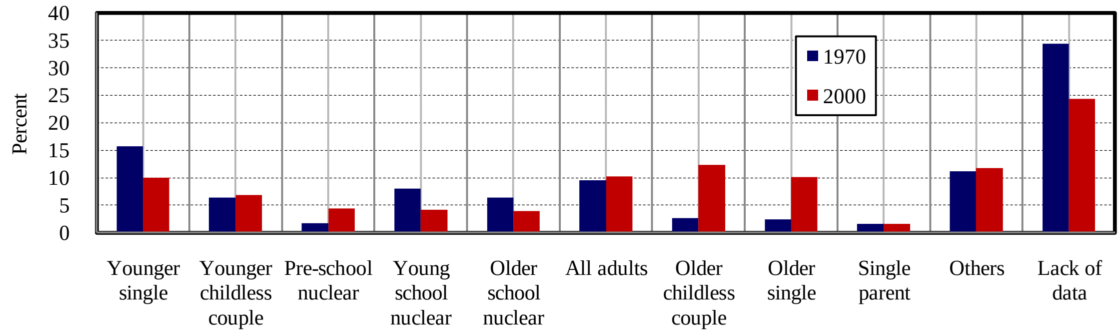
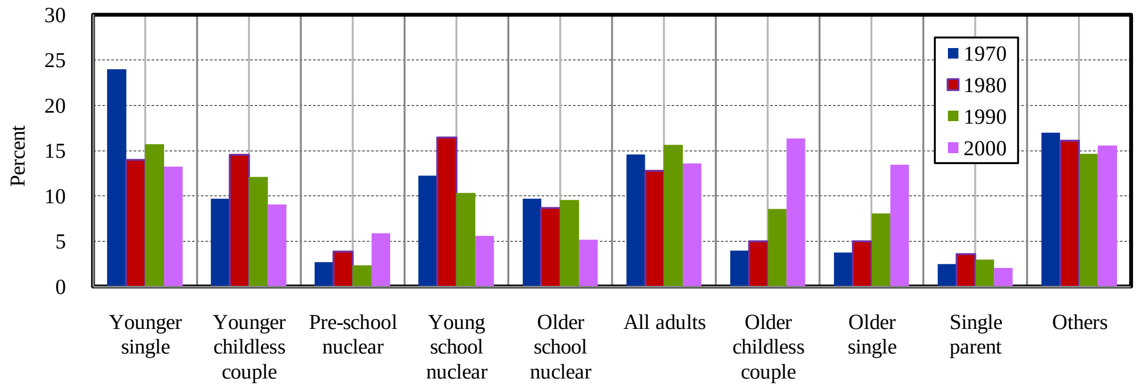


Figure 4.4 Changes in lifecycle stage in 1970 through 2000



4.4 Automobility across lifecycle stages over time

As we mentioned before that the mobility of urban residents has been expanding over time and this expansion is due to increasingly prevailing automobility. The level of automobility is operationally defined in this study in terms of: automobile ownership, fraction of auto trips, total auto travel time, the fraction of trip attraction in traditional

[1] CIA - The World Factbook – Rank Order – Life expectancy at birth. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2102rank.html

central city or in suburbs in the study area. This section explores how automobility characteristics change within all lifecycle stages in 1970 and 2000 in the Kyoto-Osaka-Kobe metropolitan area?

The automobility characteristics across lifecycle stages in 1970 and 2000 are summarized in Figure 4.5. All automobility characteristics have shown a great growth of *total mean* from 1970 to 2000, except trip attraction in traditional central city, which is a little decrease over 1970 through 2000.

Household of *others* show the highest automobile ownership 0.48 vehicle in 1970, while households of *all adults* show the highest automobile ownership 1.55 vehicles in 2000. *All adults* or *others* households with highest automobile ownership, in either event, it means the more household members at working age, the higher of automobile ownership. It seems that age is also another explainer for automobile ownership. The difference between *maximum* value and *minimum* value are 0.44 and 1.41 vehicles in 1970 and 2000, which means the difference of auto ownership between stages are greater in 2000 than 1970.

Younger childless couple households show the highest value of 21.8% and 39.1% in fraction of auto trips either in 1970 or 2000 comparing with other lifecycle stages, which means younger childless couple households tend to use car for trips comparing with other lifecycle stages. Also, the difference between maximum and minimum value are greater in 2000, which is 27.1%, than in 1970, which is 16.3%.

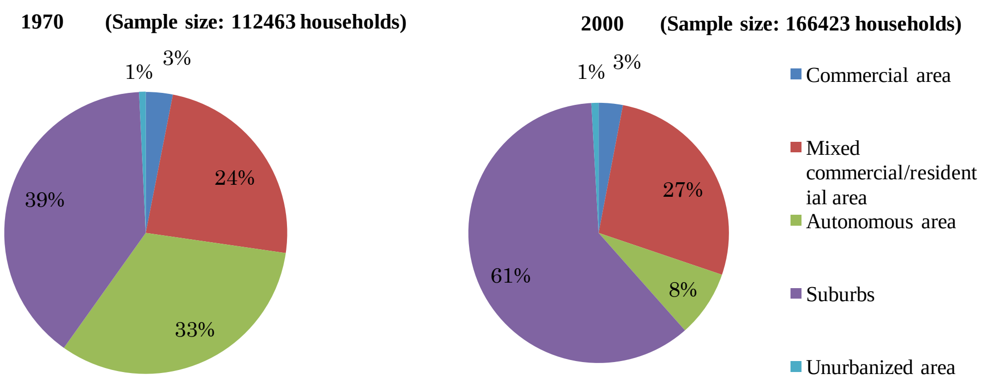
The largest in total auto travel time per household are households of *all adults* which is about 45 minutes in 1970 and 80 minutes per day in 2000. The difference between maximum and minimum value of total auto travel time are greater in 2000, which is 71.93 minutes, than in 1970, which is 41.15 minutes.

Younger single households make the maximum of fraction of trip attraction in traditional central city with 12.5% in 1970 and 15.4% in 2000 comparing with other lifecycle stages because households of younger single lived in the commercial area is nearly 25%.

Nuclear families with pre-school children show the maximum of fraction of trip attraction in suburbs in 2000. However, pre-school nuclear households lived in suburbs is fewer than all adults households, older childless couple families, and older single families although pre-school nuclear households who lived in suburbs have increased in 2000 (Figure 4.6). Figure 4.6 shows that there is no obvious change in each area type, and the commonness is the older person, including older childless couple and older single person households, increased for each area type over 1970 through 2000. High trip attraction in suburbs happened in pre-school nuclear families can be explained as more work trip, leisure trip, or other non-home trip made in suburbs.

The fraction of visit traditional central city trips show a little decline over 1970 through 2000, but the fraction of suburbs trips have highly increased from 1970 to 2000. It is because the changes in the study area. We can see the results of Figure 4.7; it shows the changing percentage of household numbers for each area in 1970 and 2000. In compare with 1970, a great change is a big increase in the number of households who living in suburbs, on the contrary, a great decrease in the number of households who living in the autonomous area.

Figure 4.7 Changes in percentage of household numbers by residence areas in 1970 and 2000



In brief, all automobility characteristics have shown a great growth of total mean in 1970 through 2000, except trip attraction in traditional central city. There is a great distinction across lifecycle stages on auto ownership, fraction of auto trips, and total auto travel time in 2000 compared to 1970. It indicates that lifecycle is a useful classificatory variable in explaining automobility characteristics, especially in 2000. It indicates that the distinction across lifecycle stages become remarkable when the process of motorization transforms urban area. Figure 4.5 shows that *younger childless couple* households and families with *all adults* are more auto-oriented, such as auto ownership and auto use; and *older single* households show less auto-oriented and auto use compared with other lifecycle stages in 1970 and 2000. This will be further discussed in section 4.6. In compare with 1970, the total mean of automobility has increased except traditional central city trips in 2000, and the differences between the maximum and minimum of automobility characteristics across stages are greater in 2000. It's worth noting that high auto ownership and high total automobile travel time showed in *nuclear families* with pre-school, young school, and older school children, but low ratio of auto trips to all trips in nuclear families. It means that household members have big difference in auto use, and children usually go to school by walking or by public transport in Japan while their parents much prefer to travel by cars. It seems that age is another explainer of automobility characteristics and will be tested by a four variable ANOVA analysis see section 4.7.

4.5 Automobility within different residence areas over time

Our environment affects our choices on travel behavior to a large extent. People who lived in suburbs may travel differently compared to who lived in the central city, especially on automobility characteristics. This section discusses how automobility characteristics change within different residence areas over time regardless of lifecycle stage. Figure 4.8 shows that decrease or little increase of automobility characteristics happened in commercial or mixed commercial/residential areas, but automobility characteristics increased greatly in suburbs, unurbanized, and autonomous areas. Distinction of automobile ownership and automobile use become clearer across different residence areas in 2000 in compared with 1970.

4.6 Automobility across lifecycle stages within different residence areas over time

The changes of automobility across lifecycle stages or across different residence areas over time are already discussed above. Since both lifecycle stage and residential area affect our travel behavior, these two effects are considers contemporaneously, namely to explore the changes of automobility characteristics across lifecycle stages with respect to each residence area over time in this section.

4.6.1 Automobility across lifecycle stages by residence areas over time

Figure 4.9 shows the changes in automobiles per household by each residential area type in 1970 through 2000, according to their lifecycle stages. Auto ownership is shown a little increased over time in commercial area, the differences among lifecycle stages are not remarkable at the range of 0.1~0.7 automobiles. More increase of automobiles over time appeared in mixed commercial/residential area, the differences among lifecycle stages are a little obvious in comparison with commercial area. The results of suburbs, unurbanized area, and autonomous area show automobiles of households are highly increased in the range of 0~2 automobiles depending on lifecycle stage over time.

The similar results are showed in figure 4.10. The fraction of auto trips of households is nearly unchanged but little decreased over time in the commercial area, or little increased over time in the mixed commercial/residential area, the differences among lifecycle stages is unobvious, not more than 17% in commercial and mixed commercial/residential area. The mean of auto trips of households are highly increased in the range of 0 ~ 40% depending on lifecycle stage in suburbs, unurbanized area, and autonomous area over time.

Figure 4.11 also show a small change about 0 ~ 18 minutes in the mean of total auto travel time per day appeared in commercial and mixed commercial/residential areas within each lifecycle stage, but the auto travel time for suburbs, unurbanized and autonomous area increased over time in the range of 0 ~ 32 minutes depending on the lifecycle stage.

The above results suggest that even within each lifecycle stage, change in the auto use – auto ownership, fraction of auto trips, and auto travel time – over time is suppressed in commercial and mix commercial/residential areas. However, the auto use for suburbs, unurbanized areas, and autonomous areas increased over time in the range of 0 to 4 times depending on the lifecycle stage.

Are these results telling us the truth or could we say the above suggestion? What is the relationship among lifecycle stage, residence area, and time? Which one is a strong explainer for the automobility characteristics? These will be verified through a three variable ANOVA analysis, including lifecycle effect, residence area effect, time effect and their interaction effects.

4.6.2 Significant explainers for automobility characteristics

The effects of lifecycle, residence area and time and their interaction effects are examined by using a three way factorial analysis of variance (ANOVA). ANOVA was used to determine if the differences observed were statistically different for each separate analysis. It was completed for the auto ownership, fraction of automobile trips, and total auto travel time by all households across the previously defined developed areas for the years 1970 and 2000. A three-way general linear model (GLM) is showed as followed:

$$X = \beta_0 + \beta_i^{LC} LC_i + \beta_j^{RA} RA_j + \beta_k^{Y} Y_k + \beta_{ij}^{LC*RA}(LC_i)(RA_j) + \beta_{ik}^{LC*Y}(LC_i)(Y_k) + \beta_{jk}^{RA*Y}(RA_j)(Y_k) + \beta_{ijk}^{LC*RA*Y}(LC_i)(RA_j)(Y_k) + \varepsilon \quad (4.1)$$

The variables in the three-way GLM are shown in Table 4.2.

Table 4.2

Variables in the 3-way general linear model

Variable		Variable Label
Dependent variables	X	**Automobility characteristics:** Auto ownership, Fraction of auto trips, Total auto travel time
Explanatory variables	LC_i: Lifecycle Stage	i : A~J
	RA_j: Residence Area	j: commercial area, mixed commercial area, suburbs, unurbanized area, and autonomous area.
	Y_k: Year	k: 1970, and 2000

The results (see table 4.3, 4.4, & 4.5) show all main effects – lifecycle stage, residence area, and year– are significant, also each F-value are more than 1.00, which means the average assessment scores of automobility characteristics are statistically different across each main effect group –lifecycle groups, residence area groups, and year groups.

The results also show the two-way and three-way interaction effects – lifecycle stage * residence area, lifecycle stage * year, residence area * year, and lifecycle stage * residence area * year – are significant, also each F-value is more than 1.00, which means lifecycle stage, residence area and year effects are not independent, that is to say, lifecycle stage is not the only explainer for the automobility characteristics.

According to the *sum of squares* of each effect, residence area effect shows the strongest impact on auto ownership, fraction of auto trips and auto travel time, in comparison with other effects, such like lifecycle, year and their interaction effects.

According to this three variable ANOVA analysis of lifecycle stage, residence area, and time confirms that the residence area rather than lifecycle stages is a significant explainer for automobile ownership and automobile use for a household. However, from table 4.3-4.5, it can be seen that the automobility explained by the lifecycle stage (*sum of squares*) is still larger to some extent.

4.6.3 Auto-oriented lifecycle stages

Parameter estimates of ANOVA analysis for automobility characteristics (Table 4.6-4.8) confirm that *younger childless couple* households and families with *all adults* are more auto-oriented. From the three tables, it can be seen that the parameter of auto ownership and auto use explained by all adults' families and younger childless couple families are larger than other stage of lifecycle. It also can be seen that the parameter of auto use explained by unurbanized areas and autonomous areas are larger than other areas, which means that people who lived in these areas are more auto-oriented. The parameter of auto ownership and auto use in 2000 are higher than that in1970, which means increasing auto use happened in Osaka metropolitan areas from 1970 through 2000.

However, there may still be variance between lifestyles within each lifecycle stage. Therefore, the number of trips that the person of the different lifecycle stages completes over a day will be compared. The number of trips may be an indication of how often the person engages in activities outside their home. This will be discussed in the next section.

4.7 Travel Activity Behavior across Lifecycle stages over time

Travel activity behavior describe the number of trips, peak-period trips such as work trips, school trips, and home trips, generation shopping and leisure trips etc. The travel activity behavior is expressed as the frequency of total daily trips, peak-period trips (including work trips, school trips, and home trips), leisure trips, and shopping trips etc. per person per day in this study. The frequency of trips is used here as a proxy for how often a person engages in activities outside the home. These results may show if there are significant differences in lifestyles, such like, a high number of trips may suggest a highly active and engaged person, while a low number of trips may suggest a more sedentary life.

Figure 4.12 showed the frequency of total daily trips, work trips, school trips, home trips, leisure trips, shopping trips, private business trips (including pick up/drop off trips, trips to hospital, trips for learning etc.) and work related trips per person per day within all lifecycle stages for 1970 and 2000 year. Almost all the types of trips showed nearly unchanged from 1970 to 2000, in which certain lifecycle stages have showed subtle increase in trip-making from 1970 to 2000, whereas certain lifecycle stages showed a subtle decline. However, an obvious united increase showed in the number of leisure trips and private business trips within all lifecycle stages through 1970 over 2000, though there is merely a little increase.

In compare with other lifecycle stages, *younger single* show the highest in trip-making in 1970 with 2.63 trips per person per day, but *nuclear families with pre-school children* show the highest 2.91 trips in 2000. Lifecycle stage of *younger single and younger childless couple* makes the largest work trips and work related trips within all the lifecycle stages both in 1970 and 2000. *Nuclear families with young school children* make the maximum value in home trips in 1970 and 2000. Lifecycle of *single parent* makes more school trips in comparison with other lifecycles. A remarkable result showed that *older childless couple* and *older single* households make the highest leisure and private business trips in 2000 as compared with others. In summary, there is no obvious distinction across lifecycle stages in the frequency of daily trip-making from 1970 to 2000, except that certain lifecycle families that have no children make nothing school trips in comparison with other lifecycles with children. An obvious united increase showed in the frequency of leisure trips and private business trips within all lifecycle stages through 1970 over 2000, especially in *older childless couple* and *older single* families, though it is less than 1 trip increase. This result in particular deserves a mention.

The results can be seen in Figure 4.12 which shows that there is very little difference from 1970 to 2000, but that differences can be seen across the lifecycle stages. This suggests that persons of same lifecycle stage are completing a similar number of trips per day, no matter the motorization, and that there are distinct differences between lifecycle stages. This result in combination with the Figure 4.9-4.11 would suggest that the residence area will determine the auto ownership and auto use, and that the differences seen in Figure 4.5 are not a result of different household lifecycle or lifestyle with respect to the number of trips being made.

4.8 Age as another explainer for automobility characteristics

It will be discussed that age is a very important factor for explain the auto ownership and auto use see section 5.7 of chapter 5. Furthermore, in section 4.4, it has been mentioned that *all adults* (all household members at their working age) are more auto-oriented, but *older single* households show less auto-oriented. Age of the members belong to these two stages of lifecycle are all adults, but auto travel behavior show totally different between these two lifecycle stages. It may be discussed that age is another explainer of automobility characteristics. A four variable ANOVA analysis, including age effect, was used to determine if the age effect is another important explainer for automobility characteristics. It was completed for the auto ownership, fraction of automobile trips, and total auto travel time across the previously defined developed areas for the years 1970 and 2000. The four-way general linear model (GLM) is showed in equation 4.2.

$$\begin{aligned} X = \beta_0 &+ \beta_i^{LC} LC_i + \beta_j^{RA} RA_j + \beta_k^{Y} Y_k + \beta_L^{A} A_L + \beta_{ij}^{LC*RA} (LC_i)(RA_j) + \beta_{ik}^{LC*Y} (LC_i)(Y_k) \\ &+ \beta_{iL}^{LC*A} (LC_i)(A_L) + \beta_{jk}^{RA*Y} (RA_j)(Y_k) + \beta_{jL}^{RA*A} (RA_j)(A_L) \\ &+ \beta_{kL}^{Y*A} (Y_k)(A_L) + \beta_{ijk}^{LC*RA*Y} (LC_i)(RA_j)(Y_k) + \beta_{ijL}^{LC*RA*A} (LC_i)(RA_j)(A_L) \\ &+ \beta_{jkL}^{RA*Y*A} (RA_j)(Y_k)(A_L) + \beta_{ijkL}^{LC*RA*Y*A} (LC_i)(RA_j)(Y_k)(A_L) \\ &+ \varepsilon \qquad (4.2) \end{aligned}$$

The variables in the four-way GLM are shown in Table 4.9.

Table 4.9 Variables in the 4-way general linear model

Variable		Variable Label
Dependent variables	X	**Automobility characteristics:** Auto ownership, Fraction of auto trips, Total auto travel time
Explanatory variables	LC_i: Lifecycle Stage	i : A~J
	RA_j: Residence Area	j: commercial area, mixed commercial area, suburbs, unurbanized area, and autonomous area
	Y_k: Year	k : 1970, and 2000
	A_l: Age	L: <=9, 10-19, 20-29, 30-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-74, and 75 +

The results of the four variables ANOVA analysis, which include lifecycle stage effect, residence area effect, time effect, age effect, and their interaction effects, are shown in Table 4.10-4.12. Compared with the results of Table 4.3-4.5, it can be seen that the auto ownership explained by lifecycle stage (Sum of Squares) is larger than either the residence area or other main and combined effects; however, the auto portion and auto travel time explained by age (Sum of Squares) is larger than either residence area or other main and interaction effects.

The results suggest that the residence area rather than lifecycle stage is a significant explainer for automobile ownership and automobile use based on households, and the age of household members is the most important explainer for automobile use.

4.9 Summary

This chapter discussed several issues about urban auto travel related to lifecycle stage using the repeated cross-sectional data collected over the last three decades.

This study examined the changes of automobility characteristics across lifecycle stages over time. There is a great distinction across lifecycle stages on automobile ownership, the fraction of auto trips, and total auto travel time in 2000 compare to 1970. This distinction across lifecycle stages becomes remarkable when the process of motorization transforms urban area. It indicates that lifecycle is a useful classificatory variable in explaining automobility characteristics.

According to the statistical analyses of lifecycle stage, residence area, and time effect, it confirms that the residence area rather than lifecycle stage is a significant explainer for automobile ownership and automobile use. The results suggest that even within each lifecycle stage, change in the automobile use – automobile ownership, the fraction of auto trips, and total automobile travel time – over time is suppressed in commercial and mixed commercial/residential areas. However, the fraction of automobile trips for suburbs, unurbanized areas, and autonomous areas increased over time in the range of 0 to 4 times depending on the lifecycle stage.

The results showed that *younger childless couple* stage and *all adults*' stage are more auto-oriented in suburbs, unurbanized area, and autonomous areas. And this trend becomes stronger as automobility progresses.

The results suggest that each lifecycle stage are completing a similar number of trips per day, no matter the motorization, but there are distinct differences of auto ownership, the fraction of auto trips and auto travel time across lifecycle stages within different residential areas. It indicates that the residence area will determine the auto ownership and auto use, suggesting that similarly active lifestyles exist.

Since age effect is a very important factor for explain the auto ownership and auto use, age effect is included in the ANOVA analysis for examining if the age effect is an important explainer for automobility when consider residence area, lifecycle stage, age and time together. The result suggests that residence area mainly determines the automobile ownership, but household members' age is one of the main explainers for the fraction of auto trips and total auto travel time.

With respect to the previous study (Sun & Waygood etc., 2009), it investigated how the built environment may create environments where more sustainable travel is possible by considering the fraction of automobile trips across different developed areas and within distinct lifecycle stages in the previous study. The results suggest that the built environment has significant correlation with the fraction of automobile trips even when households of different lifecycle stages are compared. This result in combination with the finding of this chapter, would suggest that significantly more sustainable behavior for society would be possible with more compact built environments that facilitate non-motorized and public transit travel. Unfortunately, it takes time, money, resources, and the political will to change the built environment and initial steps that educate the public such as voluntary travel behavior change may be necessary first steps on the move to more sustainable travel.

Chapter 5
The automobility cohort as a tool in the study of urban travel

5.1 Introduction

The mobility of urban residents has been expanding over time. Kitamura and Susilo (2005) have shown that this expansion stems more from structural change than from change in demographic and socio-economic characteristics of urban residents. The structure change here means change in the relationship between travel behavior and demographic factors. For example, most metropolitan areas themselves have been changing in terms of its geographical expansion, internal land use structure, transportation networks, and auto-orientation. These changes have led to structural changes in travel. They went to conjecture that this structural change is mainly due to increasingly prevailing automobility (Urry, 2005), i.e., conversion of social and economic system and way of life to adapt to the ownership and use of the automobile. In this study, this conjecture is explored by examining automobility characteristics of automobility cohorts.

It has been pointed out that the elderly of these days behave differently than the elderly of decades ago because the current generations of elderly grew up with the automobile and have been using it ever since their habit forming ages. A hypothesis behind this study is automobility cohorts do exist, with each cohort have certain mobility traits that are unique, especially in terms of auto use. A statistical age-period-cohort analysis is used to examine the above hypothesis. Since residence area is a significant explainer for automobility characteristics, it is worth to include residence area effect into the age-period-cohort analysis. Through the examination of this hypothesis, this study attempts to offer a possible explanation of the increases in automobilty characteristics in Kyoto-Osaka-Kobe metropolitan area.

Automobility cohorts are defined by grouping individuals who turn 20 years old during the time period indicated. Each time period is chosen with respect to the level of automobility. The level of automobility is operationally defined in this study in terms of: automobile ownership, modal split, and automobile travel time. The following five cohorts are developed for the study area and used in the analysis: pre-war (up to 1945), pre-motorization (1946-1960), initial growth (1961-1970), mass-ownership (1971-1980), and multi-car ownership (1980). In addition, time effects and age effects are introduced into the analysis as in standard cohort analysis. The Kyoto-Osaka-Kobe (Keihanshin) metropolitan area of Japan is the study area of this effort.

5.2 Cohort analysis

A cohort is a group of people who share a common characteristic or experience within a defined time period. Cohort analysis refer to any study in which there are measures of some characteristic of one or more cohorts (birth or otherwise) at two or more points in time. A cohort study is a form of longitudinal study used in medicine and social science. Many studies have utilized a more analytical approach to the treatment of cohort analysis. However, the impossibility of statistically separating age, period, and cohort effects grows out of the identification problem, which exists whenever three or more independent variables need to be included in an analysis and each one is a linear function of the others.

Various cohort analysis methods have been developed for the identification of the three effects through statistical analysis. Mason, K.O. et al. (1973) consider the identification problem for situations in which the dependent quantity is treated as a joint function of age, period, and cohort membership. Three methods of cohort analysis were presented for a statistical model wherein the explanatory or exposure variables act multiplicatively on age×calendar year specific death rates by Breslow (1983). The discussion centers on the tradeoff between efficiency and bias in the selection of a particular method of analysis, and on practical issues that arise in application. Kupper (1984) focused on the statistical modeling of age-period-cohort (APC) analysis methods. The identifiability problem inherent to the model was discussed, and its adverse effects on the results of APC modeling exercises are illustrated numerically.

The paper also argues that a “typical age profile” was “shifted down” for the cohorts born between 1920 and 1939 relative the younger and older cohorts considered. Mason, W.M. (2001) described that cohort analysis treats an outcome variable as a function of cohort membership, age, and period. Panel studies, cross-sectional studies with retrospective information, and replicated cross-sections engender the analysis of a response variable as a function of age, period and cohort as well as other factors. They argued that models do not explicitly consider all three of age, period, and cohort, and yet are based on data structures that permit their inclusion, rest on the implicit assumption that age, or period or cohort is irrelevant.

The above researches have been discussed the problem in cohort analysis that results from the logical relationship among age, period and cohort. More detailed various studies about cohort analysis methods have been discussed in chapter 2. No matter which way solve identification problem, it depend on the data structure used in the study. In this study, the repeated cross-sectional data provide the basis for a solution to the identification problem.

5.3 Automobility cohort

In this study, Automobility cohorts are defined by grouping individuals who turn 20 years old during the time period indicated. Each time period is chosen with respect to the level of automobility. The level of automobility is operationally defined in this study in terms of: automobile ownership, modal split, and automobile travel time.. The following five cohorts are developed for the study area and used in the analysis: pre-war (up to 1945), pre-motorization (1946-1960), initial growth (1961-1970), mass-ownership (1971-1980), and multi-car ownership (1980-). Table 5.1 presents that age is calculated by cohort and period (survey year).

Table 5.1 Age calculated by cohort and period

Cohort	**Period**	**Age**			
		1970	1980	1990	2000
1:Pre-war	Up to 1945	>=45	>=55	>=65	>=75
2:Pre-motorization	1946-1960	30-44	40-54	50-64	60-74
3:Initial growth	1961-1970	20-29	30-39	40-49	50-59
4:Mass-ownership	1971-1980	10-19	20-29	30-39	40-49
5:Multi-car ownership	1981+	<=9	<=19	<=29	<=39

The computation is defined as:

$$\text{Age} = \text{Period} - \text{Cohort} + 20 \qquad (5.1)$$

This computation shows that knowledge of placement on any two of age, period, and cohort determines placement on the third. This dependency raised the questions of whether and how all three of age, period, and cohort can be included in cohort models. The linear dependency between age, period, and cohort, also known as the cohort analysis identification problem, is the point of departure for all modern discussions of techniques of cohort analysis. The identification problem is present irrespective of data structure. In this study, the repeated cross-sectional data of Kyoto-Osaka-Kobe metropolitan areas provide the basis for a solution to the identification problem. The following sections attempt to solve this identification problem by using age-period-cohort model in the analysis.

5.4 Descriptive cohort-age-period analysis

A descriptive age-period-cohort analysis first assembles auto ownership, fraction of auto trips, and auto travel time in a standard cohort tables (Table 5.2). The rows represent categories of age at occurrence, the columns define categories of period of occurrence, and the diagonals (in the same color) permit tracking of a single automobility cohort over time. The data highlighted blue represent pre-war cohort, green represent pre-motorization cohort, purple represent initial growth cohort, yellow represent mass-ownership cohort, and pink represent multi-car ownership cohort.

Table 5.2 Auto ownership by age, 1970-2000

Age	Period			
	1970	1980	1990	2000
<=9	0.51	0.87	1.20	1.41
10-19	0.47	0.85	1.15	1.42
20-29	0.48	0.96	1.28	1.50
30-39	0.48	0.86	1.18	1.34
40-44	0.45	0.83	1.13	1.37
45-49	0.45	0.89	1.19	1.45
50-54	0.49	0.93	1.25	1.51
55-59	0.50	0.87	1.15	1.40
60-64	0.44	0.77	0.96	1.18
65-74	0.40	0.70	0.80	0.94
75+	0.46	0.77	0.85	0.88

The information from Table 5.2 summarizes auto ownership by rows, columns, and diagonals. The most immediately visible pattern is the association between period and auto ownership.

In all age or cohort categories, auto ownership has increased from 1970 to 2000. There appears to be not so much variation across ages or cohorts within each period. It is because the auto ownership is based on a household in this survey. The person at any age or at any automobility cohort belongs to each household and therefore the result show not so much variation across ages or cohorts within each period. The results would suggest that period is a stronger explainer of automobile ownership.

Table 5.3 Fraction of auto trips by age, 1970-2000

Age	Period			
	1970	1980	1990	2000
<=9	1.3%	2.7%	6.6%	13.2%
10-19	2.6%	1.9%	3.1%	5.1%
20-29	19.2%	27.1%	30.4%	34.3%
30-39	23.0%	31.3%	38.1%	43.1%
40-44	20.0%	30.0%	36.7%	44.7%
45-49	16.9%	26.8%	33.3%	43.0%
50-54	13.5%	22.9%	30.5%	39.9%
55-59	11.8%	18.7%	27.8%	36.4%
60-64	9.4%	14.0%	23.5%	33.0%
65-74	7.2%	9.8%	16.1%	26.0%
75+	7.0%	7.7%	11.1%	17.9%

Table 5.3 lists the fraction of auto trips by ages, periods, and cohorts. The overall level of fraction of auto trips appears to be much variation over the past few decades. There has been a largely positive relationship between period and fraction of auto trips. There also appears to be much variation across ages or across cohorts in each period. The result also shows variation across cohorts, but even in the same cohort, it seems much variation happened between different age categories. On this point it would suggest that age is a stronger explainer of the fraction of travel time. However, we cannot get any information about which effect is the main explainer of fraction of auto trips from this table because effects of cohort, age, and period are confounded with one another.

Table 5.4 lists auto travel time by ages, periods, and cohorts. The similar results are shown that obvious visible pattern is the relationship between age and auto travel time, and there are appears to be much variation between ages. There also has been positive relationship between period and auto travel time except the younger person under 20 and older person over 65 from 1970 through 1980. The result also shows variation across cohorts, but even in the same cohort, it seems much variation happened between different age categories. The results would suggest that age is a stronger explainer of the auto travel time.

Table 5.4 Auto travel time by age, 1970-2000

Age	Period			
	1970	1980	1990	2000
<=9	0.82	1.24	2.67	5.30
10-19	2.48	1.56	2.21	3.16
20-29	21.27	22.60	25.51	27.95
30-39	26.05	27.67	30.73	35.09
40-44	19.15	26.97	30.43	34.94
45-49	17.60	23.25	28.50	34.31
50-54	13.83	19.87	27.25	32.90
55-59	10.13	15.17	23.97	31.79
60-64	8.47	10.93	18.77	29.28
65-74	6.82	6.78	11.27	19.31
75+	6.48	4.24	6.25	9.82

The above results would suggest that period effect is a stronger explainer of automobile ownership and age is a stronger explainer of automobile use, in terms of, fraction of auto trips and auto travel time. Whether the period effect or age effect even automobility cohort effect can explain automobility characteristics, we cannot find by the above descriptive analysis like table 5.2-5.4. Such quantification can only be achieved via the use of statistical modeling procedures which will be discussed in section 5.7.

5.5 Automobility characteristics across automobility cohorts over time

The automobility characteristics across automobility cohorts over 1970 through 2000 are summarized in Figure 5.1. On the whole, automobility characteristics have shown a great growth over 1970 through 2000, except auto travel time are nearly unchanged of pre-war cohort and pre-motorization cohort over 1970 through 2000.

It is interesting to note that auto ownership by households, which pre-war and pre-motorization cohorts belong to, has increased more than 2 times over 1970 through 2000, but the fraction of auto trips show little, roughly 6%, increase while auto travel time nearly unchanged for pre-war and pre-motorization cohorts. This result would suggest that although the automobile ownership by households, which pre-war and pre-motorization cohorts belong to, has increased, they are still shown not auto-oriented over 1970 through 2000.

The automobile ownership of initial growth, mass-ownership, and multi-car ownership cohorts show a great growth and the fraction of auto trips and auto travel time also show respective growth of these three cohorts. Compared with other cohorts, mass-ownership cohorts show the greatest growth over time on fraction of auto trips and auto travel time.

The above results would suggest that pre-war and pre-motorization cohorts do not show rely increasingly on automobile use; however initial growth, mass-ownership, and multi-car ownership cohorts grow increasingly to rely on auto use over 1970 through 2000. This suggestion will be further confirmed through statistical cohort-age-period analysis in section 5.7.

5.6 Automobility characteristics across age categories over time

Figure 5.2 shows the automobility characteristics across age groups over 1970 through 2000. The automobile ownership and automobile use for most of age categories have shown increasing growth over time except minors and old people. There is no distinct difference across age categories over time for automobile ownership, but the fraction of auto trips and auto travel time show distinct differences across age categories over time.

An interesting result shows that the fraction of auto trips and auto travel time of middle-aged people have a great increase over 1970 through 2000. Especially people, whose age are between 60 and 64, show increasing auto travel time over 1970 through 2000.

In brief, the automobile ownership and automobile use show increasing growth across most of the age categories over 1970 through 2000. Especially the middle-aged people show a great increasing growth in auto ownership and auto use over time. It will be further discussed in the next section.

5.7 Statistical Age-Period-Cohort analysis

In this study, we focus primarily on the age-period-cohort (APC) model in which the dependent quantity is treated as a joint function of age, period, and cohort membership for separating effects of the categorized age, period and cohort variables. The APC model has the specific structure

$$Y = \beta_0 + \beta_i A_i + \beta_j P_j + \beta_k C_k + \varepsilon \qquad (5.2)$$

In which Y represents observations, A_i is the fixed effect of the ith age category, P_j is the fixed effect of jth period category, C_k is the fixed effect of the kth cohort category. The variables and their labels in this APC model are shown in Table 5.5.

Table 5.5 Variables and their labels in APC model

Variable	Variable Label
Y	Auto ownership, Fraction of auto trips, and Total auto travel time.
Age_i	i : -9, 10-19, 20-29, 30-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-74, and 75+.
$Period_j$	j: 1970, 1980, 1990, and 2000.
$Cohort_k$	k: Pre-war, Pre-motorization, Initial growth, Mass-ownership, and Multi-car ownership.

Having defined the APC model, the statistical goal is then to estimate as accurately as possible the age, period, and automobility cohort parameters in that model. It is standard practice to make separate plots of the estimated age, period, and automobility cohort effects. From an inspection of Table 5.6, 5.7 & 5.8, it can be seen that the APC model, as with more standard three-way ANOVA-type models, assumes that cohort effect, age effect, and period effect are significant, also each F-value is more than 1.00, which means the average assessment scores of automobility characteristics are statistically different across each main effect categories – automobility cohort categories, age categories, and period categories. It confirms that automobility cohorts do exist.

From table 5.6, it can be seen that the automobile ownership explained by the period (Sum of Squares) is larger than either the automobility cohort effect or the age effect. However, the fraction of auto trips and automobile travel time explained by the age (Sum of Squares) is larger than either the automobility cohort effect or period effect (Table 5.7 & 5.8). It indicates that period plays an important part in automobile ownership orientation, but age effect mainly determines automobile use orientation.

Parameter estimates of APC model for auto ownership, fraction of auto trips, and auto travel time represented in Table 5.9, 5.10 and 5.11. It can be seen that the auto ownership of multi-car ownership cohort families (see Beta value of Table 5.9) are higher than other automobility cohorts; and the fraction of auto trips and auto travel time of mass-ownership cohort (see Beta value of Table 5.10 & 5.11) is larger than other automobility cohorts. It illustrates numerically that multi-car ownership cohorts show more automobile ownership orientation compared with other automobility cohorts, and mass-ownership cohorts show more automobile-oriented.

It also can be confirmed that middle-aged people, especially whose age between 30 and 44, show more automobile-oriented. The results illustrate that automobility characteristics show an increasing growth over 1970 through 2000.

5.8 Residence area in age-period-cohort model

It has been discussed that residence area is a significant explainer for automobility characteristics (see section 4.6.2 in chapter 4). It is worth to include residence area effect in the APC model. The model (APC-RA model)

$$Y = \beta_0 + \beta_i A_i + \beta_j P_j + \beta_k C_k + \beta_l RA_l + \varepsilon \qquad (5.3)$$

which contains age effect, period effect, cohort effect, and residence area effect and see whether residence area is a significant effect in APC-RA model. Y represents observations, A_i is the fixed effect of the ith age category, P_j is the fixed effect of jth period category, C_k is the fixed effect of the kth cohort category, and RA_l is the fixed effect of lth period category. The variables and their labels in the APC-RA model are presented in Table 5.12.

Table 5.12 Variables and their labels in APC-RA model

Variable	Variable Label
Y	Auto ownership, Fraction of auto trips, and Total auto travel time.
Age_i	i : -9, 10-19, 20-29, 30-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-74, and 75+.
$Period_j$	j: 1970, 1980, 1990, and 2000
$Cohort_k$	k: Pre-war, Pre-motorization, Initial growth, Mass-ownership, and Multi-car ownership.
Residential $area_l$	l: commercial area, mixed commercial area, suburbs, unurbanized area, and autonomous area.

The results illustrate that residence area shows a stronger impact on automobile ownership rather than period, age, and cohort effect, by inspecting the Sum of Square of each effect in Table 5.13, however age effect is still a significant explainer (Sum of Squares) for the fraction of auto trips and auto travel time rather than residence area effect, cohort effect and period effect in Table 5.14 & 5.15.

Table 5.16, 5.17 and 5.18 represent the parameter estimates of APC-RA model for auto ownership, fraction of auto trips, and auto travel time. It can be seen that the auto ownership of multi-car ownership cohort families (see Beta value of Table 5.16) are higher than other automobility cohorts; and the fraction of auto trips and auto travel time of mass-ownership cohort (see Beta value of Table 5.17 & 5.18) is larger than other automobility cohorts. It illustrates numerically that multi-car ownership cohorts show more automobile ownership orientation compared with other automobility cohorts, and mass-ownership cohorts show more automobile-oriented.

It is illustrated that middle-aged people, especially whose age between 30 and 44, show more automobile-oriented in Table 5.16, 5.17 & 5.18. The results also confirm that automobility characteristics show an increasing growth over 1970 through 2000. People who lived in unurbanized area show more auto-oriented by inspecting the Beta value in Table 5.16, 5.17 & 5.18.

5.9 Summary

Using the repeated cross-sectional data of Kyoto-Osaka-Kobe metropolitan area in 1970, 1980, 1990, and 2000, the study of this chapter has attempted to offer a possible explanation of the increases in automobilty characteristics in Kyoto-Osaka-Kobe metropolitan area by examining automobility characteristics of automobility cohorts. It focused on statistical age-period-cohort analysis using the popular multiple classification APC model. The identifiability problem attendant with the use of APC model was discussed with repeated cross-sectional data. As mentioned early in section 5.8, since residence area is a significant explainer for automobility characteristics (we can find the evidence in chapter 4), APC-RA model is developed for exploring which effect is the main explainer of automobility progress in the study area.

An interesting finding is shown that *pre-war* and *pre-motorization* cohorts show little, roughly 6%, increase on the fraction of auto trips and nearly unchanged on total auto travel time over 1970 through 2000, although their household automobile ownership has increased more than 2 times. *Initial growth*, *mass-ownership*, and *multi-car ownership* cohorts show a great growth of automobile ownership, the fraction of auto trips, and auto travel time from 1970 to 2000, but a little surprising result is that *mass-ownership* cohorts, not *multi-car ownership* cohorts, show the largest increases to rely on auto use over 1970 through 2000. The above results confirm that each cohort having certain automobility traits that are unique, especially in terms of auto use.

Middle-aged person, especially whose age between 30 and 44, show a great increasing growth of automobile ownership, the fraction of auto trips, and auto travel time over 1970 through 2000.

The standard age-period-cohort analysis confirms that automobility cohort effect do exist, but it is regret that cohort effect is not an important explainer for automobility characteristics, while time effect plays an important part in automobile ownership choice, and age effect mainly determines automobile use – the fraction of auto trips and auto travel time.

An attempt at APC-RA model illustrate that residence area rather than time effect have the strongest impact on automobile ownership, and age effect is still a significant explainer for the fraction of auto trips and auto travel time. This result is different with the results of age-period-cohort analysis, which further emphasize that residence area is a significant explainer for household automobile ownership in the Kyoto-Osaka-Kobe metropolitan area from 1970 to 2000.

Chapter 6
Determinants of Urban Travel: Demographics vs. Structural Change

6.1 Introduction

Significant changes in demographic and socio-economic characteristics of urban resident have taken place over the past several decades. Most notable are: aging of the population and resulting increases in retired, non-employed individuals; decreasing household size caused by increasing fractions of single individuals and couples with fewer children; increased labor force participation by women; general increases in income; and increasing auto ownership and auto dependence. For example, in the Kyoto-Osaka-Kobe metropolitan area of Japan, the fraction of individuals aged 60 years and older has increased by nearly 15% from 11% to 26% between 1970 and 2000, and the average number of automobiles per household increased from 0.38 to 1.06 in the same period. The overall effects on travel of these changes are complex and future trends are not immediately obvious, partly because some of the changes have opposite, cancelling effects on travel, and partly because these changes themselves are not independent but closely linked to each other. Prevailing tendencies in travel, however, have been expansion—urban residents' travel has continuously expanded over time in terms of total travel time (or distance), auto use, energy consumption, and the spatial extension of their action space. Will these trends continue into the future? Or will the trend change due to the aging of the urban population? Or are there other factors at work? If so, what are the magnitudes of demographic effects relative to theirs?

Results of repeated household travel surveys in the Kyoto-Osaka-Kobe metropolitan area, conducted in 1970, 1980, 1990 and 2000, are examined in this study to evaluate the effects of demographic changes on travel, and to assess possible future trends. Also addressed is the issue of structural change, i.e., change in the relationship between travel behavior and demographic factors. For example, it has been pointed out that the elderly of these days behave differently than the elderly of decades ago because the current generations of elderly grew up with the automobile and have been using it ever since their habit forming ages. In addition to such cohort effects, the metropolitan area itself has been changing in terms of its geographical expansion, internal land use structure, transportation networks, and auto-orientation. In fact it has been argued that "the structural relationships are instable" and that "changes in non-workers' travel patterns are largely due to the instability in the structural relations while changes in demographic and socio-economic factors play relatively minor roles, and that urban residents' travel has the tendency to expand over time."(Kitamura, 2005)

The focus of this study is on auto travel. The analysis examines how auto travel has changed over time with changing demographics, residential location, and metropolitan structure. A simultaneous equations model system is developed at the household level, with auto ownership, fraction of auto trips, and total auto travel time as its dependent (or endogenous) variables. Using the repeated household travel survey results, the stability over time of the simultaneous equations system is statistically examined, and thereby the effects of demographic changes are separated from those of structural change. Using the results, it is shown how much of the change in urban travel is due to changes in demographics and how much is due to structural change. In addition, the resultant model system is applied in a scenario analysis to forecast possible changes in future auto travel that will follow hypothetical demographic changes in the metropolitan area.

6.2 Changing of automobility characteristics

Among the many unpleasant realities, one of the most surprising, to many, was this: our nearly total dependence on automobiles. A century ago, getting to work seldom required a lengthy commute. In rural area, farmers walked out the kitchen door to their jobs. And most urban residents either lived within walking distance of their places of employment or could rely on convenient public transit systems like streetcars. Today, however, two-thirds of residents in metropolitan areas live in the suburbs, and two-thirds of new jobs are located there as well. It's therefore no surprise that 88 percent of workers drive to their jobs in U.S.[1].

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1 Auto-Mobility: Subsidizing America's Commute?
http://www.brookings.edu/articles/2005/10transportation_waller.aspx

Motorization in Japan was not appreciable before 1960. The number of registered automobiles in the country began to rise in the first half of the 1960's. In fact annual growth peaked in 1960 with a growth rate exceeding 30%. Vehicle ownership in Japan increased from a mere 0.0018 vehicle per person in 1995 to 0.33 in 1999. At the same time, rail's share, dominant at 90.0% of total person-kilometers in 1950, declined to 34.0% in 1995; auto's share increased from a mere 0.6% to 51.7% in the same period (Kitamura, 2005).

Like most metropolitan areas of industrialized countries, Kyoto-Osaka-Kobe metropolitan areas underwent substantial changes in the second half of the 20th century. With the rapid urbanization after the World War Ⅱ, metropolitan areas expand outwards with the suburbs absorbing much of the influx of population. Changes of automobility characteristics in the last three decades are discussed on the following sub-sections.

Increasing fraction of automobile use

In all areas except for the commercial and mixed-commercial areas, a significant growth 2~ 4 times in the fraction of household trips completed by automobile can be seen in Figure 6.1. From these results, it appears that the more densely developed built environments, commercial and mixed-commercial, had a limiting effect on the fraction of automobile trips. However, without knowing how households of different lifecycle stages behave within each of those areas, it could be argued that the same people are continuing to live in the commercial and mixed-commercial areas, and that their behavior is simply entrenched. It is interesting to note that even in the most extreme cases; the fraction of household travel is roughly 50%. Speculatively, this may be a result of mixed land-use in all areas.

Increasing automobile ownership across different residential areas

Figure 6.2 shows that owning an automobile has become very common except commercial area because it is a widely available form of transportation. Exceed 50 percent households own 2 and more cars in unurbanized areas and autonomous areas.

Are these changes due to changes in demographic of urban residents? Significant changes in demographic and socio-economic characteristics of urban residents have taken place over the past several decades, such as, population aging, household size decreasing, increases in non-employed individuals etc. Such changing demographic will be described in the next section.

6.3 Changes in demographic of urban residents

The world is in the midst of a major demographic transition. Not only is population growth slowing, but the age structure of the population is changing, with the share of the young failing and that of the elderly rising. Different countries and regions, however, are at varying stages of this demographic transition. In most advanced countries, the aging process is already well under way. In developing countries, however, the demographic transition is less advanced, and working-age populations will increase in the coming decades. Kyoto-Osaka-Kobe metropolitan area, like most metropolitan areas of industrialized countries, underwent significant changes in demographic over the past several decades.

Population aging

Figure 6.3 (Changes in age: 1970-2000) shows that Kyoto-Osaka-Kobe metropolitan areas face aging population from 1980. In 1970 and 1980 there were roughly 10 percent people aged 60 or older. By 2000, this ratio rise to more than 25 percent. The sources of population aging lie in two demographic phenomena: rising life expectancy and declining fertility. The aging population poses a serious challenge to the support for the elderly, social security, social welfare and services, including the development of public transport facilities.

Household size shrinking

The average number of people living in Kyoto-Osaka-Kobe households has dropped from 1980 (see Figure 6.4, Changes in household size: 1970-2000). The portion of one-member and two-member households have increased 10 percent over 1980 through 2000, but three or more member households have dropped 8 percent. A combination of cultural factors is behind the shrinking household and this shrinking will have impact on the urban travel today.

Increases in elder childless couple and elder single families

The aging of the population and shrinking of the household size result increases in elder childless couple and elder single families in Osaka metropolitan. The proportion of these families have increased roughly 10 percent over 1970 through 2000 corresponding to the decreased in primary school nuclear and middle-high school nuclear families, see

Changes in lifecycle stage of Figure 6.5.

Increasing non-employed individuals

Changes in employments status over 1970 through 2000 showed in Figure 6.6. The proportion of employee workers nearly unchanged from 1970 to 2000 while the ratio of students have declined from 27% in 1980 to 18% in 2000, but the ratio of non-employed workers is increasing 6% from 1970 to 2000 in the Kyoto-Osaka-Kobe metropolitan areas.

As the early mention is that prevailing tendencies in travel have been expansion – urban residents' travel has continuously expanded over time in terms of total travel time, auto use, auto use, energy consumption, and the spatial extension of their action space. Are these changes due to changes in demographic of urban residents? Or are there other factors at work? It will be explored in the following sections.

6.4 Model systems

The model system is developed in this study taking into consideration the automobility characteristics that influence urban travel behavior. The model system includes as endogenous variables: automobile ownership, fraction of auto trips and auto travel time. The model system embodies the causal structure postulated for these variables. The basic structure of the model systems developed in this study is illustrated in Figure 6.7.

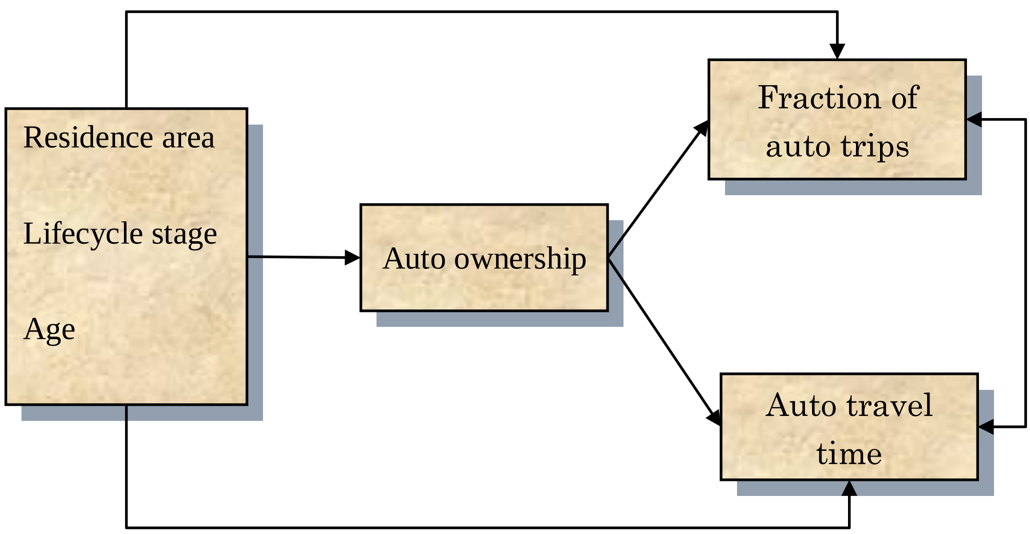


Figure 6.7 Relations among automobility characteristics

The model systems embody the following set of assumptions: Automobile ownership and automobile travel time is expected to be influenced by the age of the person, which residential area person lived, and what kind of lifecycle stage families which the person belongs to. Then the fraction of automobile trips is secondly determined not only the above elements, also decided by whether the family, which the person belongs to, own automobiles or not and the travel time by automobile transit is spent.

The model system is first illustrated along with the two-stage estimation procedure adopted in this study. Let the endogenous variables of the model system be Y_{AO} = automobile ownership of households which people belong to, Y_{AT} = total automobile travel time per person per day, Y_{FA} = the fraction of automobile trips per person per day. The simultaneous equation model system is given by:

$$\begin{cases} Y_{AO} = h_{Y_{AO}}(LC, RA, A) \\ Y_{AT} = h_{Y_{AT}}(AO, FA, LC, RA, A) \\ Y_{FA} = h_{Y_{FA}}(AO, AT, LC, RA, A) \end{cases} \tag{6.1}$$

Where LC is the vector of exogenous variables representing lifecycle stage which the person belong to, including younger single stage, younger childless couple stage, pre-school nuclear families stage, young school nuclear families stage, older school nuclear families stage, all adults stage, older childless couple stage, older single stage, single parent stage, and others' families. RA is the vector of residential area in which person lived, contain: commercial area, mixed commercial/residential area, suburbs, unurbanized area, and autonomous area. A is the vector of variables representing the age of individuals, containing 11 groups of age levels, which are <=9, 10-19, 20-29, 30-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-74, and >=75.

$$\begin{cases}
\begin{cases} Y_{AO} = \begin{cases} Y_{AO}^{*} & \text{if } Y_{AO} > 0 \\ 0 & \text{otherwise} \end{cases} \\ Y_{AO}^{*} = \beta_0 + \beta_{AO,LC} X_{LC} + \beta_{AO,RA} X_{RA} + \beta_{AO,A} X_A + \varepsilon_{AO} \end{cases} \\
\begin{cases} Y_{AT} = \begin{cases} Y_{AT}^{*} & \text{if } Y_{AT} > 0 \\ 0 & \text{otherwise} \end{cases} \\ Y_{AT}^{*} = \beta_0 + \beta_{AT,LC} X_{LC} + \beta_{AT,RA} X_{RA} + \beta_{AT,A} X_A + \gamma_{AT,AO} \hat{Y}_{AO} + \gamma_{AT,FA} \hat{Y}_{FA} + \varepsilon_{AT} \end{cases} \\
\begin{cases} Y_{FA} = \begin{cases} Y_{FA}^{*} & \text{if } Y_{FA} > 0 \\ 0 & \text{otherwise} \end{cases} \\ Y_{FA}^{*} = \beta_0 + \beta_{FA,LC} X_{LC} + \beta_{FA,RA} X_{RA} + \beta_{FA,A} X_A + \gamma_{FA,AO} \hat{Y}_{AO} + \gamma_{FA,AT} \hat{Y}_{AT} + \varepsilon_{FA} \end{cases}
\end{cases} \tag{6.2}$$

It can be seen that endogenous variables appear on the right-hand side of equation for Y_{AT} and for Y_{FA} in equation 6.1. This could potentially lead to inconsistent estimation. In order to obtain consistent estimates, a two-stage procedure is adopted in this study. In the first stage, Tobit equation is applied to the respective model equations with each normal error term which is expressed as equation 6.2.

Firstly, Tobit equation 6.2 is estimated using maximum likelihood estimation (MLE) method. Based on the estimated vectors of coefficients, the fitted values are estimated and the reduced form of each equation is:

$$\begin{cases} \widehat{Y}_{AO}{}^{*} = \beta_0 + \beta'_{AO,LC}X_{LC} + \beta'_{AO,RA}X_{RA} + \beta'_{AO,A}X_A \\ \widehat{Y}_{AT}{}^{*} = \beta_0 + \beta'_{AT,LC}X_{LC} + \beta'_{AT,RA}X_{RA} + \beta'_{AT,A}X_A + \gamma'_{AT,AO}\widehat{Y}_{AO} + \gamma'_{AT,FA}\widehat{Y}_{FA} \\ \widehat{Y}_{FA}{}^{*} = \beta_0 + \beta'_{FA,LC}X_{LC} + \beta'_{FA,RA}X_{RA} + \beta'_{FA,A}X_A + \gamma'_{FA,AO}\widehat{Y}_{AO} + \gamma'_{FA,AT}\widehat{Y}_{AT} \end{cases} \quad (6.3)$$

Sencondly, using the fitted instead of actual values on the right hand of side of each equation 6.3, the simultaneous equations system is estimated:

$$\begin{cases} Y_{AO}{}^{*} = \beta_0 + \beta'_{AO,LC}X_{LC} + \beta'_{AO,RA}X_{RA} + \beta'_{AO,A}X_A + \varepsilon_{AO} \\ Y_{AT}{}^{*} = \beta_0 + \beta'_{AT,LC}X_{LC} + \beta'_{AT,RA}X_{RA} + \beta'_{AT,A}X_A + \gamma'_{AT,AO}\widehat{Y}_{AO} + \gamma'_{AT,FA}\widehat{Y}_{FA} + \varepsilon_{AT} \\ Y_{FA}{}^{*} = \beta_0 + \beta'_{FA,LC}X_{LC} + \beta'_{FA,RA}X_{RA} + \beta'_{FA,A}X_A + \gamma'_{FA,AO}\widehat{Y}_{AO} + \gamma'_{FA,AT}\widehat{Y}_{AT} + \varepsilon_{FA} \end{cases} \quad (6.4)$$

These model systems are estimated and then applied to examine how auto travel has changed from 1970 to 2000 with changing demographics, residential location, and metropolitan structure in Osaka metropolitan area in the next section.

The simultaneous equation model systems are deployed in this study because they aid in locating the source of instability; using these model systems makes it possible to discern whether a change in behavior is due to changes in the demographic factors, including the attributes of urban residents, such as living in a certain area, belonging to a certain stage of lifecycle, at a certain age, or it is due to changes in structural change. It is thus possible to determine the factors that have caused the recent trends of increasing travel demand seen in many urbanized areas of industrialized countries.

6.5 Estimation results

The simultaneous equation model systems shown as equations 6.2 are estimated using the two-stage procedure described in the previous section. Assuming that the error terms are not correlated across the equations within the model system, each model is estimated individually.

The results of simultaneous equation model for automobility characteristics estimated using the 1970 data and 2000 data are shown in Table 6.1 & 6.2. This particular estimation is based on the sample of 317,464 individuals in 1970 and 429,627 individuals in 2000. A lot of interesting observations can be made from the coefficient estimates presented the table.

People who live in unurbanized areas positively influence automobile ownership (0.249), and the fraction of auto trips (0.030) compared with people who live in other areas in 1970 (Figure 6.1). This result can be explained that people who live in the unurbanized areas own more automobiles and more auto trips happened compared with people who do not lived in the unurbanized areas in 1970. On the other hand, younger single, younger childless couple, and older childless couple show higher fraction of auto trips and auto travel time than other stages in 1970 though their families have fewer vehicles. The group that has the highest auto travel time and the highest fraction of auto trips are those aged between 20 and 49 in 1970.

It can be seen that people who live in unurbanized areas own more automobiles (0.070) and have longer travel time by vehicles (1.560) than people who live in other areas, but they tend to have less fraction of auto trips (-0.030) compared with people who live in autonomous areas in 2000 (Figure 6.2). Older childless couple families tend to have more auto travel time (5.517) and more fraction of auto trips (0.076) than other lifecycle stages in 2000. Middle-aged person between 30 and 54 show higher auto travel time and higher fraction of auto trips compared with people at other ages in 2000.

In order to examine the stability of automobility characteristics in the Osaka metropolitan area between 1970 and 2000, how much of the change in urban travel is due to changes in demographics and how much is due to structural change, the following method is introduced into this study. To separate the effects of variations in explanatory variable values and those in coefficient vectors on the three automobility characteristics, the 1970 and 2000 mean explanatory variable values are input to the respective model to compute index values with the estimated 1970 and 2000 coefficient vectors. Results are summarized in Table 6.3.

Let a model equation in the model system be denoted as $\overline{Y} = h(\overline{X}_y : \beta_{y'})$, where $\overline{Y}$ is the endogenous variable, $\overline{X}_y$ is the vector of mean explanatory variable values for year y.

a. Estimating the mean value of each automobility characteristics, using the data from year *y* and the coefficient vector from year *y*', and each cell corresponding *y*, *y'*.

b. Predicting the values of the endogenous variables on data from 1970 and 2000, using the coefficient estimates from one of the two years and comparing the predicting values across the years. It indicates how changes in the characteristics of demographics, such as residential areas or aging, have prompted changes in behavior. Let

$$\overline{Y}_{y:70} = h(\overline{X}_y : \hat{\beta}_{1970}), \ \overline{Y}_{y:00} = h(\overline{X}_y : \hat{\beta}_{2000})$$

For y = 1970, and 2000. The equality between $\overline{Y}_{y:70}$ and $\overline{Y}_{y:00}$ is inspected here.

c. Predicting the values of the endogenous variables using the coefficient estimates from 1970 and 2000 and the data from and compare the predicted values across the years. This method indicates structural change in behavior over time as reflected in the value of the endogenous variable. Let

$$\overline{Y}_{70:y'} = h(\overline{X}_{1970} : \hat{\beta}_{y'}), \ \overline{Y}_{00:y'} = h(\overline{X}_{2000} : \hat{\beta}_{y'})$$

For y' = 1970, and 2000. In this method, the equality between $\overline{Y}_{y:70}$ and $\overline{Y}_{y:00}$ is inspected. It shows how the behavior of an urban resident of a given set of attributes, living in a certain area and being a certain stage of lifecycle and age, has changed over time due to structural change as represented by the change in $\beta_{y'}$.

Inspecting the values in the respective diagonals of each automobility characteristics in section (a) of the Table 6.3, such as, the auto ownership have increased from 0.47 vehicles in 1970 to 1.32 vehicles in 2000, and travel time by auto has increased from 11.56 minutes in 1970 to 15.58 minutes in 2000. Also, fraction of auto trips has increased 2 percent from 1970 to 2000.

Regardless of the year of the coefficient vector, the values of the respective automobility characteristics with the year of data are shown in section (b). Surprising results show that Y_{AO} decreased roughly 15% due to changes in mean explanatory variable value under coefficient vectors of 1970 and also decreased over 15% under that of 2000. It may be inferred that demographic changes between 1970 and 2000 have by themselves induced a decrease in auto ownership. The similar results show that Y_{AT} and Y_{FA} declined due to changes in mean explanatory variable value under any of the two coefficient vectors. This result would suggest that the mixed effects of changing in residential areas, changes in the stage of lifecycle and urban residents' aging, do not prompt the increase of auto ownership and auto use; on the contrary, have cancelling effects on auto travel behavior.

Section (c) shows the values of the respective automobility characteristics with the year of the coefficient vector regardless of the year of data. Y_{AO} increased more than 3 times due to changes in coefficient vectors regardless of the year of data. It may be inferred that changes of structural relationship between 1970 and 2000 have induced a large growth in auto ownership. The similar results show that Y_{AT} and Y_{FA} increased due to changes in coefficient vectors under any of two years. This result would suggest that changing in structural relationship greatly prompt the increase of auto ownership and auto use.

Comparing sections (b) and (c) of Table 6.3, one may conclude that changes in structural relationships prompt the process of motorization, after offsetting the part of the changes of demographic which have opposite effects on auto travel.

The statistical analyses of this section have made evident that the structural relationships have been changing in the direction of expanding automobility activities and travel. This tendency offset the effects of changes in individual and household attributes on auto travel, which are pointing in the direction of expanding automobility activities and travel, has produced the unmistakable increases in automobile ownership, auto travel time, and fraction of auto trips.

6.6 Summary

The Kyoto-Osaka-Kobe metropolitan area of Japan, like many other metropolitan areas in the world, experienced substantial change in the second half of the 20th century. The most significant driving forces have been motorization and suburbanization. Suburbanization, which progressed hand in hand with motorization, represented the predominant force that defined urban growth in this period. Japanese urban areas have retained until now their dense and mixed land use patterns. Changes in demographic factors have been substantial as well with residential areas changing, household size shrinking, and the resident population aging. In all areas except for the commercial and mixed-commercial areas, a significant growth 2~ 4 times in the fraction of household trips completed by automobile can be seen in suburbs, unurbanized, and autonomous areas. Owning an automobile has become very common except commercial area because it is a widely available form of transportation. Exceed 50 percent households own 2 and more cars in unurbanized areas and autonomous areas.

On the other hand, the result shows that Kyoto-Osaka-Kobe metropolitan areas face aging population from 1980. In 1970 and 1980 there were roughly 10 percent people aged 60 or older. By 2000, this ratio rise to more than 25 percent. The portion of one-member and two-member households have increased 10 percent over 1980 through 2000, but three or more member households have dropped 8 percent. The proportion of *elder childless couple* stage and *elder single* stage of lifecycle have increased roughly 10 percent over 1970 through 2000 corresponding to the decreased in *primary school nuclear* and *middle-high school nuclear* families. The ratio of non-employed workers is increasing 6% from 1970 to 2000 in the Kyoto-Osaka-Kobe metropolitan areas.

This study has been an attempt to examine how these changes have impacted urban residents' auto travel patterns. The study has adopted a holistic approach by exploring the stability in structural relationships underlying several most pertinent characteristics of automobility, using simultaneous equations model systems. Observed changes in household travel survey data collected in 1970 and 2000 are decomposed to those due to changes in demographic factors, and those due to changes in structural relationships. The statistical analyses have offered strong evidence that urban residents' auto use have been expanding. The results have further indicated that this expansion has been caused primarily by changes in the structural relationships even mixed changes in demographic factors have had opposite, cancelling effects on auto travel.

Chapter 7
Conclusion

Like most metropolitan areas, the Kyoto-Osaka-Kobe metropolitan area of Japan underwent substantial changes in the second half of the 20th century. Suburbanization, which progressed hand in hand with motorization, represented the predominant force that defined urban growth in this period. Japanese urban areas have retained until now their dense and mixed land use patterns. Using results of household travel surveys conducted in 1970, 1980, 1990, and 2000, this study has investigated how automobilty characteristics changed across lifecycle stages within different residential areas over time, and how automobility cohort effect affect automobility characteristics, and further how urban residents' auto travel patterns have changed over time with changing demographics, residential areas, and metropolitan structure.

The analyses of this study offer sufficient information that warrants holding definitive positions with respect to the hypotheses postulated at the outset of this paper:

- Lifecycle stage and auto use are closely associated and certain lifecycle stages are more auto-oriented. This tie becomes stronger as automobility progresses: The results suggest that lifecycle stage and auto use are not closely associated, but they are associated with each other, and the difference across lifecycle stages on automobility characteristics becomes remarkable when the process of motorization transforms urban area. *Younger childless couple* stage and *all adults*' stage are more auto-oriented in suburbs, unurbanized area, and autonomous areas, and this trend becomes stronger as automobility progresses.

- As more and more services become auto-oriented with prevailing automobility, distinction in spatial behavior becomes clearer across lifecycle stages: This is not at all case. It is true for visit suburbs trips, but the fraction of visit central city trips is nearly unchanged across lifecycle stages.

- Lifecycle stage is not the only effect which is associated with auto use, and residence area is another important effect. Lifecycle effects are suppressed by the residence area: The results confirm that the residence area rather than lifecycle stage is a significant explainer for automobile ownership and automobile use. It suggests that even within each lifecycle stage, change in the automobility characteristics over time is suppressed in commercial and mixed commercial/residential areas. However, the fraction of automobile trips for suburbs, unurbanized areas, and autonomous areas increased over time in the range of 0 to 4 times depending on the lifecycle stage.

- Automobility cohorts do exist, with each cohort having certain mobility traits that are unique, especially in terms of auto use: The standard age-period-cohort analysis confirms that automobility cohort effect do exist, unfortunately, cohort effect is not an important explainer for automobility characteristics, while time effect plays an important part in automobile ownership choice, and age effect mainly determines automobile use – the fraction of auto trips and auto travel time. *Pre-war* and *pre-motorization* cohorts show no auto-orientation even automobility progresses, but *Initial growth*, *mass-ownership*, and *multi-car ownership* cohorts show a great growth of automobility characteristics from 1970 to 2000.

- Urban residents' travel has the tendency to expand over time, especially on auto travel, and this expansion has been caused primarily by changes in the structural relationships while changes in demographic factors have had relatively minor effects: This is partly right. The statistical analyses have offered strong evidence that urban residents' auto use have been expanding. The results have further indicated that this expansion has been caused primarily by changes in the structural relationships even mixed changes in demographic factors have had opposite, cancelling effects on auto travel

Except that the above hypotheses are examined by respective statistical analyses, a few interesting findings also have been described in this study.

- No significant differences were observed in the numbers of trips for households of the same lifecycle stage across different residential areas, suggesting that similarly active lifestyles exist.

- The results suggest that household members' age is also a strong explainer for the fraction of auto trips and total auto travel time, through a four variable ANOVA analysis, including lifecycle stage, residence area, time, and age effect.

- An attempt at APC-RA model illustrate that residence area rather than time effect have the strongest impact on automobile ownership, and age effect is still a significant explainer for the fraction of auto trips and auto travel time.

To face the coming global energy crisis and air pollution issues, the above results with the findings of this study would suggest that significantly more sustainable behavior for society would be possible with more compact built environments that facilitate non-motorized and public transit travel. Unfortunately, it takes time, money, resources, and the political will to change the built environment and initial steps that educate the public such as voluntary travel behavior change may be necessary first steps on the move to more sustainable travel.

As a suggestion for future works, more statistical analysis on interaction effects of three variables or four variables ANOVA analysis, including lifecycle stage, residence area, time, and age effects, need to be considered. Also, the interaction effects of age-period-cohort analysis need us to pay more attention on the future work. The simultaneous equations model system is developed as an attempt to explore how much of the change in urban travel is due to changes in demographics and how much is due to structural change, more endogenous variables could be considered in the future research, such as, residential location, commute distance, and commute trip mode choice.

Table 4.3 ANOVA Table of three-way GLM model for auto ownership by household

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	57540.941	99	581.222	643.904	0.000
Intercept	5293.991	1	5293.991	5864.930	0.000
Lifecycle stage (LC)	1716.056	9	190.673	211.236	0.000
Residence area (RA)	2144.567	4	536.142	593.963	0.000
Year (Y)	1430.092	1	1430.092	1584.322	0.000
LC * RA	1186.948	36	32.971	36.527	0.000
LC * Y	318.015	9	35.335	39.146	0.000
RA * Y	1388.019	4	347.005	384.428	0.000
LC * RA * Y	695.614	36	19.323	21.406	0.000
Error	180165.729	199596	0.903		
Total	337143.000	199696			
Corrected Total	237706.671	199695			

Table 4.4 ANOVA Table of three-way GLM model for fraction of auto trips by household

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2394.786	99	24.190	271.949	0.000
Intercept	425.943	1	425.943	4788.595	0.000
Lifecycle stage (LC)	41.664	9	4.629	52.044	0.000
Residence area (RA)	289.076	4	72.269	812.471	0.000
Year (Y)	58.804	1	58.804	661.098	0.000
LC * RA	25.811	36	0.717	8.060	0.000
LC * Y	3.588	9	0.399	4.481	0.000
RA * Y	235.571	4	58.893	662.090	0.000
LC * RA * Y	15.470	36	0.430	4.831	0.000
Error	16024.082	180148	0.089		
Total	27381.591	180248			
Corrected Total	18418.868	180247			

Table 4.5 ANOVA Table of three-way GLM model for auto travel time by household

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	113412739.650	99	1145583.229	93.700	0.000
Intercept	17258221.024	1	17258221.024	1411.585	0.000
Lifecycle stage (LC)	4294489.474	9	477165.497	39.028	0.000
Residence area (RA)	5386978.551	4	1346744.638	110.153	0.000
Year (Y)	1197020.698	1	1197020.698	97.907	0.000
LC * RA	2601626.102	36	72267.392	5.911	0.000
LC * Y	249284.221	9	27698.247	2.265	0.016
RA * Y	4464173.944	4	1116043.486	91.283	0.000
LC * RA * Y	1652285.665	36	45896.824	3.754	0.000
Error	2202512070.107	180148	12226.126		
Total	2685133691.000	180248			
Corrected Total	2315924809.757	180247			

Table 4.6 Parameter estimates for auto ownership by household

	B	t
Intercept	2.285	117.016
Younger single	-1.678	-48.421
Younger childless couple	-.745	-19.012
Pre-school nuclear	-.531	-11.789
Young school nuclear	-.464	-9.799
Older school nuclear	-.287	-6.024
All adults	-.004	-.114
Older childless couple	-1.277	-42.122
Older single	-2.082	-62.352
Single parents	-1.242	-17.208
Others	0(a)	.
Commercial area	-1.527	-31.850
Mixed commercial/residential area	-1.481	-61.129
Suburbs	-.809	-37.700
Unurbanized area	.117	2.139
Autonomous area	0(a)	.
1970	-1.707	-70.774
2000	0(a)	.

Table 4.7 Parameter estimates for fraction of auto trips by household

	B	t
Intercept	.527	83.670
Younger single	-.076	-6.547
Younger childless couple	.108	8.544
Pre-school nuclear	-.090	-6.341
Young school nuclear	-.116	-7.747
Older school nuclear	-.065	-4.320
All adults	.095	9.159
Older childless couple	-.079	-7.567
Older single	-.284	-20.905
Single parents	-.154	-6.734
Others	0(a)	.
Commercial area	-.393	-24.977
Mixed commercial/residential area	-.363	-46.247
Suburbs	-.191	-27.574
Unurbanized area	.027	1.559
Autonomous area	0(a)	.
1970	-.386	-49.921
2000	0(a)	.

Table 4.8 Parameter estimates for auto travel time by household

	B	t
Intercept	104.416	44.694
Younger single	-73.536	-17.010
Younger childless couple	-24.191	-5.165
Pre-school nuclear	-6.313	-1.197
Young school nuclear	-9.321	-1.682
Older school nuclear	-1.144	-.206
All adults	10.359	2.692
Older childless couple	-49.864	-12.934
Older single	-89.760	-17.843
Single parents	-52.727	-6.202
Others	0(a)	.
Commercial area	-70.177	-12.031
Mixed commercial/residential area	-65.511	-22.534
Suburbs	-32.584	-12.689
Unurbanized area	23.566	3.605
Autonomous area	0(a)	.
1970	-59.986	-20.952
2000	0(a)	.

Table 4.10 ANOVA Table of four-way GLM model for auto ownership by person

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	244241.618	856	285.329	225.690	0.000
Intercept	3606.105	1	3606.105	2852.364	0.000
Lifecycle stage (LC)	1928.375	10	192.838	152.531	0.000
Residence area (RA)	601.192	4	150.298	118.883	0.000
Year (Y)	1214.266	1	1214.266	960.462	0.000
Age (A)	32.658	10	3.266	2.583	0.004
LC * RA	1239.232	40	30.981	24.505	0.000
LC* Y	433.004	10	43.300	34.250	0.000
LC * A	644.811	71	9.082	7.184	0.000
RA * Y	795.518	4	198.879	157.310	0.000
RA * A	42.005	40	1.050	0.831	0.767
Y * A	17.662	10	1.766	1.397	0.174
LC * RA * Y	821.097	40	20.527	16.237	0.000
LC * RA * A	591.294	272	2.174	1.719	0.000
LC * Y* A	196.754	65	3.027	2.394	0.000
RA * Y* A	58.610	40	1.465	1.159	0.227
LC * RA * Y * A	372.309	239	1.558	1.232	0.008
Error	907039.742	717452	1.264		
Total	1755607.000	718309			
Corrected Total	1151281.360	718308			

Table 4.11 ANOVA Table of four-way GLM model for fraction of auto trips by household

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15512.787	847	18.315	140.537	0.000
Intercept	240.964	1	240.964	1849.002	0.000
Lifecycle stage (LC)	10.831	10	1.083	8.311	0.000
Residence area (RA)	91.971	4	22.993	176.431	0.000
Year (Y)	71.660	1	71.660	549.875	0.000
Age (A)	118.671	10	11.867	91.061	0.000
LC * RA	9.999	40	0.250	1.918	0.000
LC* Y	2.920	10	0.292	2.241	0.013
LC * A	34.722	71	0.489	3.753	0.000
RA * Y	115.842	4	28.960	222.223	0.000
RA * A	58.899	40	1.472	11.299	0.000
Y * A	24.407	10	2.441	18.728	0.000
LC * RA * Y	7.408	40	0.185	1.421	0.041
LC * RA * A	62.511	266	0.235	1.803	0.000
LC * Y* A	21.989	64	0.344	2.636	0.000
RA * Y* A	80.047	40	2.001	15.356	0.000
LC * RA * Y * A	48.173	236	0.204	1.566	0.000
Error	78560.927	602825	0.130		
Total	124367.507	603673			
Corrected Total	94073.713	603672			

Table 4.12 ANOVA Table of four-way GLM model for auto travel time by household

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	103063232.453	847	121680.322	33.884	0.000
Intercept	1580701.962	1	1580701.962	440.172	0.000
Lifecycle stage (LC)	79383.497	10	7938.350	2.211	0.015
Residence area (RA)	310973.407	4	77743.352	21.649	0.000
Year (Y)	357557.617	1	357557.617	99.568	0.000
Age (A)	857944.586	10	85794.459	23.891	0.000
LC * RA	117363.232	40	2934.081	0.817	0.788
LC* Y	15779.620	10	1577.962	0.439	0.928
LC * A	562043.943	71	7916.112	2.204	0.000
RA * Y	381366.092	4	95341.523	26.549	0.000
RA * A	265943.297	40	6648.582	1.851	0.001
Y * A	173330.106	10	17333.011	4.827	0.000
LC * RA * Y	83896.562	40	2097.414	0.584	0.983
LC * RA * A	812590.572	266	3054.852	0.851	0.963
LC * Y* A	167212.579	64	2612.697	0.728	0.950
RA * Y* A	345073.970	40	8626.849	2.402	0.000
LC * RA * Y * A	611003.671	236	2588.999	0.721	1.000
Error	2164803441.684	602825	3591.098		
Total	2491780854.000	603673			
Corrected Total	2267866674.137	603672			

Table 5.6 ANOVA table of APC model for auto ownership

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	168440.162	17	9908.245	8166.083	0.000
Intercept	745888.399	1	745888.399	614739.216	0.000
Cohort	1155.508	4	288.877	238.084	0.000
Age	11751.558	10	1175.156	968.529	0.000
Period	35228.011	3	11742.670	9677.963	0.000
Error	1886192.236	1554544	1.213		
Total	3532594.000	1554562			
Corrected Total	2054632.397	1554561			

Table 5.7 ANOVA table of APC model for fraction of auto trips

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	23853.026	17	1403.119	10176.208	0.000
Intercept	31586.010	1	31586.010	229079.482	0.000
Cohort	806.539	4	201.635	1462.369	0.000
Age	9984.963	10	998.496	7241.656	0.000
Period	537.065	3	179.022	1298.365	0.000
Error	178744.018	1296352	0.138		
Total	266523.197	1296370			
Corrected Total	202597.044	1296369			

Table 5.8 ANOVA table of APC model for auto travel time

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	175837248.120	17	10343367.536	2765.189	0.000
Intercept	216768961.877	1	216768961.877	57950.876	0.000
Cohort	5085594.213	4	1271398.553	339.895	0.000
Age	81365204.702	10	8136520.470	2175.212	0.000
Period	2452599.581	3	817533.194	218.559	0.000
Error	4849087623.507	1296352	3740.564		
Total	5487392026.000	1296370			
Corrected Total	5024924871.627	1296369			

Table 5.9 Parameter estimates of APC model for auto ownership

	B	t
Intercept	1.160	122.959
Pre-war cohort	-.140	-14.649
Pre-motorization cohort	-.165	-23.998
Initial growth cohort	-.108	-21.042
Mass-ownership cohort	-.044	-10.946
Multi-car ownership cohort	0(a)	.
Age <=9	.189	15.953
Age 10-19	.175	16.048
Age 20-29	.290	29.264
Age 30-39	.244	28.212
Age 40-44	.264	33.430
Age 45-49	.315	42.276
Age 50-54	.410	58.384
Age 55-59	.324	48.947
Age 60-64	.184	28.091
Age 65-74	.021	3.661
Age 75+	0(a)	.
1970	-.815	-165.142
1980	-.441	-124.377
1990	-.181	-65.457
2000	0(a)	.

a This parameter is set to zero because it is redundant.

Table 5.10 Parameter estimates of APC model for fraction of auto trips

	B	t
Intercept	.328	82.324
Pre-war cohort	-.158	-44.016
Pre-motorization cohort	-.081	-31.845
Initial growth cohort	-.031	-16.145
Mass-ownership cohort	.020	13.376
Multi-car ownership cohort	0(a)	.
Age <=9	-.212	-44.448
Age 10-19	-.242	-54.011
Age 20-29	.010	2.400
Age 30-39	.093	24.893
Age 40-44	.106	30.431
Age 45-49	.091	27.445
Age 50-54	.089	27.834
Age 55-59	.074	23.945
Age 60-64	.057	18.230
Age 65-74	.017	5.789
Age 75+	0(a)	.
1970	-.109	-59.182
1980	-.077	-58.435
1990	-.047	-45.302
2000	0(a)	.

a This parameter is set to zero because it is redundant.

Table 5.11 Parameter estimates of APC model for auto travel time

	B	t
Intercept	22.337	34.071
Pre-war cohort	-12.361	-20.953
Pre-motorization cohort	-4.150	-9.898
Initial growth cohort	-.830	-2.659
Mass-ownership cohort	.683	2.836
Multi-car ownership cohort	0(a)	.
Age <=9	-16.121	-20.508
Age 10-19	-16.452	-22.292
Age 20-29	5.594	8.201
Age 30-39	12.214	19.899
Age 40-44	11.587	20.226
Age 45-49	11.147	20.357
Age 50-54	10.373	19.729
Age 55-59	9.348	18.437
Age 60-64	7.317	14.323
Age 65-74	2.285	4.791
Age 75+	0(a)	.
1970	-5.649	-18.545
1980	-5.378	-24.824
1990	-3.377	-19.865
2000	0(a)	.

a This parameter is set to zero because it is redundant.

Table 5.13 ANOVA Table of APC-RA model for auto ownership

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	219853.489	21	10469.214	9129.849	0.000
Intercept	238250.352	1	238250.352	207770.122	0.000
Cohort	1109.349	4	277.337	241.856	0.000
Age	11331.751	10	1133.175	988.204	0.000
Period	37669.237	3	12556.412	10950.025	0.000
Residence area	68771.225	4	17192.806	14993.268	0.000
Error	1706365.518	1488064	1.147		
Total	3280235.000	1488086			
Corrected Total	1926219.008	1488085			

Table 5.14 ANOVA Table of APC-RA model for fraction of auto trips

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	24417.934	21	1162.758745	8715.120	0.000
Intercept	9664.066	1	9664.066258	72434.196	0.000
Cohort	733.066	4	183.2664962	1373.621	0.000
Age	9151.736	10	915.173608	6859.417	0.000
Period	549.438	3	183.146025	1372.718	0.000
Residence area	2978.857	4	744.7143156	5581.789	0.000
Error	165435.146	1239971	0.133418561		
Total	247814.261	1239993			
Corrected Total	189853.080	1239992			

Table 5.15 ANOVA Table of APC-RA model for auto travel time

	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	170894578.302	21	8137837.062	2964.115	0.000
Intercept	60858849.563	1	60858849.56	22167.143	0.000
Cohort	5417892.807	4	1354473.202	493.351	0.000
Age	73541177.974	10	7354117.797	2678.654	0.000
Period	2073604.424	3	691201.4747	251.762	0.000
Residence area	8258804.791	4	2064701.198	752.044	0.000
Error	3404282090.184	1239971	2745.452991		
Total	3992126205.000	1239993			
Corrected Total	3575176668.486	1239992			

Table 5.16 Parameter estimates of APC-RA model for auto ownership

	B	t
Intercept	1.528	158.917
Pre-war cohort	-.167	-17.599
Pre-motorization cohort	-.180	-26.353
Initial growth cohort	-.120	-23.476
Mass-ownership cohort	-.060	-14.938
Multi-car ownership cohort	0(a)	.
Age <=9	.160	13.638
Age 10-19	.153	14.088
Age 20-29	.277	28.191
Age 30-39	.238	27.723
Age 40-44	.256	32.572
Age 45-49	.309	41.726
Age 50-54	.404	57.997
Age 55-59	.327	49.692
Age 60-64	.191	29.267
Age 65-74	.026	4.654
Age 75+	0(a)	.
1970	-.842	-170.625
1980	-.441	-124.070
1990	-.151	-55.089
2000	0(a)	.
Commercial area	-.636	-102.854
Mixed commercial/residential area	-.652	-224.704
Suburbs	-.370	-146.194
Unurbanized area	.323	38.378
Autonomous area	0(a)	.

a This parameter is set to zero because it is redundant.

Table 5.17 Parameter estimates of APC-RA model for fraction of auto trips

	B	t
Intercept	.403	98.586
Pre-war cohort	-.155	-43.116
Pre-motorization cohort	-.078	-30.520
Initial growth cohort	-.029	-15.262
Mass-ownership cohort	.018	12.128
Multi-car ownership cohort	0(a)	.
Age <=9	-.216	-44.915
Age 10-19	-.244	-54.232
Age 20-29	.003	.652
Age 30-39	.084	22.378
Age 40-44	.097	27.596
Age 45-49	.083	24.777
Age 50-54	.081	25.114
Age 55-59	.068	22.058
Age 60-64	.052	16.614
Age 65-74	.014	4.934
Age 75+	0(a)	.
1970	-.116	-62.134
1980	-.078	-58.330
1990	-.039	-37.673
2000	0(a)	.
Commercial area	-.156	-66.394
Mixed commercial/residential area	-.149	-137.244
Suburbs	-.070	-74.263
Unurbanized area	.047	14.667
Autonomous area	0(a)	.

a This parameter is set to zero because it is redundant.

Table 5.18 Parameter estimates of APC-RA model for auto travel time

	B	t
Intercept	26.154	44.556
Pre-war cohort	-13.777	-26.638
Pre-motorization cohort	-5.290	-14.403
Initial growth cohort	-1.405	-5.138
Mass-ownership cohort	.543	2.576
Multi-car ownership cohort	0(a)	.
Age <=9	-17.886	-25.942
Age 10-19	-18.163	-28.108
Age 20-29	3.425	5.727
Age 30-39	10.096	18.776
Age 40-44	10.218	20.337
Age 45-49	9.741	20.309
Age 50-54	9.309	20.220
Age 55-59	8.586	19.293
Age 60-64	6.816	15.197
Age 65-74	1.916	4.582
Age 75+	0(a)	.
1970	-6.209	-23.094
1980	-5.225	-27.274
1990	-2.882	-19.435
2000	0(a)	.
Commercial area	-8.221	-24.375
Mixed commercial/residential area	-6.604	-42.332
Suburbs	-1.330	-9.776
Unurbanized area	4.465	9.657
Autonomous area	0(a)	.

a This parameter is set to zero because it is redundant.

Table 6.1 Simultaneous equation model for automobility characteristics in 1970

	Auto ownership (Y_{AO})		Auto travel time (Y_{AT})		Fraction of auto trips (Y_{FA})	
	Coefficient	t	Coefficient	t	Coefficient	t
Constant	0.615	135.494*	2.531	7.884*	0.017	16.687*
Live in commercial area	-0.001	-0.086	-3.529	-3.541*	-0.016	-5.108*
Live in mixed commercial area	-0.161	-28.999*	-3.590	-9.380*	-0.021	-17.077*
Live in suburbs	-0.113	-22.911*	-1.583	-4.683*	-0.005	-4.308*
Live in unurbanized area	0.249	10.576*	-0.297	-0.184*	0.030	5.835*
Live in autonomous area	0.000	.	0.000	.	0.000	.
Younger single family	-0.463	-44.708*	1.782	2.494*	0.005	2.411*
Younger childless couple family	-0.210	-18.345*	1.179	1.495*	0.012	4.610*
Pre-school nuclear family	-0.096	-6.272*	-1.121	-1.065	-0.002	-0.749
Young school nuclear family	-0.096	-12.800*	-1.402	-2.717*	-0.015	-8.998
Older school nuclear family	-0.099	-12.109*	-1.457	-2.584*	-0.014	-7.814
All adults family	-0.078	-10.450*	-0.873	-1.701	-0.002	-1.239
Older childless couple family	-0.404	-22.790*	1.561	1.279*	0.002	0.526*
Older single family	-0.481	-18.776*	-0.474	-0.269	0.001	0.247
Single parent family	-0.361	-19.454*	-4.297	-3.369*	-0.029	-7.071*
Others' family	0.000	.	0.000	.	0.000	.
<=9	0.025	3.028	-1.103	-1.914*	-0.010	-5.231
10-19	0.028	4.183*	0.812	1.795*	0.006	4.271
20-29	0.045	7.880*	16.810	42.708*	0.147	117.690*
30-39	0.000	-0.008	21.276	51.708*	0.183	140.186*
40-44	-0.009	-1.046	15.376	24.856*	0.159	80.996*
45-49	-0.008	-0.760	13.713	20.064*	0.128	58.987*
50-54	0.046	4.085*	9.683	12.601*	0.089	36.751*
55-59	0.055	4.765*	5.963	7.506*	0.069	27.444*
60-64	0.021	1.674	3.948	4.674*	0.043	16.239*
65-74	-0.040	-3.612*	1.688	2.242*	0.019	7.778
75+	0.000	.	0.000	.	0.000	.
Y_{AO}	.	.	2.936	24.056*	0.034	86.918*
Y_{AT}	.	.	.	.	8.645	172.361*
Y_{FA}	.	.	8.645	172.361*	.	.

N = 317464, All exogenous variables are dummy variables, * = significant at $\alpha = 0.05$

Table 6.2 Simultaneous equation model for automobility characteristics in 2000

	Auto ownership(Y_{AO})		Auto travel time(Y_{AT})		Fraction of auto trips(Y_{FA})	
	Coefficient	t	Coefficient	t	Coefficient	t
Constant	2.078	673.090*	-2.421	-11.599*	0.042	24.122*
Live in commercial area	-1.211	-122.224*	-7.526	-15.838*	-0.18	-45.482*
Live in mixed commercial area	-1.107	-319.049*	-5.057	-27.792*	-0.157	-103.496*
Live in suburbs	-0.697	-234.735*	-0.751	-5.051*	-0.083	-67.049*
Live in unurbanized area	0.070	4.854*	1.560	2.288*	-0.030	-5.224*
Live in autonomous area	0.000	.	0.000	.	0.000	.
Younger single family	-1.113	-150.996*	1.105	3.097	0.005	1.838
Younger childless couple family	-0.509	-80.263*	4.399	14.608*	0.029	11.442*
Pre-school nuclear family	-0.320	-57.551*	2.896	10.986*	0.026	11.890*
Young school nuclear family	-0.367	-64.415*	1.870	6.935*	0.027	12.070*
Older school nuclear family	-0.255	-42.431*	0.368	1.292	-0.003	-1.203
All adults family	-0.046	-10.676*	-2.608	-12.955*	-0.038	-22.853*
Older childless couple family	-0.840	-173.373*	5.517	23.347*	0.076	38.645*
Older single family	-1.257	-172.135*	2.879	8.083*	0.056	18.748*
Single parent family	-0.888	-80.748*	3.550	6.794*	0.061	14.057*
Others' family	0.000	.	0.000	.	0.000	.
<=9	0.203	30.706*	-2.382	-7.638*	0.017	6.444*
10-19	0.286	62.491*	-4.310	-19.904*	-0.065	-36.073*
20-29	0.332	77.537*	17.717	87.081*	0.201	118.896*
30-39	0.162	38.891*	24.574	125.07*	0.286	175.259*
40-44	0.230	38.360*	24.064	85.103*	0.292	124.179*
45-49	0.291	51.054*	23.018	85.402*	0.270	120.685*
50-54	0.339	66.576*	21.356	88.408*	0.241	119.920*
55-59	0.294	54.135*	19.953	77.529*	0.208	97.420*
60-64	0.264	46.334*	15.963	59.202*	0.152	68.009*
65-74	0.109	23.535*	7.148	32.816*	0.079	43.893*
75+	0.000	.	0.000	.	0.000	.
Y_{AO}	.	.	7.128	99.069*	0.100	167.807*
Y_{AT}	.	.	.	.	11.005	357.295*
Y_{FA}	.	.	11.005	357.295*	.	.

N = 429627, All exogenous variables are dummy variables, * = significant at $\alpha = 0.05$, CFI=0.220, RMSEA=0.127

Table 6.3 Automobility characteristics produced with 1970, 2000 coefficient vectors at 1970, 2000 mean explanatory variable values

(a) Automobility characteristics

Data (*y*)	Coefficient vector (*y'*)					
	Y_{AO}		Y_{AT}		Y_{FA}	
	1970	2000	1970	2000	1970	2000
1970	0.47	1.56	11.56	15.19	0.10	0.13
2000	0.40	1.32	9.60	15.58	0.09	0.12

For each of the automobility characteristics variables (Y_{AO}, Y_{AT}, Y_{FA}), its mean value, with the data from year *y* and the coefficient vector from year *y'*, is shown in the cell corresponding *y*, *y'*.

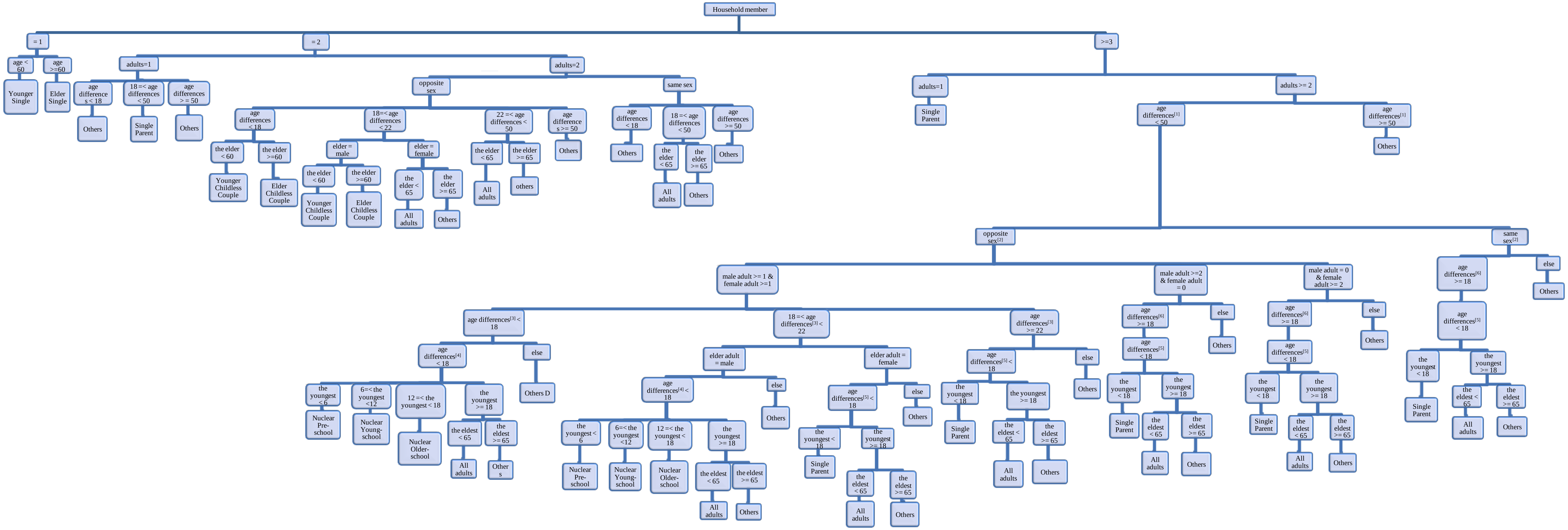
(b) Change in automobility characteristics due to change in explanatory variable values (value with 1970 data = 100)

Data (*y*)	Coefficient vector (*y'*)					
	Y_{AO}		Y_{AT}		Y_{FA}	
	1970	2000	1970	2000	1970	2000
1970	100	100	100	100	100	100
2000	85.11	84.62	83.04	102.57	90	92.31

(c) Change in automobility characteristics due to change in coefficient vector (value with 1970 coefficient vector = 100)

Data (*y*)	Coefficient vector (*y'*)					
	Y_{AO}		Y_{AT}		Y_{FA}	
	1970	2000	1970	2000	1970	2000
1970	100	331.91	100	131.40	100	130
2000	100	330	100	162.29	100	133.33

Figure 4.2 Flowchart for Lifecycle Stage classification



[1] Age differences between the eldest and the youngest in one household

[2] Sex differences between the adults in one household

[3] Age differences between the oldest male and the oldest female in one household

[4] Age differences between the third oldest member and the youngest member in one household is less than 18 (for finding nuclear family, no three generation living in one household.)

[5] Age differences between the second oldest member and the youngest oldest member in one household (for finding single parent, no three generation living in one household).

[6] Age differences between the oldest member and the second oldest member in one household (for finding single parent family)

Figure 4.5 Automobility characteristics across lifecycle stages in 1970 and 2000

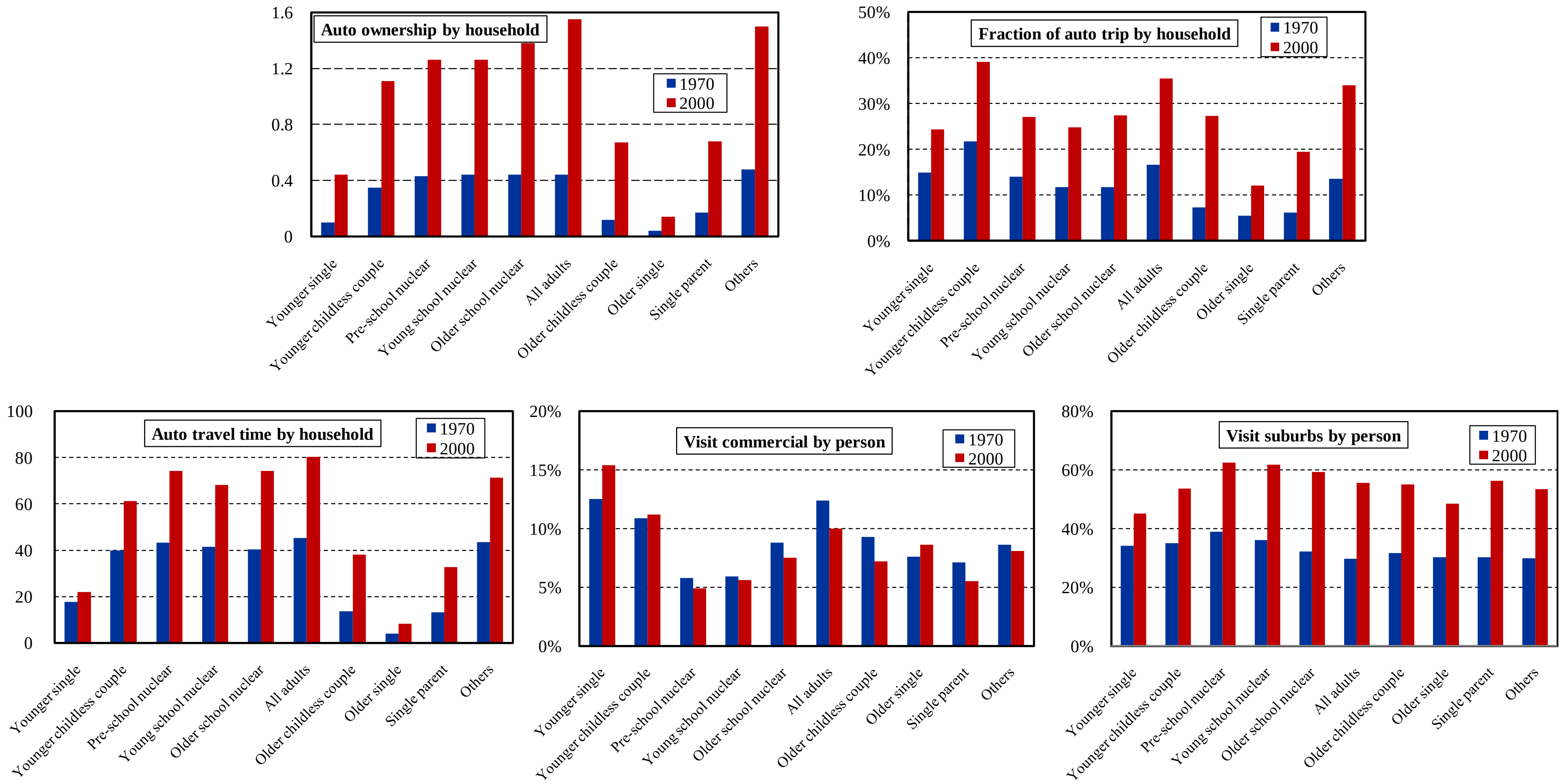


Figure 4.6 Changes in percentage of household numbers across lifecycle stages by area type in 1970 and 2000

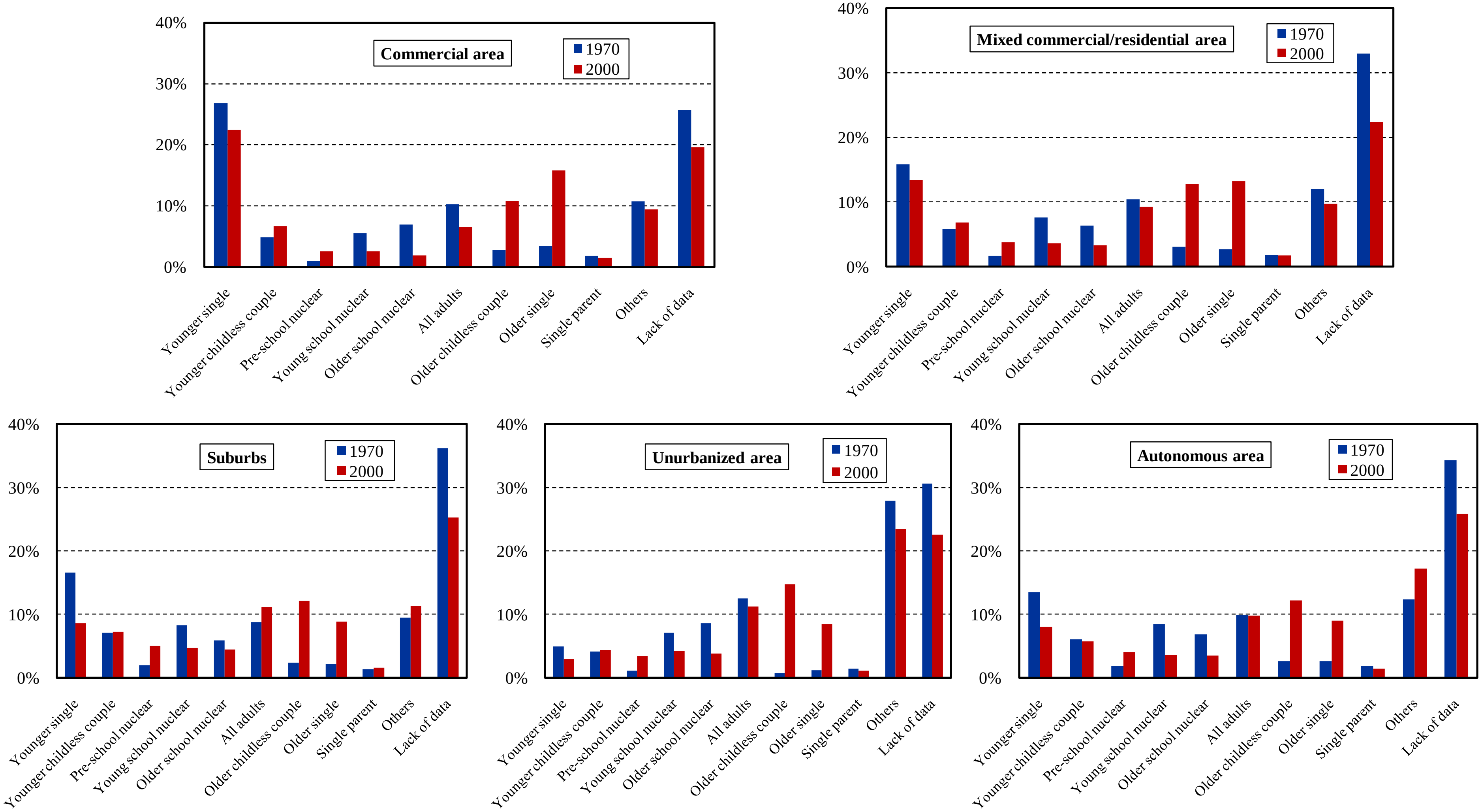


Figure 4.8 Automobility characteristics within different residence areas in 1970 and 2000

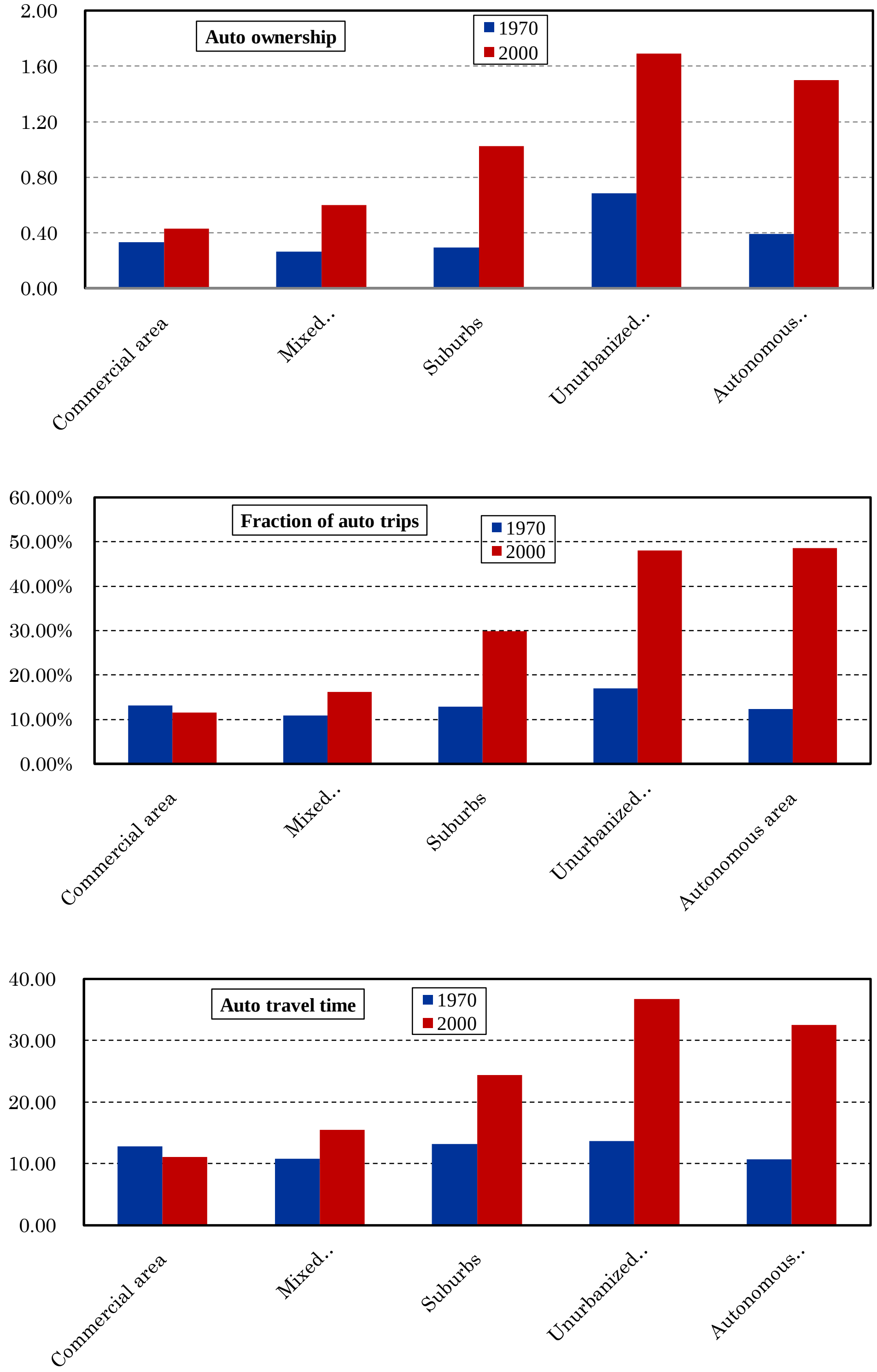


Figure 4.9

Changes in automobiles per household across lifecycle stages by area type in 1970 and 2000

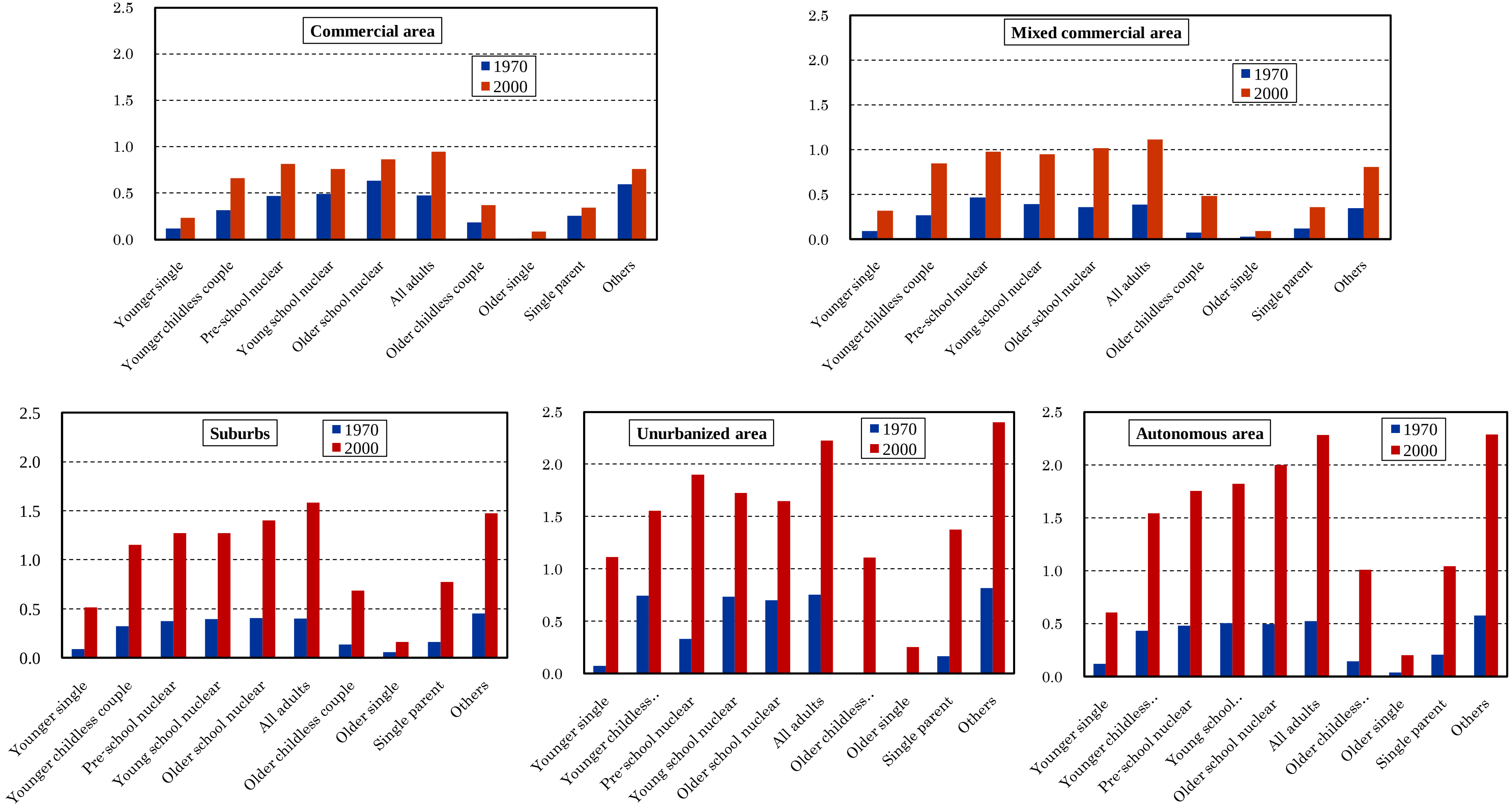


Figure 4.10

Changes in fraction of auto trips across lifecycle stages by area type in 1970 and 2000

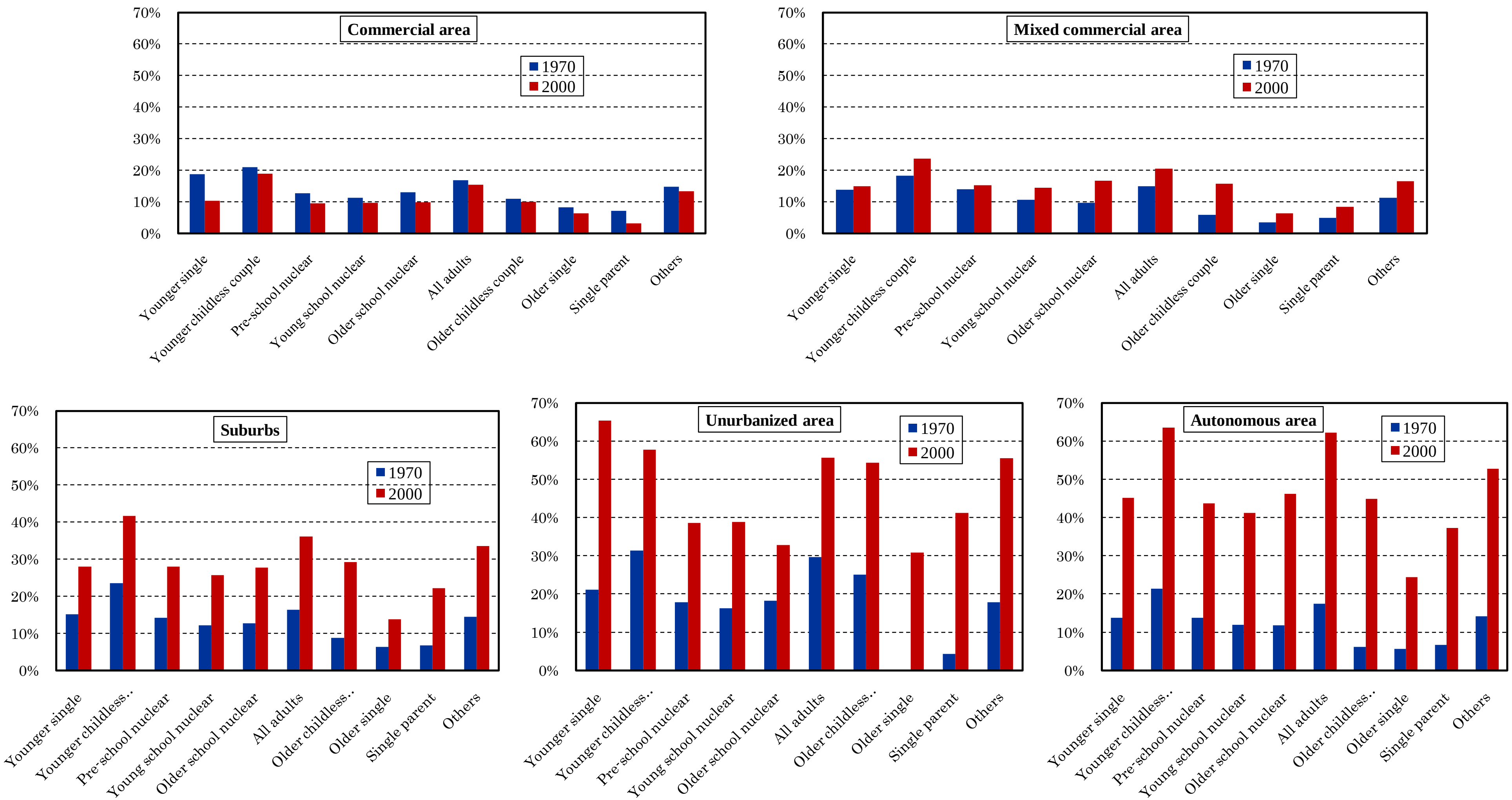


Figure 4.11

Changes in auto travel time across lifecycle stages by area type in 1970 and 2000

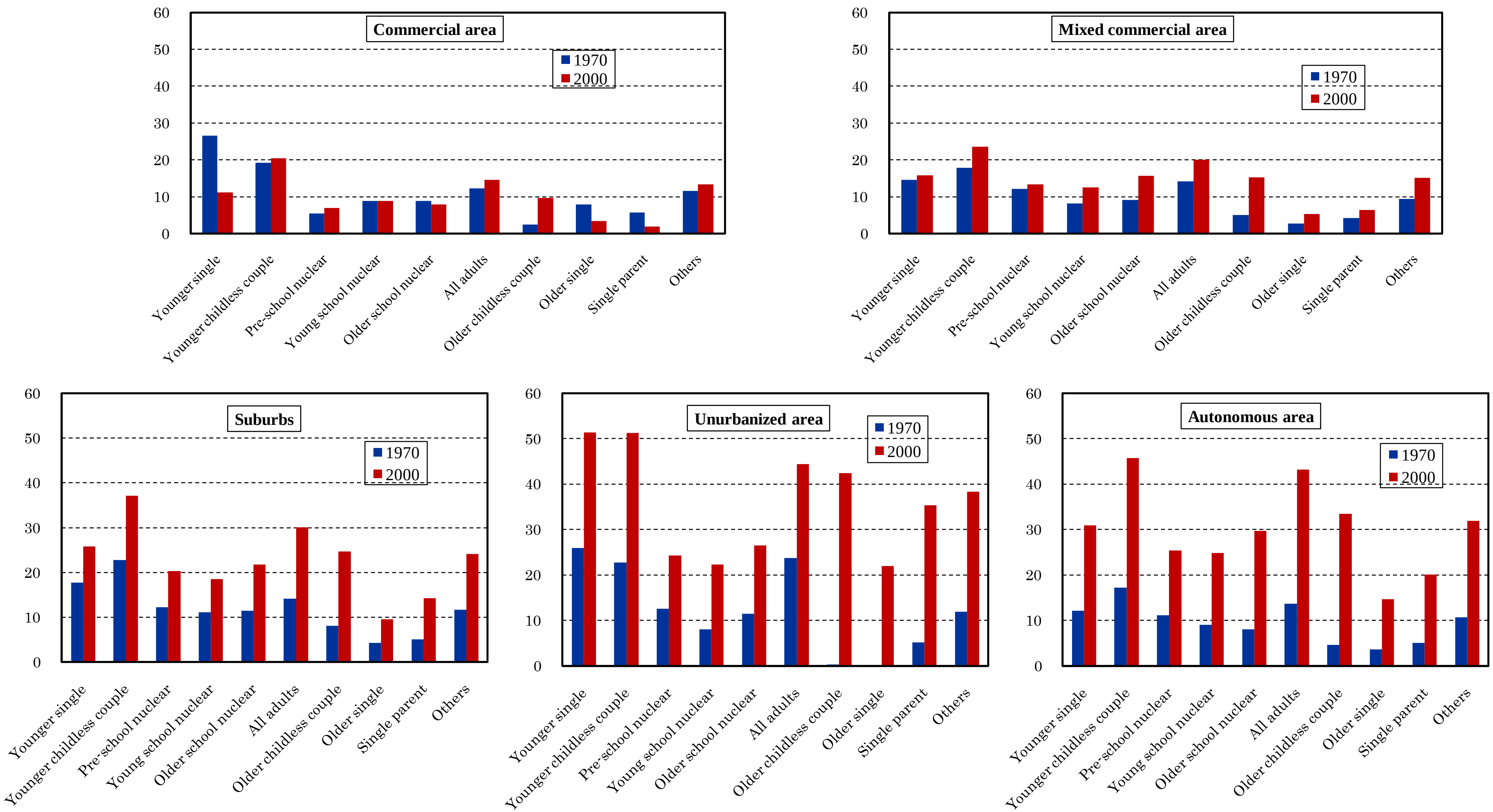


Figure 4.12

Travel activity behavior across lifecycle stages in 1970 and 2000

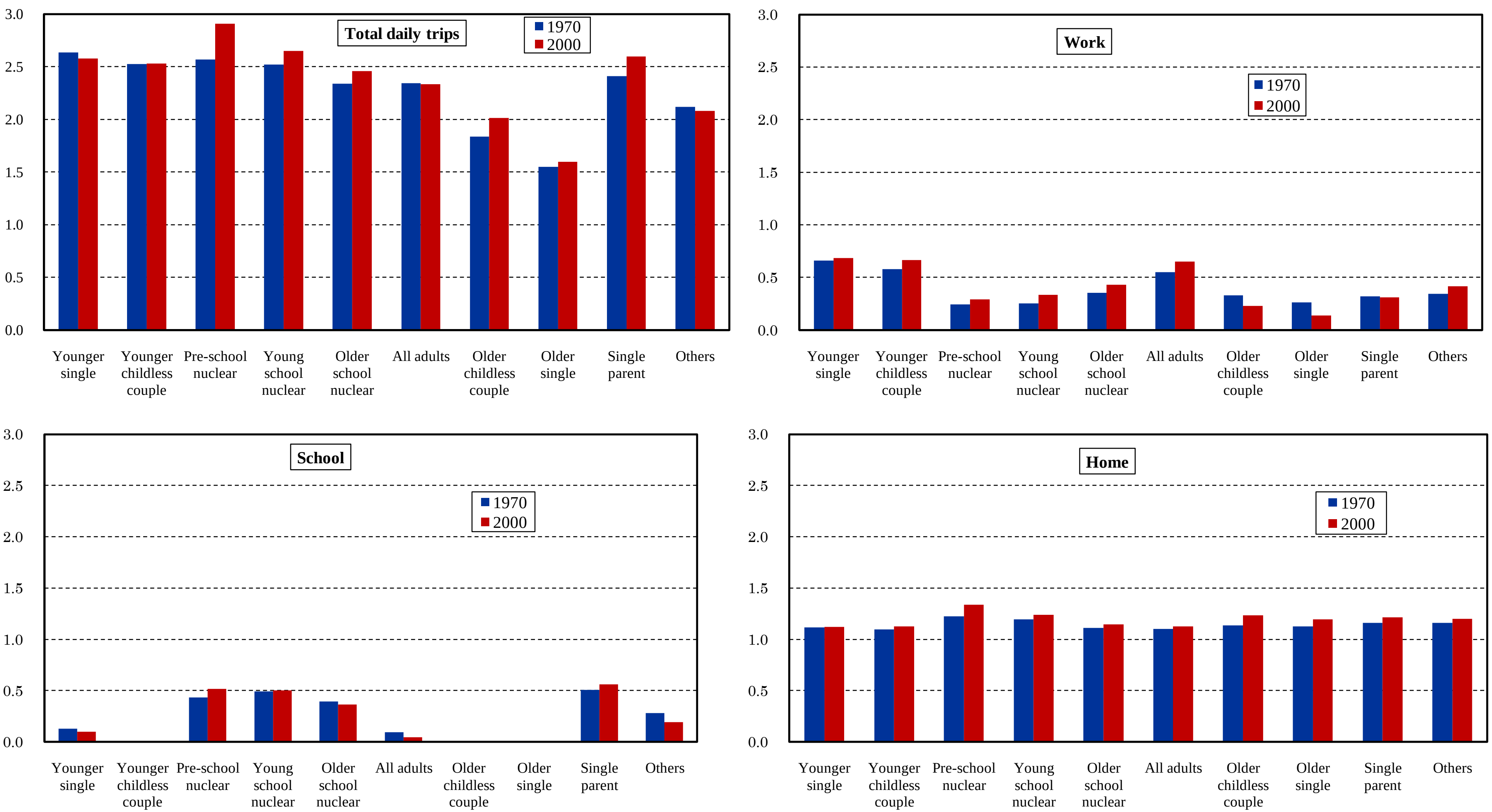


Figure 4.12 (continued) Travel activity behavior across lifecycle stages in 1970 and 2000

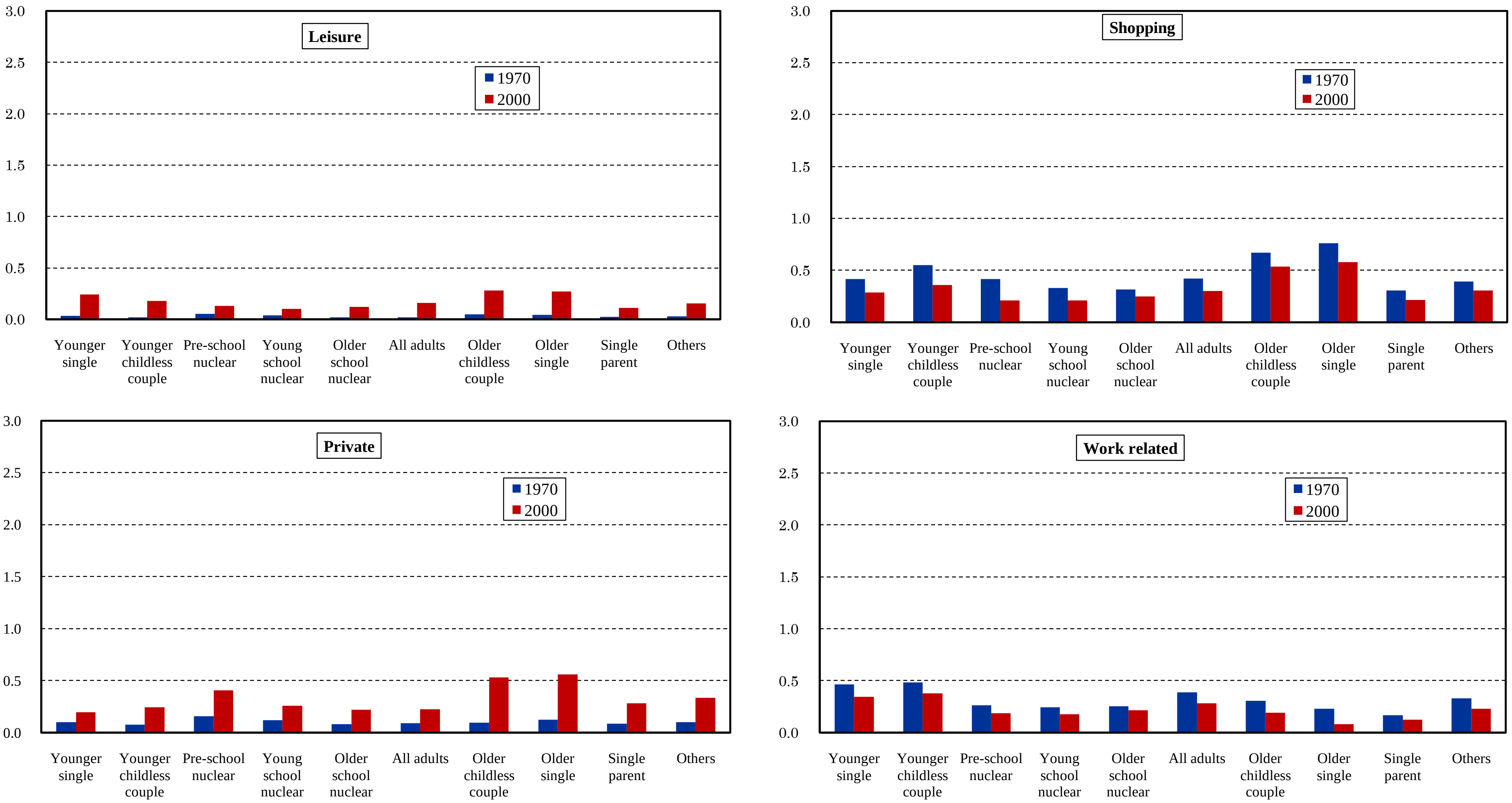


Figure 5.1 Automobility characteristics across cohorts over time

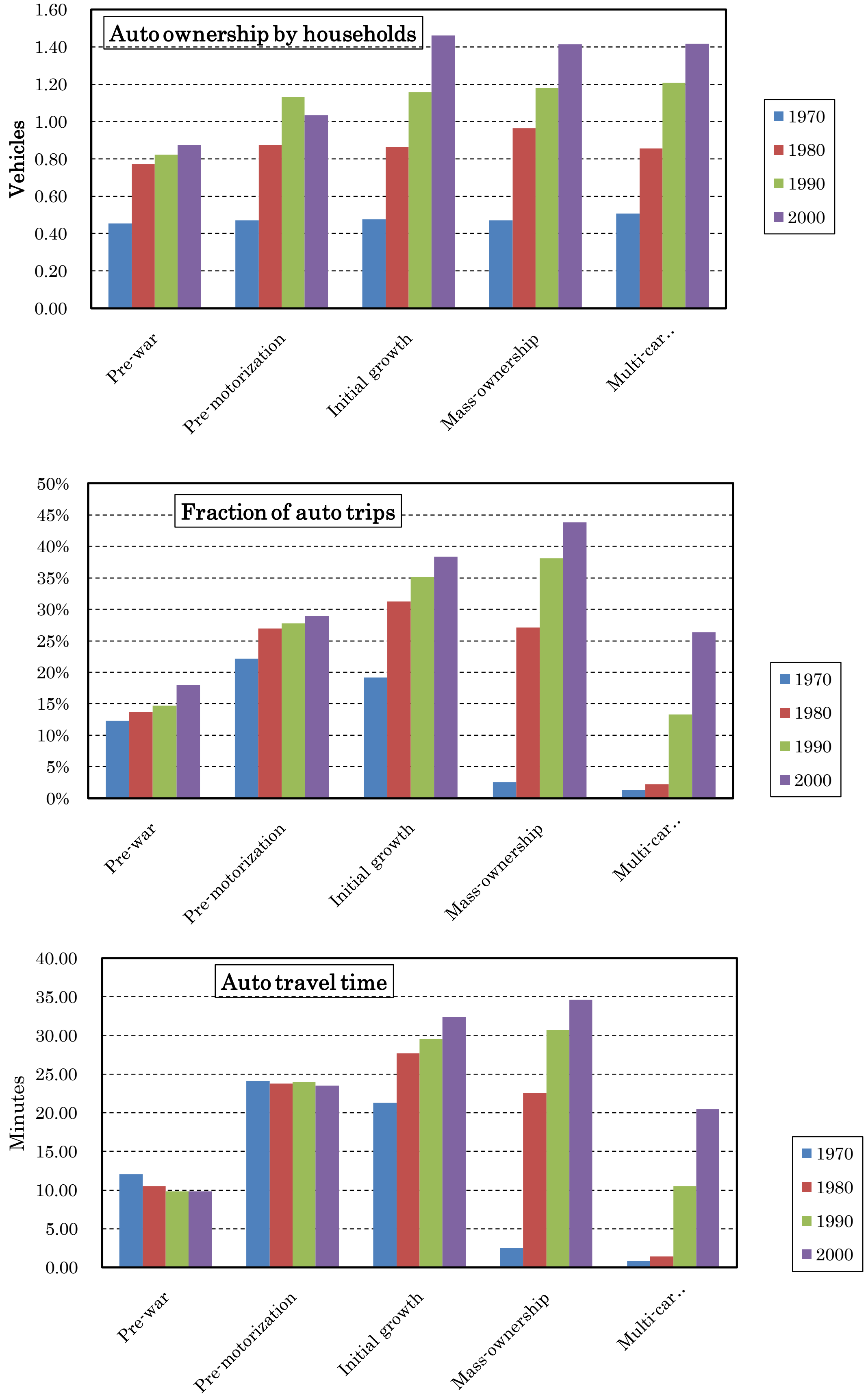
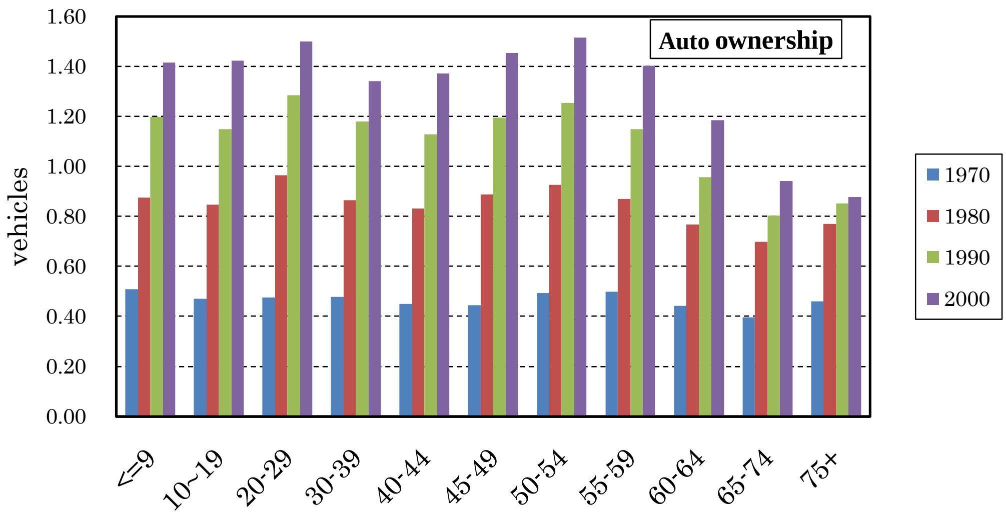
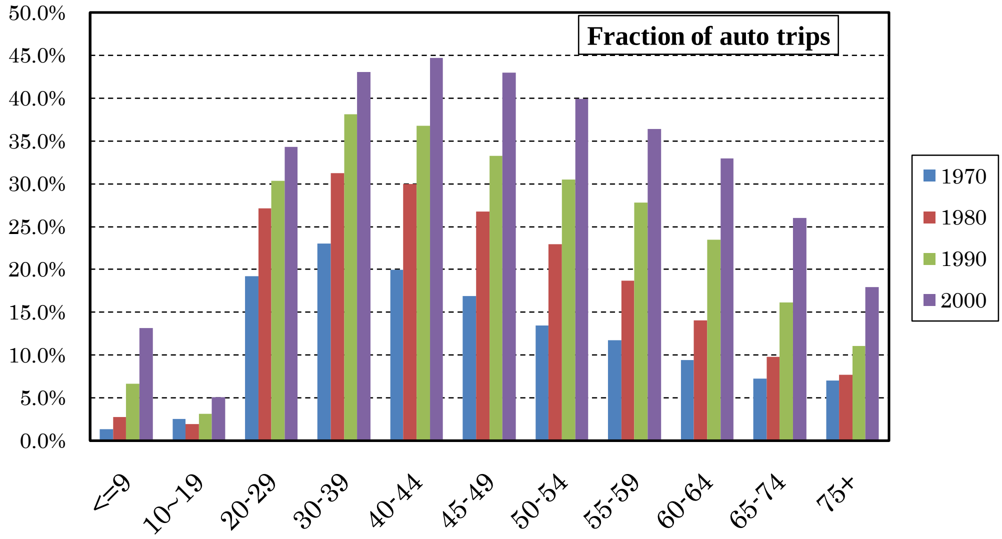


Figure 5.2 Automobility characteristics across age categories over time





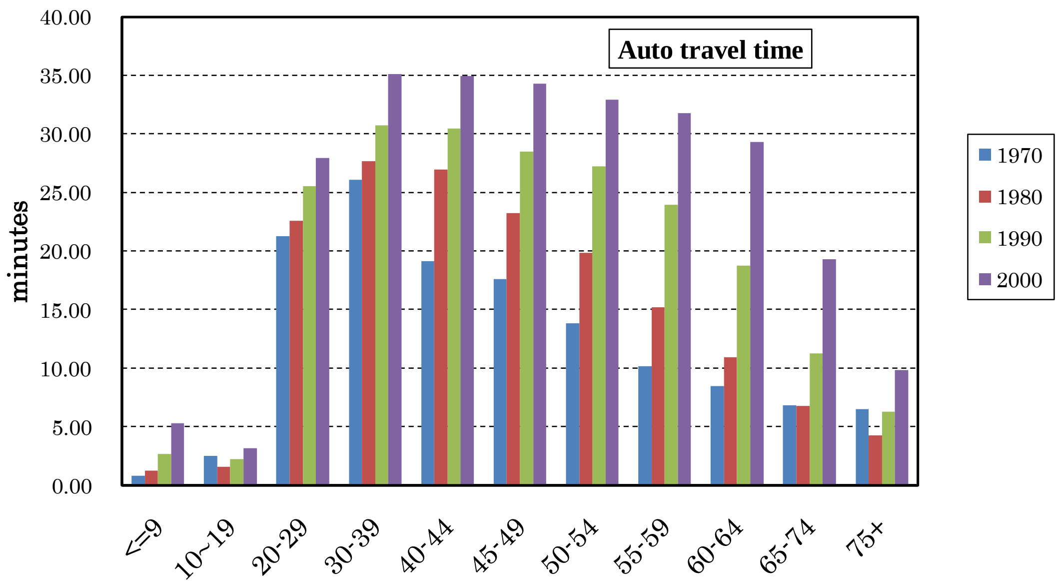


Figure 6.1 Changes in the Fraction of Auto Trips by Area Type: 1970 – 2000

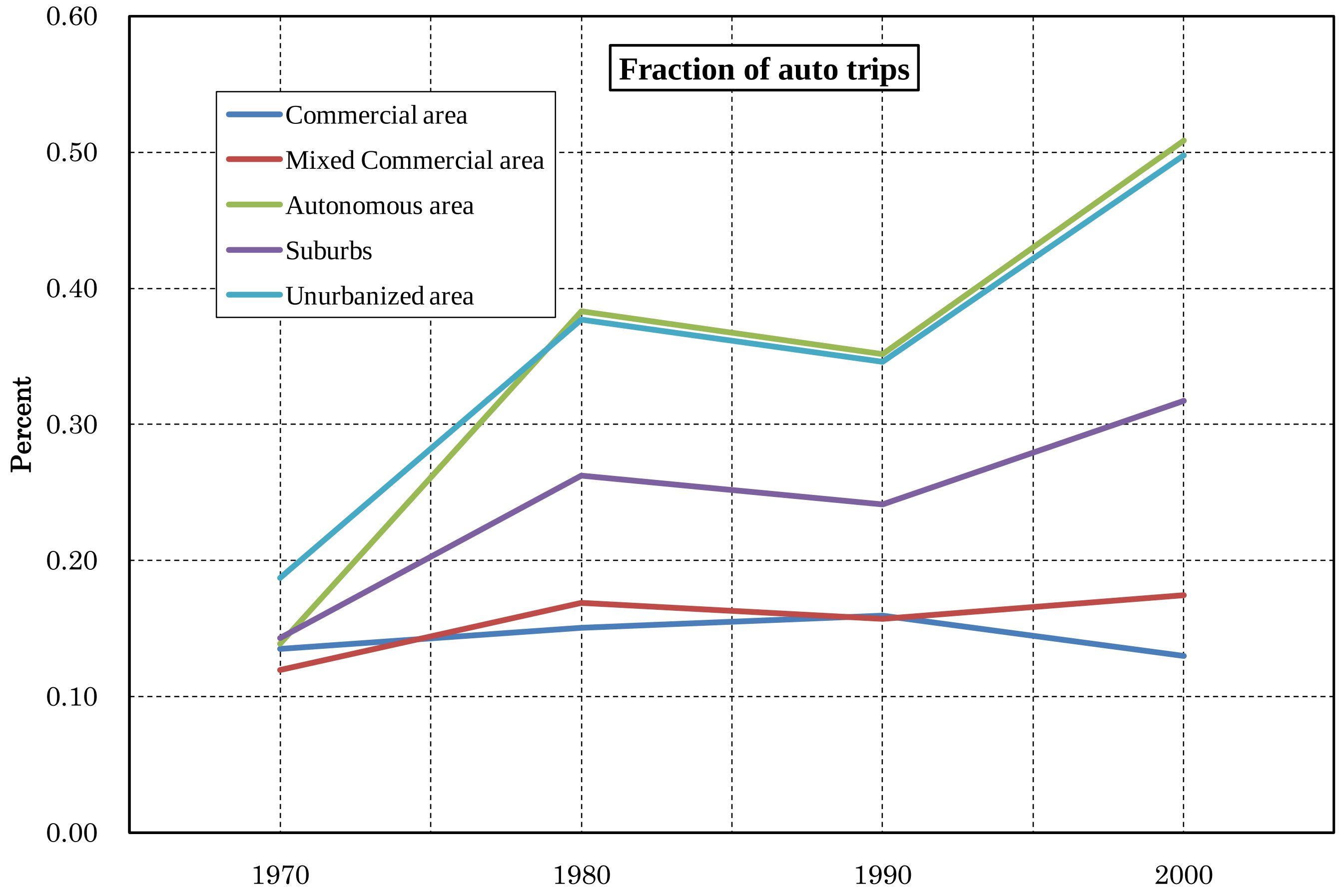


Figure 6.2 Changes in automobiles of households by Area Type: 1970 – 2000

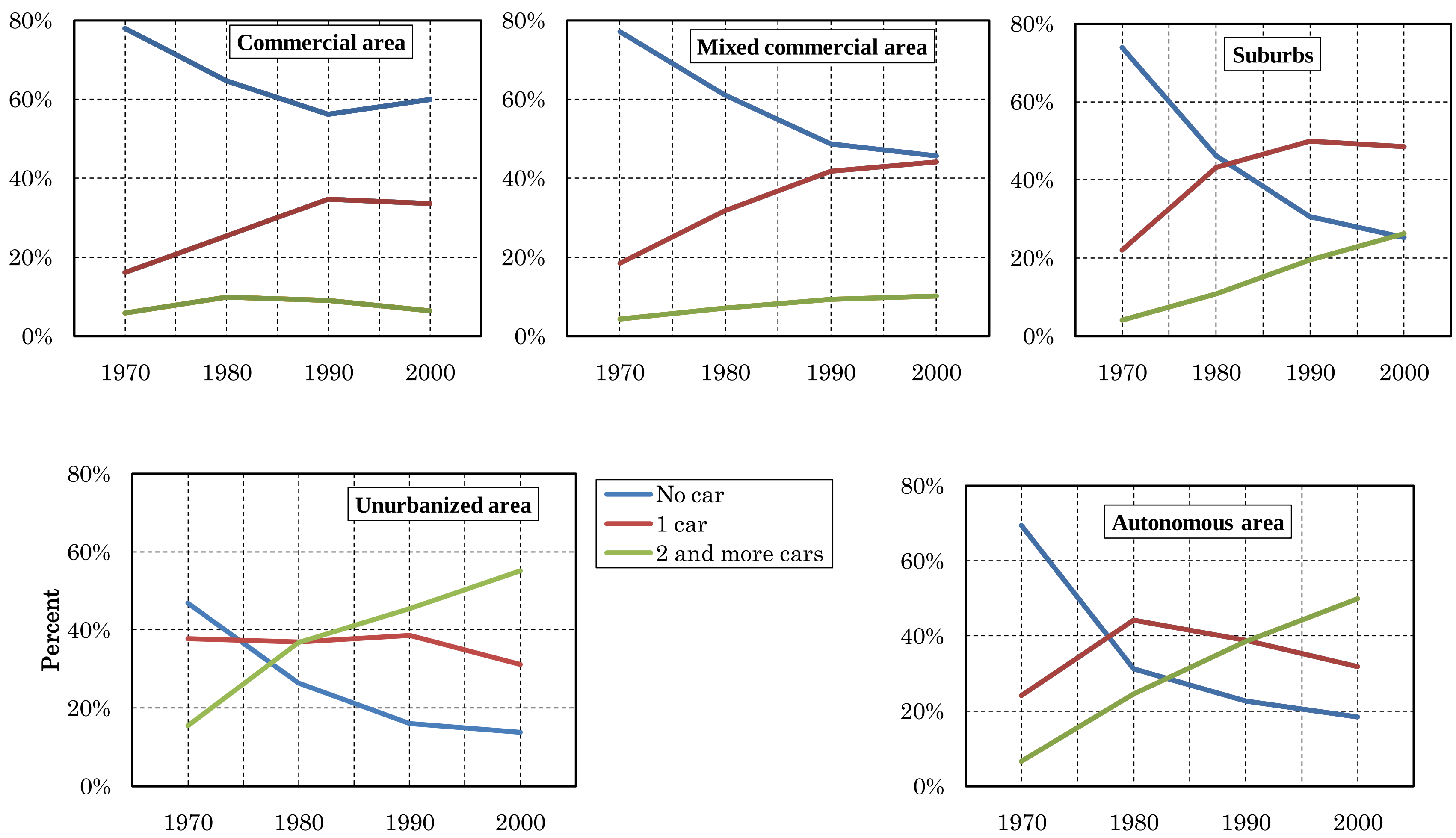


Figure 6.3 Changes in age: 1970 – 2000

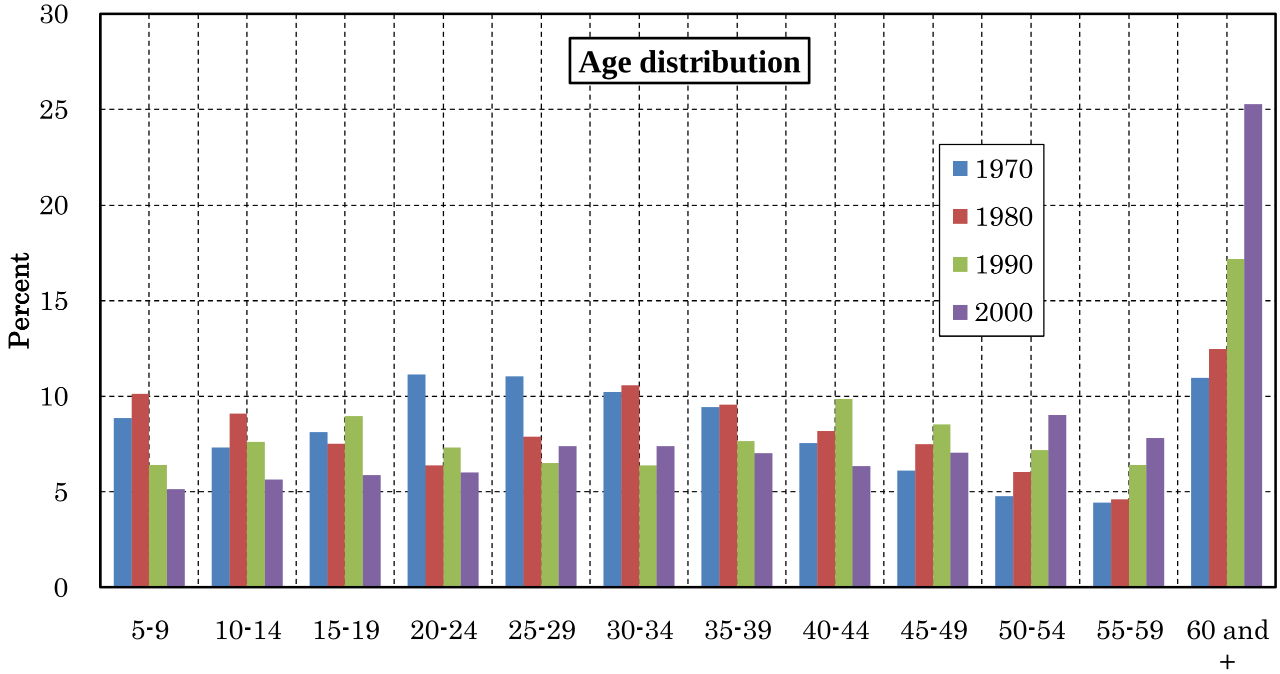


Figure 6.4 Changes in household size: 1970 – 2000

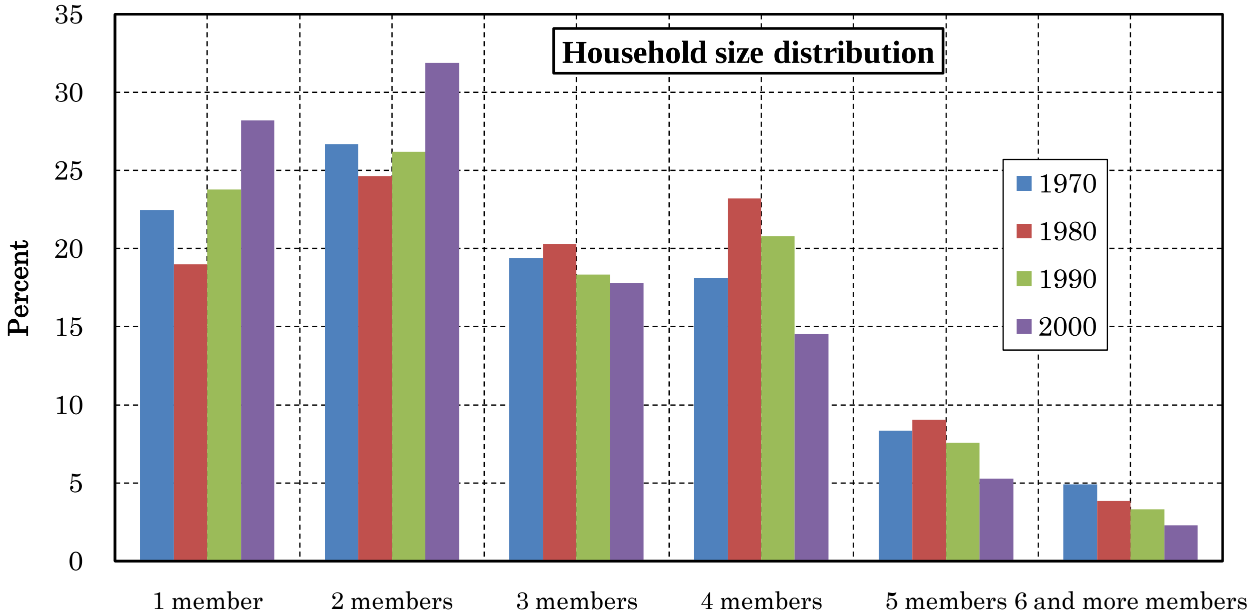


Figure 6.5 Changes in lifecycle stage: 1970 – 2000

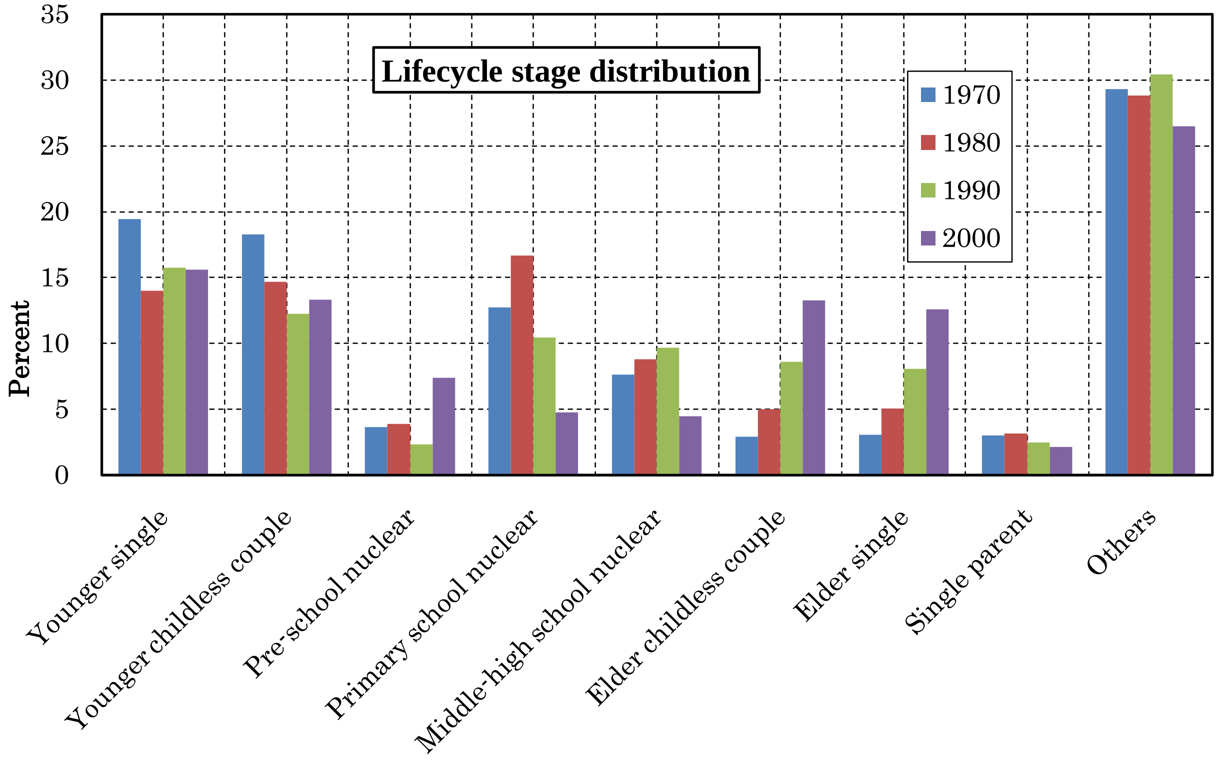
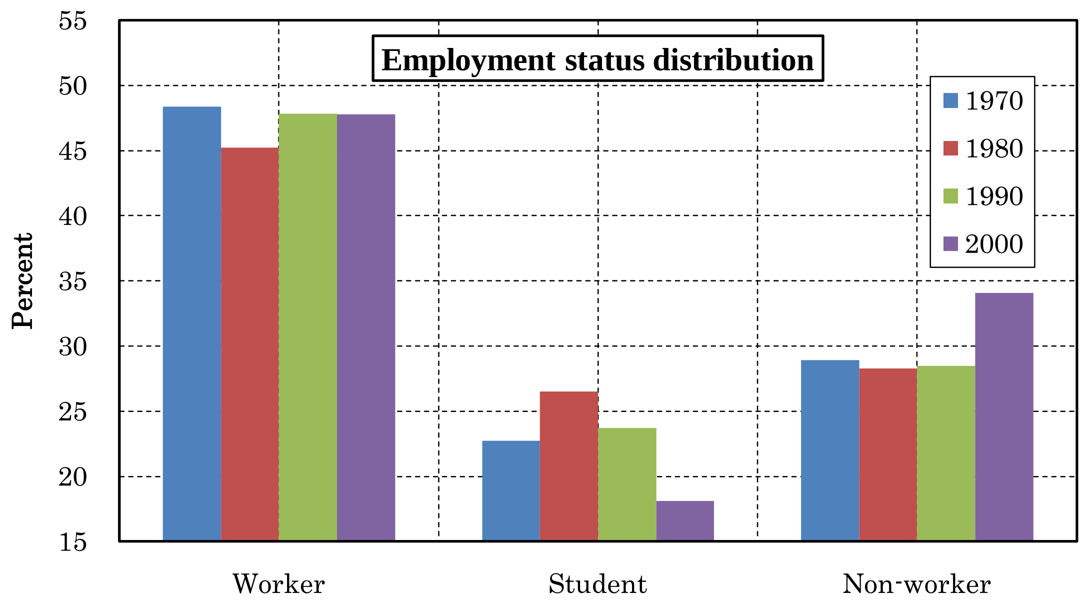


Figure 6.6 Changes in employment status: 1970 – 2000



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Appendix
Program of lifecycle classification

```
COMPUTE HOUSEHOLD_ID = TRUNC(id/100).
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /調査人数= N(id).
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /年齢_max = MAX(年齢).
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /年齢_min = MIN(年齢).
COMPUTE Max_Min 年齢差 = 年齢_max - 年齢_min .
COUNT 年齢 18 歳以下 = 年齢 (Lowest thru 17) .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /年齢 18 歳以下_sum = SUM(年齢 18 歳以下).
COMPUTE 成人人数 = 調査人数 - 年齢 18 歳以下_sum .

DO IF (性別 = 1) .
RECODE
  性別
  (ELSE=1) INTO 男性 .
ELSE.
RECODE
性別
(ELSE=0) INTO 男性 .
```

```
END IF .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /男性_sum = SUM(男性).

DO IF (性別 = 2) .
RECODE
  性別
  (ELSE=1)  INTO  女性 .
ELSE.
RECODE
性別
(ELSE=0) INTO 女性 .
END IF .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /女性_sum = SUM(女性).

COMPUTE HH_sex_ID = HOUSEHOLD_ID * 1000 + 男性 .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HH_sex_ID
  /男女最大年齢 = MAX(年齢).

DO IF (男性 = 1 ) .
RECODE
  男女最大年齢
 (ELSE = Copy)  INTO  男性最大年齢 .
ELSE .
RECODE
  男女最大年齢
```

```
  (ELSE= 0 ) INTO  男性最大年齢  .
END IF .
DO IF (女性  = 1) .
RECODE
  男女最大年齢
 (ELSE= Copy )   INTO   女性最大年齢  .
ELSE IF (女性=0).
RECODE
  男女最大年齢
  (ELSE = 0 ) INTO  女性最大年齢  .
END IF .

RECODE
  男性最大年齢  (SYSMIS=0)   .
RECODE
  女性最大年齢  (SYSMIS=0)   .

STRING  家庭性別 (A8) .
DO IF (調査人数  EQ  男性_sum OR  調査人数  EQ  女性_sum) .
  RECODE
  調査人数
  (ELSE='同性')   INTO   家庭性別  .
ELSE.
RECODE
  調査人数
  (ELSE='異性')   INTO   家庭性別  .
END IF.
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /男性最大年齢_max = MAX(男性最大年齢).
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
```

```
  /女性最大年齢_max = MAX(女性最大年齢).

IF (調査人数  GT 1 &  家庭性別  EQ '異性')  男性 Max_女性 Max 年齢差  = ABS(男性最大年
齢_max -
  女性最大年齢_max)  .
RECODE
  男性 Max_女性 Max 年齢差  (SYSMIS=0)  .

DO IF (年齢  >= 18 &  性別  = 1) .
RECODE
  性別
  (ELSE=1)  INTO  男性成人 .
END IF .

RECODE
  男性成人  (1=1)  (SYSMIS=0)  .

DO IF (年齢  >= 18 &  性別  = 2) .
RECODE
  性別
  (ELSE=1)  INTO  女性成人 .
END IF .

RECODE
  女性成人  (1=1)  (SYSMIS=0)  .

AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /男性成人人数  = SUM(男性成人) /女性成人人数  = SUM(女性成人).


DO IF (男性最大年齢_max >=  女性最大年齢_max) .
RECODE
  女性最大年齢_max
```

```
  (ELSE=copy)   INTO   家庭第二年齢  .
ELSE IF (女性最大年齢_max >  男性最大年齢_max).
RECODE
男性最大年齢_max
(ELSE=copy) INTO   家庭第二年齢  .
END IF .

COMPUTE  第二年齢との差  =  家庭第二年齢  -  年齢  .

DO IF (第二年齢との差  > 0) .
RECODE
  年齢
  (ELSE=copy)   INTO   第二代から年齢  .
ELSE IF (第二年齢との差  <= 0).
RECODE
年齢
(ELSE=0) INTO   第二代から年齢  .
END IF .

AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /第二代から年齢_max = MAX(第二代から年齢).

COMPUTE  第二代から年齢_max と最小年齢の差  =  第二代から年齢_max-年齢_min.


COMPUTE  最大年齢との差  =  年齢_max -  年齢  .
DO IF (最大年齢との差  > 0) .
RECODE
  年齢
  (ELSE=copy)   INTO   第二大年齢_bak .
ELSE IF (最大年齢との差  = 0).
RECODE
年齢
```

```
(ELSE=0) INTO　第二大年齢_bak .
END IF .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /第二大年齢 ＝MAX(第二大年齢_bak).

COMPUTE 最二大年齢との差 = 第二大年齢 - 年齢 .
DO IF (最二大年齢との差 > 0) .
RECODE
  年齢
  (ELSE=copy)　INTO　第三大年齢_bak .
ELSE IF (最大年齢との差 <= 0).
RECODE
年齢
(ELSE=0) INTO　第三大年齢_bak .
END IF .
AGGREGATE
  /OUTFILE=*
  MODE=ADDVARIABLES
  /BREAK=HOUSEHOLD_ID
  /第三大年齢 ＝MAX(第三大年齢_bak).

COMPUTE 最大年齢と第二大年齢の差 = 年齢_max - 第二大年齢.
COMPUTE 第二大年齢と最小年齢の差 = 第二大年齢 - 年齢_min.
COMPUTE 第三大年齢と最小年齢の差 = 第三大年齢 - 年齢_min.

STRING Lifecycle_Stage (A8) .


DO IF (調査人数 EQ 1 & 年齢 LT 60) .
  RECODE
  調査人数
  (ELSE='A')　INTO　Lifecycle_Stage .
ELSE IF (調査人数 EQ 1 & 年齢 GE 60) .
```

RECODE
調査人数
(ELSE='G')　INTO　Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 1 & Max_Min 年齢差 LT 18) .
RECODE
調査人数
(ELSE='J')　INTO　Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 1 & Max_Min 年齢差 GE 18 & Max_Min 年齢差 LT 50) .
RECODE
調査人数
(ELSE='H')　INTO　Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 1 & Max_Min 年齢差 GE 50) .
RECODE
調査人数
(ELSE='K')　INTO　Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 LT 18 & 年齢_max LT 60) .
RECODE
調査人数
(ELSE='B')　INTO　Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 LT 18 & 年齢_max GE 60) .
RECODE
調査人数
(ELSE='F')　INTO　Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 GE 18 & Max_Min 年齢差 LT 22 & 男性最大年齢 GT 女性最大年齢 & 年齢_max LT 60) .
RECODE

調査人数
(ELSE='B') INTO Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 GE 18 & Max_Min 年齢差 LT 22 & 男性最大年齢 GT 女性最大年齢 & 年齢_max GE 60) .
RECODE
調査人数
(ELSE='F') INTO Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 GE 18 & Max_Min 年齢差 LT 22 & 女性最大年齢 GT 男性最大年齢 & 年齢_max LT 65) .
RECODE
調査人数
(ELSE='L') INTO Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 GE 18 & Max_Min 年齢差 LT 22 & 女性最大年齢 GT 男性最大年齢 & 年齢_max GE 65) .
RECODE
調査人数
(ELSE='N') INTO Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 GE 22 & Max_Min 年齢差 LT 50 & 年齢_max LT 65) .
RECODE
調査人数
(ELSE='L') INTO Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 GE 22 & Max_Min 年齢差 LT 50 & 年齢_max GE 65) .
RECODE
調査人数
(ELSE='N') INTO Lifecycle_Stage .
ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '異性' & Max_Min 年齢差 GE 50) .
RECODE
調査人数

（ELSE='K'）　INTO　Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '同性' & Max_Min 年齢差 LT 18) .

RECODE

調査人数

（ELSE='J'）　INTO　Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '同性' & Max_Min 年齢差 GE 18 & Max_Min 年齢差 LT 50 & 年齢_max LT 65) .

RECODE

調査人数

（ELSE='L'）　INTO　Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '同性' & Max_Min 年齢差 GE 18 & Max_Min 年齢差 LT 50 & 年齢_max GE 65) .

RECODE

調査人数

（ELSE='N'）　INTO　Lifecycle_Stage .

ELSE IF (調査人数 EQ 2 & 成人人数 EQ 2 & 家庭性別 EQ '同性' & Max_Min 年齢差 GE 50) .

RECODE

調査人数

（ELSE='K'）　INTO　Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 EQ 1) .

RECODE

調査人数

（ELSE='H'）　INTO　Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 LT 18 & 第二代から年齢_max と最小年齢の差 LT 18 & 年齢_min LT 6) .

RECODE

調査人数

（ELSE='C'）　INTO　Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 LT 18 & 第二代から年齢_max と最小年齢の差 LT 18 & 年齢_min GE 6 & 年齢_min LT 12) .
RECODE
調査人数
(ELSE='D') INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 LT 18 & 第二代から年齢_max と最小年齢の差 LT 18 & 年齢_min GE 12 & 年齢_min LT 18) .
RECODE
調査人数
(ELSE='E') INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 LT 18 & 第二代から年齢_max と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max LT 65) .
RECODE
調査人数
(ELSE='Z') INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 LT 18 & 第二代から年齢_max と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max GE 65) .
RECODE
調査人数
(ELSE='O') INTO Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 男性最大年齢 GT 女性最大年齢 & 第三大年齢と最小年齢の差 LT 18 & 年齢_min LT 6) .
RECODE
調査人数
(ELSE='C') INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 男性最大年齢 GT 女性最大年齢 & 第三大年齢と最小年齢の差 LT 18 & 年齢_min GE 6 & 年齢_min LT 12) .

RECODE
調査人数
（ELSE='D'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 男性最大年齢 GT 女性最大年齢 & 第三大年齢と最小年齢の差 LT 18 & 年齢_min GE 12 & 年齢_min LT 18) .
RECODE
調査人数
（ELSE='E'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 男性最大年齢 GT 女性最大年齢 & 第三大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max LT 65) .
RECODE
調査人数
（ELSE='Z'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 男性最大年齢 GT 女性最大年齢 & 第三大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max GE 65) .
RECODE
調査人数
（ELSE='O'） INTO Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 女性最大年齢 GT 男性最大年齢 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min LT 18) .
RECODE
調査人数
（ELSE='H'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 女性最大年齢 GT 男性最大年齢 & 第二大年齢

と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max LT 65) .
RECODE
調査人数
(ELSE='L') INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 18 & 男性 Max_女性 Max 年齢差 LT 22 & 女性最大年齢 GT 男性最大年齢 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max GE 65) .
RECODE
調査人数
(ELSE='N') INTO Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 22 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min LT 18) .
RECODE
調査人数
(ELSE='H') INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 22 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max LT 65) .
RECODE
調査人数
(ELSE='L') INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 1 & 女性成人人数 GE 1 & 男性 Max_女性 Max 年齢差 GE 22 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max GE 65) .
RECODE
調査人数
(ELSE='N') INTO Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 2 & 女性成人人数 EQ 0 & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min LT 18) .
RECODE

調査人数
（ELSE='H'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 2 & 女性成人人数 EQ 0 & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max LT 65) .
RECODE
調査人数
（ELSE='L'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 GE 2 & 女性成人人数 EQ 0 & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max GE 65) .
RECODE
調査人数
（ELSE='N'） INTO Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 EQ 0 & 女性成人人数 GE 2 & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min LT 18) .
RECODE
調査人数
（ELSE='H'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 EQ 0 & 女性成人人数 GE 2 & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max LT 65) .
RECODE
調査人数
（ELSE='L'） INTO Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '異性' & 男性成人人数 EQ 0 & 女性成人人数 GE 2 & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max GE 65) .
RECODE
調査人数
（ELSE='N'） INTO Lifecycle_Stage .

ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '同性' & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢

```
_min LT 18) .
RECODE
調査人数
 (ELSE='H')   INTO   Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '同性' & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max LT 65) .
RECODE
調査人数
 (ELSE='L')   INTO   Lifecycle_Stage .
ELSE IF (調査人数 GE 3 & 成人人数 GE 2 & Max_Min 年齢差 LT 50 & 家庭性別 EQ '同性' & 最大年齢と第二大年齢の差 GE 18 & 第二大年齢と最小年齢の差 LT 18 & 年齢_min GE 18 & 年齢_max GE 65) .
RECODE
調査人数
 (ELSE='N')   INTO   Lifecycle_Stage .

ELSE.
RECODE
調査人数
 (ELSE='M')   INTO   Lifecycle_Stage .
END IF.
EXECUTE.

DO IF (調査人数 NE 世帯人数) .
RECODE
調査人数
 (ELSE='DATA 不足')   INTO   Lifecycle_Stage .
end if.
execute.
```

后　记

----别了，我的留学生涯

历史终于翻开了崭新的一页，我即将走向归国之路，回顾七年来在日本留学生涯，理想与奋斗同在，艰辛与幸福相伴。这是我青春最美好的一段年华。

21世纪零一年十月告别北京，飞抵京都，开始了异国的留学生活。星移斗转，冬去春来。七年的时光，漫长而又短暂，轻松愉快，而又凝重艰辛。几多欢喜，多少忧愁，千般感慨，万种遗恨，冷暖炎凉，唯有心知，恰似登上一座高山后的感觉，短暂的兴奋喜悦过后，便是一阵淡淡的凉意与深深的寂寞。“八面云山来眼底，万家游忧乐到心头”。和蔼清濯的北村隆一先生引导我进入了这个专业，在学习、科研、生活诸方面，承蒙导师多方关怀；在论文的完成、撰写等方面，更倾注了先生大量的心血，使我铭记在心。在他的指导与鼓励之下，完成了这篇论文。先生的风范，堪为楷模；先生的德行学识，让我受益良多，终生难忘。我把最深的感谢献给恩师！

七年寒窗，我孤身游学他乡，远离故土，远离亲人，得到了父母，姐姐，以及丈夫全力的支持与无限的爱。那分亲情，那分期待，是支撑我完成学业的精神力量。我要把感谢献给他们！无论是在天涯海角，他们都是我心中坚实的依靠。

“让我怎样感谢你，当我走向你的时候，我原想收获一缕春风，你却给了我整个春天。”

谨将此论文献给尊敬的导师----北村隆一先生！

“轻轻的我走了，正如我轻轻的来；我轻轻的招手，作别西天的云彩，……但我不能放歌，悄悄的是离别的笙箫；夏虫也为我沉默，沉默是今晚的康桥！悄悄的我走了，正如我悄悄的来；我挥一挥衣袖，不带走一片云彩。”