SPATIAL DIMENSIONS OF WORKPLACES

AND THE EFFECTS ON COMMUTING:

THE CASE OF METROPOLITAN DALLAS-FORT WORTH

A Dissertation

by

SANGYOUNG SHIN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2002

Major Subject: Urban and Regional Science

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ABSTRACT

Spatial Dimensions of Workplaces and the Effects on Commuting:
The Case of Metropolitan Dallas-Fort Worth. (August 2002)

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There has been a lively debate over using land use strategies to reduce automobile dependence over the past decade. As a part of the issue, this study investigates the spatial characteristics around workplaces and their relationships to commuting made by the employees in metropolitan Dallas-Fort Worth. The tools of geographic information systems (GIS) are utilized to measure workplace environs. Several statistical methods are applied to analyze commuting behavior.

This study finds that low-density suburban workplaces are associated with shorter vehicle travel times but more drive-alone trips. While major suburban centers attain some level of compact development in terms of local activity mix and regional accessibility, employees in these centers are far more automobile dependent than employees in older centers in the central city. In the suburban locations, workplaces in residence-based centers and master planned communities with a mix of activities are associated with less drive-alone commuting and more carpooling. Workers take advantage of the abundance of activities, as larger and denser centers are associated with more non-work activity stops after work. Yet, the trip chaining is overwhelmingly driven by automobile use.

This study also finds that spatial factors are significant in explaining commuting behavior. Yet, the importance of spatial factors varies with the aspect of travel. Spatial factors do a better job in explaining travel times than in explaining travel mode and trip chaining. The way a particular spatial factor affects commuting also varies with the

aspect of travel. For instance, land use intensity factors are associated with longer travel times but less drive-alone trips. While this study suggests that concerted planning may affect travel, some socioeconomic variables, including income and automobile ownership, are strongly related to more automobile travel.

The findings suggest that the land use strategies to cope with transportation and air quality problems, such as new urbanism and jobs-housing balance, would be a viable option in and around employment locations. But, such strategies should be carefully designed because of the differences in effectiveness of spatial factors with travel outcomes and the trade-offs between travel outcomes with a particular spatial factor.

To my family, Kyunghee, Heejin, and Dongjun.

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INTRODUCTION

Over recent decades, suburban jobs have rapidly grown in most metropolitan regions in the United States. Suburban jobs increased from 33% to 37% in the nation between 1980 and 1990, while central city jobs decreased from 38% to 34% over the same period (Pisarski 1996). The location of office space, which was predominantly found in the center of metropolitan regions, has also shown a dramatic change. In the thirteen largest metropolitan regions, suburban office space increased from 26% to 42% between 1979 and 1999 while central-city office space decreased from 74% to 58% over the same period (Lang 2000). Consequently, suburban jobs are changing the traditional concept of "central-city jobs, suburban homes" by forming suburb-to-suburb commuting as a dominant pattern. While suburban population accounts for 62% of metropolitan population in 1990, suburb-to-suburb commuting accounts for 44% of metropolitan commuting (Pisarski 1996). Now, many Americans live and work in suburbs.

Employment decentralization is an important urban policy issue because it is related to various urban issues such as the direction of future urban growth, demand for new transportation provisions, deterioration of older downtowns, job opportunities for low-income people, and suburban anti-growth movements. Transportation problems such as traffic congestion are another important concern. Low-density dispersed suburban employment development can have significant influences on worsening suburban traffic congestion and air quality by increasing automobile dependence and cross commuting.

From a theoretical perspective, employment decentralization gives rise to the possibility for reduction in overall commute time and distance as firms and workers locate closer to each other in the suburbs. According to the "co-location" hypothesis, the urban development process facilitates shorter travel times and distances as labor supply attracts firms to the suburbs. Firms are also located in closer proximity to workers to

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minimize labor costs. Some empirical studies provide evidence for the notion of co-location by finding that overall commute times tend to decline or remain stable (Gordon, Richardson, and Jun 1991; Levinson and Kumar 1994).

However, analyses based on larger travel surveys do not clearly support better traffic conditions in metropolitan regions. The overall commute time appears stable only showing a modest increase. For example, the 1990 Census shows that the national commute time increased from 21.7 minutes in 1980 to 22.4 minutes in 1990 (Pisarski 1996). The 1995 Nationwide Personal Transportation Survey (NPTS) also shows that the overall commute time increased from 18.2 minutes in 1983 to 20.7 minutes in 1995 (Hu and Young 1999).

Commute distance and automobile use have increased more than commute time. The 1995 NPTS shows that the average vehicle work trip length increased from 8.6 miles to 11.8 miles between 1983 and 1995. The annual VMT (vehicle miles traveled) to and from work per household increased from 3,540 miles to 6,490 miles during the same period (Hu and Young 1999). Overwhelming automobile dependence appears to almost reach the limit of increase. The 1990 Census shows that single-occupant vehicles (SOVs) raised the share from 64.4% to 73.2% in the nation between 1980 and 1990. The overall personal vehicle share increased from 84.1% to 86.5% over the same period. SOVs are the only mode of commuting that gained its share during 1980s (Pisarski 1996).

Urban transportation system conditions are getting worse as motorized trips are increasing faster than road expansions. The 2001 urban mobility study for the 68 U.S. major urban areas by the Texas Transportation Institute (TTI) shows that the average annual delay per person, the amount of extra time spent traveling due to road congestion, increased from 11 hours in 1982 to 36 hours in 1999 (Schrank and Lomax 2001).

The reports based on larger travel surveys indicate that, while commute time has modestly increased or remained stable, people are traveling longer distances with automobile dependence. Congestion levels on the major urban roadway system have grown, as the transportation demands are higher than roadway expansions and improvements.

From these trends, a question would be, "Why have urban traffic conditions not so improved in spite of the outward migration of jobs to suburbs where a majority of workers live?" Steady growth in population, income, and a widespread availability of automobiles may have contributed to more travel and more automobile dependence. Some suburbanites have migrated out farther from the urban core for better residences, as suburban jobs give them the opportunity to exodus from increasingly degraded existing suburbs. Non-work travel, including shopping, personal and family business, and social and recreation trips, has greatly increased recently. Additionally, firms rely more on highway trucking for operation and distribution.

Another important reason for worsening traffic conditions may be location and land use characteristics of suburban employment, which enable people to take longer journeys in private automobiles. While certain types of suburban development could shorten travel distance and time, therefore reducing automobile dependence, other types may create the opposite effect. In other words, sprawling suburban employment, which exhibits poor physical accessibility and overwhelming dependence on individual mobility, may be among the important causes of urban transportation problems.

Upon analyzing the body of research on suburban workplaces, it is found that a majority of empirical studies investigate the physical and economic characteristics of suburban employment centers. Employment decentralization has taken a polycentric form with a number of subcenters. Suburban employment centers have received considerable interest from scholars and policymakers because of their increasing importance in urban economy and transportation (Baerwald 1982; Leinberger 1988; Hartshorn and Muller 1989; Cervero 1989a; Garreau 1991; Giuliano and Small 1991; Pivo 1993; McDonald and Prather 1994; Fujii and Hartshorn 1995; Cervero and Wu 1997; Freestone and Murphy 1998; Giuliano and Small 1999).

Looking solely into suburban centers has some limit in capturing the evolving suburban landscape because scatteration is another important form of decentralization. There is a large share of scattered employment establishments sprawling beyond centers (Fishman 1987; Pivo 1990; Lang 2000). According to a survey (Lang 2000), in

America's 13 largest metropolitan regions, 37 % of all office space in 1999 was found in highly dispersed, "edgeless" locations lacking well-defined boundaries.

Polycentrism and scatteration provide complex implications for urban travel patterns. Larger employment centers are related to longer travel distance and times than smaller centers because the concentration level of large centers attracts a large amount of travel and thus the possibility of more traffic congestion (Giuliano and Small 1991). Yet, employment centers can become nodes of public transportation such as light rail, and provide alternative travel choices.

Individual work sites have the potential to be able to shorten commute times as long as firms try to maximize proximity to their employees and customers. Reality is often different however. New suburban business locations tend to be decided on the assumption that workers and customers are completely dependent on automobiles. A new suburban office park accompanied by spacious parking lot may be almost impossible to access without car. Thus, a compromise would be to seek for a suburban employment location type between concentration and decentralization, which allows non-private automobile modes such as public transit to be a viable option.

In recent years, many scholars and policymakers have explored using land use strategies to address transportation problems. These studies focus on travel outcomes, usually non-work travel, by alternative land use patterns in terms of density, activity mix, accessibility, and street design (Handy 1993b; Ewing, Haliyur, and Page 1994; Frank and Pivo 1994; Holtzclaw 1994; Cervero and Gorham 1995; Handy 1996b; Cervero 1996b; Cervero and Kockelman 1997; Boarnet and Sarmiento 1998; Crane and Crepeau 1998). Most studies are related to alternative approaches to physical design for suburban communities, often referred to as "new urbanism", including traditional neighborhood development (TND) and transit-oriented development (TOD).

A majority of these studies focus on the problems from the standpoint of residential neighborhoods, that is, how different land use characteristics of neighborhoods influence travel patterns. Some studies include indicators for workplace characteristics such as employment density, jobs-housing ratio, and nonhome-based accessibility as a part of residential-based travel studies (Ewing, Haliyur, and Page 1994; Frank and Pivo 1994). These indicators tend to be secondary to neighborhood physical indicators.

A few empirical studies present comprehensive and detailed investigations into the relationship between physical characteristics of workplaces and travel patterns (Cervero 1989a; Cambridge Systematics, Inc. 1994). Some studies provide important locational strategies for transportation problems such as "jobs-housing balance" (Cervero 1989b; Cervero 1996a; Levine 1998). Compared to neighborhood-based travel studies, workplace-based studies appear to be less vital in quantity and debate in recent years.

Part of the reason for less research about the link between workplace and travel may be because of the less discretionary nature of work travel. Unlike non-work trips such as shopping and recreation, work trips tend to be constant and thus are likely to be less sensitive to land use configurations (Handy 1996b). Further, work trips appear to lend little room for non-motorized trips because of the regional or long-distance nature of trips in many cases.

Work trips are still an important part in people's daily trips and urban transportation planning. Of trip purposes in 1995, work trips (commuting and work related business) account for about 28.2% in terms of person miles of travel (PMT). It is the second largest share of trips, following social and recreational trips (Hu and Young 1999). Now, workers are making more trip chains to link their work trips to various non-work activities such as shopping and personal businesses (Levinson and Kumar 1995). Increasing non-work trips should be attributed to activity stops during work trips as well as to traditional home-based non-work trips.

Mixing jobs and housing in and around workplaces may contribute to shortening commute length and reducing automobile use. For example, new urbanist communities are likely to be more successful in and around workplace concentrations because land markets may facilitate more compact land use patterns. The link between residential and non-residential activities is an important feature of new urbanist designs.

There is a break between the studies based on macro-level or regional structure and the studies based on micro-level or local land use. Although some studies take into account trade-offs in travel effects of regional and local contexts of urban form (Handy 1993b), many studies tend to focus on either level of urban form, particularly local land use patterns. Part of the reason may be that land use power is largely under local control in the United States and thus local indicators such as density and street design may bring more practical policy implications. However, the effectiveness of the incremental approach through local land use planning may be different by the metropolitan context in which a particular planning area is located. If a regional indicator has strong influences in explaining travel patterns, it implies that a metropolitan-wide approach is the more effective policy tool to combat transportation problems despite difficulty in the effective implementation. There is growing attention to regionalism in both governance and design (Downs 1994; Neuman 2000; Calthorpe and Fulton 2001). Therefore, studies need to take into account complementary and conflicting effects of spatial context functioning at both regional and local level.

Research Objectives

The purpose of this study is to examine workplace environs, particularly of suburban workplaces, and their effects on commuting patterns measured by travel time, mode split, and trip chaining. Major research questions are as follow:

1) How can we conceptualize and measure the relationship between workplace environs around a given workplace and their impacts on commuting behavior made by the employees there?
2) What aspects of workplace environs are important in defining workplace locations? Particularly, what spatial characteristics of suburban workplace locations distinguish them from their counterparts of the central city?

3) Are there any differences in commuting patterns--time traveled, travel mode, and trip chaining--made by their employees? Particularly, do employees of suburban workplaces exhibit significantly different commuting patterns from their counterparts in the central area?
4) What aspects of workplace environs are important in explaining commuting behavior--time traveled, travel mode, and trip chaining--made by individual employees? Is there any conflicting or supplementary effect among spatial factors in affecting an aspect of commuting?
5) What kind of urban policy at work locations can be applied to addressing urban transportation issues such as traffic congestion and automobile dependence?

Workplace environs are defined by a number of local and regional spatial factors around an individual workplace. Various tools provided by Geographic Information Systems (GIS) are used to process spatially referenced data. Commuting characteristics are examined in terms of time traveled, travel mode, and trip chains made during commuting trips. This study uses a workplace survey and GIS database (land use, jobs, housing, etc.) for metropolitan Dallas-Fort Worth.

Several multivariate statistical techniques (e.g., factor analysis, cluster analysis) are used to identify the spatial dimensions of workplace environs and to classify workplaces by their environs. A comparison analysis is conducted to compare spatial characteristics and commuting outcomes by workplace location type. To identify the contribution of each factor of workplace environs, the commuting behavior measures are estimated through statistical models (e.g., multiple regression, binomial logit models) that include both personal-household characteristics of the individual employee making a travel choice as well as characteristics of workplace environs.

Potential Contribution of the Study

This study may contribute to the body of research and urban policy in several ways. First, this study may contribute to the large body of research on the link between urban form and travel by providing empirical findings from the standpoint of employment location. The complementary and conflicting effects of various spatial factors on work trip indicators may help more fully understand the transportation consequences of suburban employment development.

Second, this study may contribute to expanding external validity of research on the link of land use and transportation by providing a case in the southern United States. A majority of existing studies is based on the cases of the East and West coasts, primarily California.

Third, this study may provide an opportunity to evaluate workplace environs, particularly suburban, with respect to transportation. Findings may provide policy implications for urban transportation and air quality issues.

Organization of the Study

The remainder of this study is structured as follows. Chapter II develops a conceptual framework and hypotheses for the link between workplace environs and commuting patterns. Chapter III reviews previous research on workplaces locations and their effects on travel patterns to position this study under the context of relevant studies. Chapter IV presents data sources and analytical methods for the empirical analysis. The study case is a number of workplaces in metropolitan Dallas-Fort Worth, Texas. Chapter V presents the empirical analysis of the spatial characteristics around workplaces by using a series of comparative schemes. Chapter VI presents the empirical analysis of the relationship between spatial characteristics around workplaces and commuting patterns: travel time, travel mode, and trip chaining. The final chapter summarizes the important findings from the study and highlights the implications for land-use and transportation planning.

Defining Terms

This study needs to define precisely several basic concepts. First, the term "suburban" is used to refer to as the location of any land use activity around and beyond the ring of major regional beltways. In the metropolitan Dallas-Fort Worth, the regional beltways are identified roughly at nine miles away from downtown Dallas in the Dallas Metropolitan Statistical Area (MSA) and at six miles away from downtown Fort Worth in the Fort Worth MSA. Many studies use political boundaries to distinguish suburbs from the central city. The problem is not so simple if the boundaries are based on a political unit. Many large metropolitan regions include not only an older regional center such as central business district (CBD) but also suburban towns that once served as an older settlement core and have been swept into the metropolitan economy. Thus, a question is whether to include older suburban towns. For example, in the metropolitan Dallas-Fort Worth, the Bureau of the Census designates five cities as the "central cities" including Arlington, Dallas, Denton, Fort Worth, and Irving. When a study includes Arlington, Denton, and Irving as central cities, the image of suburbs might be blurred because those centers share suburban styles in terms of land use and activity patterns.

Another problem of the definition based on political boundaries is coming from the fact that many "sunbelt cities" have used the power of annexation to extend municipal services, regulations, and taxing authority to new territories. By including many land use activities farther from the older regional center as part of the central city, the definition could distort the degree of job decentralization and make the research results difficult to provide a comparable basis.

A group of studies loosely defines the "suburban" to refer to any kind of settlement at the periphery of a regional center (Fishman 1987; Cervero 1989a). For example, Cervero (1989a) operationally defines the "suburban" as "the location of any land activity outside of a regional CBD, generally at least five or more radial miles away". The decision of "cutoff distance" may be arguable however.

Some scholars might further divide the outer part of a metropolitan region into "suburban" and "exurban" to take into account the settlements between suburban and rural areas (Davis, Nelson, and Dueker 1994). This study uses the term "suburban" as a broad concept containing the typical suburban areas and beyond in the peripheries in the metropolitan region.

The term "urban form" or "urban structure" is used interchangeably in this study. Urban form is used as a broad concept encompassing land use and transportation systems (Handy 1996a). Similarly, many studies use "land use" as a generic term to refer to spatial distribution of activities. In this study, the term is used to particularly refer to local land use features such as density and mixed use. Land use is considered as one aspect of urban form (Handy 1996a). However, the rule is not always strictly complied, as in the phrase of "land use-transportation interaction."

The term "workplace" or "worksite" is an employer or a place of work where a worker is employed. In GIS, workplaces are represented in point features.

The term "workplace environs" is used to describe spatial characteristics around a particular workplace. Workplace environs may be referenced by the local and regional distribution of jobs, housing, and transportation provisions, and reflect magnitude, density, diversity, and accessibility of the opportunity for the particular workplace.

The term "employment center" is used to describe a relatively large employment concentration comprised of a number of workplaces. Scholars have used various phrases to describe a large-scale, mixed-use concentration of suburban workplaces, such as "urban village" (Leinberger 1988), "suburban employment center" (Cervero 1989a), "suburban downtown" (Hartshorn and Muller 1989), "edge city" (Garreau 1991), "subcenter" (Giuliano and Small 1991), and "suburban activity center" (Bochner 1992). Each phrase has slightly different nuance, emphasis, and criteria. This research uses those phrases interchangeably to describe a relatively large concentration of development, depending on the context of the use. But, the operational measure of suburban employment center for this study is based on size and density of employment. The specific operationalization process for this study will be presented in the relevant part.

The term "travel pattern" is used to represent collective characteristics of travel or aggregate-level characteristics of travel, while the term "travel behavior" is used to refer to individual-level characteristics of travel (Handy 1996a). Travel can be analyzed in various terms such as frequency, time, distance, mode, route, and chaining. And, among others, the term "trip length" is used as a broad concept including both travel time and physical distance.

The term "trip linking" or "trip chaining" is defined as making a sequence of trips in a journey. A trip chain can be defined in various ways (Nishii, Kondo, and Kitamura 1988; McGuckin and Murakami 1999). When a journey is referenced by the anchors of home and work, there may be four types of journey during a weekday: home-to-work, work-to-home, work-based, and home-based (McGuckin and Murakami 1999). Trip chaining is often explored activity stops on the way of commuting trips before work and after work. This study focuses on non-work stops made on the way of commuting trips between home and work.

CHAPTER II
CONCEPTUAL FRAMEWORK AND HYPOTHESES

This chapter sets up a conceptual framework to explore the relationship between workplace environs and commuting behavior made by employees. Based on the conceptual framework, a series of hypotheses are derived.

Conceptual Framework

A study concerning the relationship between workplace environs and commute patterns needs first to look at the way workers make travel choices. Commute patterns are seen as a collective product of travel decisions made by each individual worker. Economic theory of consumer behavior can provide a starting point to conceptualize individual commuting decisions.

A basic assumption about consumer behavior is that an individual will make a choice in the manner of utility maximization. The consumer equilibrium is often explained by an indifference curve, representing individual needs and preferences, and a budget line, representing resource constraints. Thus, the demand for a particular service will depend on its price relative to other services and the characteristics of the individual who makes the choice. A trade-off among the services consumed is involved in the decision-making under the constraints of objective market prices and individual resources. While neoclassical economic theory as a decision rule is based on a series of strict assumptions (e.g., perfect information in decision-making), alternative models are random utility models that allow some level of uncertainty, such as incomplete information in decision-making and inability of modeler to observe all factors (Ben-Akiva and Lerman 1985). Random utility models, often implemented by multinomial logit models, are particularly useful for discrete choice situations such as travel mode and destination choice. In this framework, an individual (e.g., tripmaker) is conceived of as selecting a choice from all possible choices (e.g., travel modes, residential locations, or the combination of both). The utility of a choice is a function of its attributes (e.g., travel cost, safety, convenience). Different people have different tastes and preferences, and thus evaluate the choices differently. Therefore, a decision-making is the result of interaction between "chooser" and "choice set" (Levine 1998).

It has been suggested that most travel is a "derived demand," indicating that travel occurs as a byproduct of participating activities such as work and shopping at destinations. This simple concept provides important implications for travel research. A tripmaker will try to minimize travel costs whenever possible. Travel costs represent all the subjective costs of travel such as time, money, and inconvenience of a particular mode. A trade-off will occur between travel costs and benefits at activity sites. For example, an individual may be willing to travel farther or pay more travel costs as the relative benefits from an activity become larger.

The concept of derived demand implies that understanding daily activity patterns is crucial. First, activity patterns will depend on individual needs, preferences, and resources, which are linked to economic and demographic characteristics of the individual such as income, gender, household type, and life style. For example, low-income workers may make shorter commuting and less trip chaining due to limited access to automobiles and less economic capability to participate in activities after work. Family commitments may dictate women to make shorter commuting trips and more trip chains for drop-off/pickup and shopping (Hanson and Schwab 1995; McGuckin and Murakami 1999). Concerning the economic-demographic factors, previous studies find that, variables related to a person's role within the household (e.g., gender, employment status) tend to have a greater impact on travel behavior than do variables related to social status (e.g., occupation, income) (Hanson and Schwab 1995).

Second, activities occur under the constraints of space and time (e.g., work during the daytime, shopping on the way home after work). Urban structure, or the spatial organization of activities, affects the costs for individuals to participate in activities because it constitutes the opportunities and constraints for urban activities. Two important components of urban structure are land use and transportation. This is related to the concept of accessibility that denotes urban opportunity structure by the relationship between land use patterns and transportation provisions (Handy and Niemeier 1997). Again, the spatial distribution of activities, thus accessibility, affects travel patterns (e.g., mode used, distance traveled, and activity stops made) by shaping the opportunity structure and thus the costs to participate in activities.

With regard to commuting, the spatial structure or environs around a workplace may be defined by the distribution of jobs, housing, and transportation provisions. Each spatial context may have various dimensions, including magnitude, density, variety, and proximity of the opportunities. Greater housing availability in the close proximity to a workplace is likely to shorten commute times and to increase non-motorized trip modes. Greater job concentration implies the possibility of more traffic congestion but less automobile dependence because of the variety of activities in close proximity to each other. High levels of automobile use in suburban workplace locations may be partly due to fewer non-automobile travel alternatives.

Given the regional nature of travel, it would be useful to vary the level of spatial context. For example, the structure of a place may be characterized at two types of accessibility: regional accessibility that is attained by a few large activity sites farther from the place but by good transportation services; and local accessibility that is attained by a number of small activity sites closer to a place (Handy 1993b). The distinction can provide an important insight for the coordination between local and regional strategies to address transportation issues because the effectiveness of a local land use strategy may be different depending upon the metropolitan context in which the particular planning area is located.

From the standpoint of a workplace where an individual employee works, the spatial context may also be identified at the level of the workplace itself. A workplace in relation to travel appears to have two aspects: spatial and institutional. First, physical characteristics of a work site may affect travel made by the employees. For example, parking availability has been long considered an important factor affecting automobile use. Architectural and establishment-specific characteristics of the workplace might affect travel, particularly non-motorized travel by providing a sense of friendliness and safety for the employees and customers (Cambridge Systematics, Inc. 1994). Second, various institutions operated by the employer may affect commuting. For example, employer-based transportation demand management (TDM) programs (e.g., ridesharing, transit subsidies) may affect automobile use. While many businesses operate fixed work hours, some may allow flexible work schedules and telecommuting.

The business type of the employer is another consideration because different types of businesses have different locational propensities. Market-sensitive activities (e.g., retailing) require high levels of accessibility to customers. Certain businesses are mostly found in major employment concentrations because the accessibility to other related firms is important in these businesses. Heavy manufacturing activities may be located farther from residential areas because of the negative features and the necessity for large sites for operation. The locational propensity of a business dictates commuting patterns made by employees.

Commuting trips can be characterized in various ways: duration, time of day, mode, route, activity stop, origin, destination, frequency, and the like. Commuting trips constitute part of trip chain in the daily activity schedule. It is important to note that the commuting attributes are interrelated in travel decision-making as an individual or household schedule activity and travel within a broad range of mobility and lifestyle decisions (Lerman 1976; Ben-Akiva and Bowman 1998). Lerman (1976) terms the joint decision criteria the "mobility bundle."

Based on the discussion, Figure 2.1 illustrates a conceptual framework for the study of the relationship between workplace environs and travel choices made by a worker. Note that the illustration does not mean this study fully covers all the factors listed. Further, the illustration may highly simplify the complex relationship. Nevertheless, it may be a helpful means to identify important factors in modeling the relationship between workplace environs and commuting.

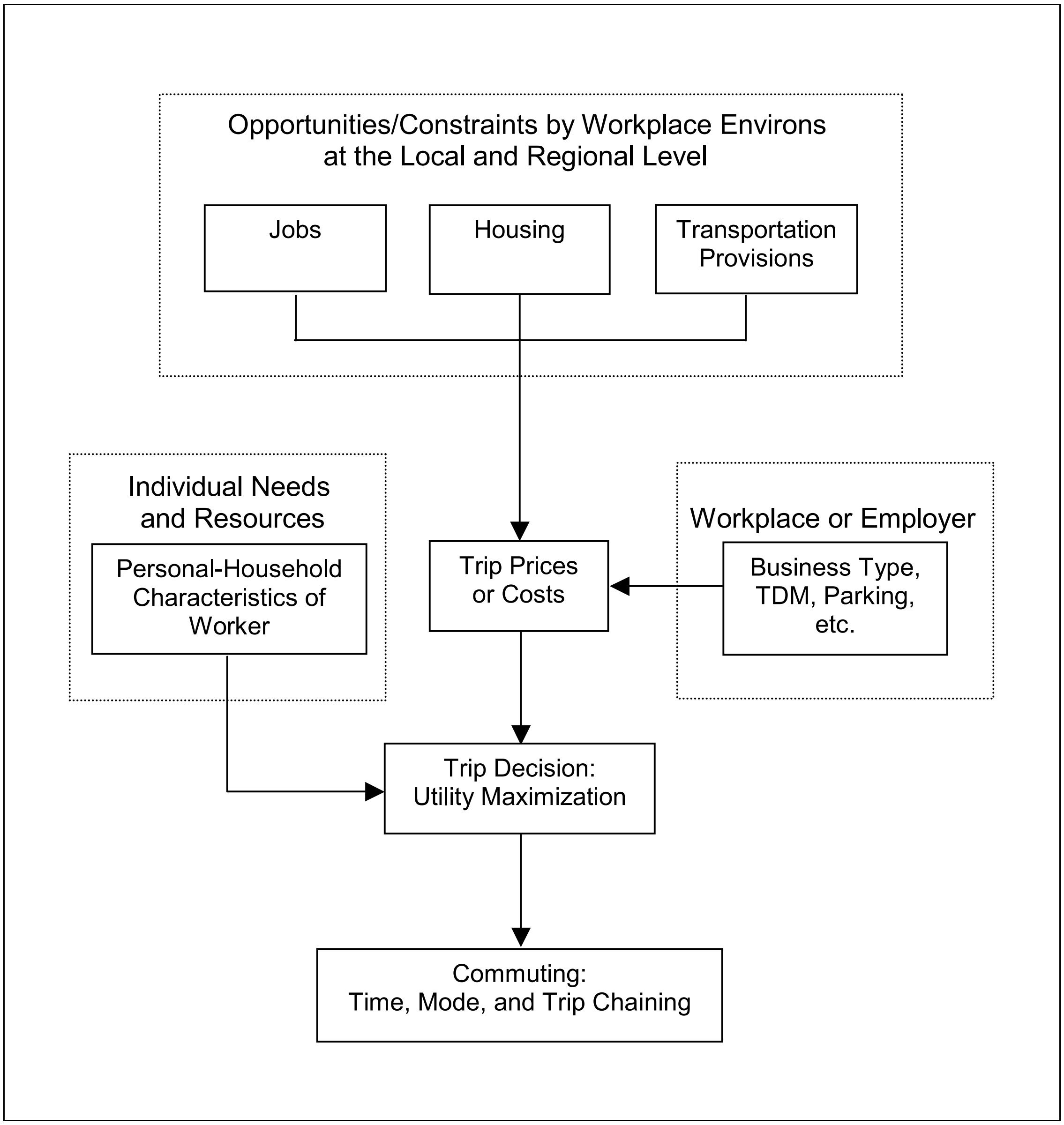

Figure 2.1 Conceptual framework for the workplace-based commuting study

Hypotheses

This section specifies hypotheses for the relationship between workplace environs and commuting choices made by employees. As mentioned, workplace environs are defined by a number of spatial factors around a particular workplace, including the local and regional distribution of jobs, housing, and transportation provisions. They reflect the magnitude, density, diversity, and accessibility of the opportunity. Commuting choices are explained in terms of travel time, travel mode, and trip chaining in which stops for non-work activities are made during commuting trips. A basic hypothesis is that location and land use characteristics surrounding a given workplace affect commuting patterns. Hypotheses are grouped into three sets: commute time related, travel mode related, and trip chaining related. Note that the measurements for various concepts stated in the hypotheses are fully specified in the chapter on research design.

Hypotheses Related to Travel Time

$H_{1.1}$: A workplace in a job-rich area, measured by the amount, density, and diversity of jobs around the workplace, is associated with longer commute times. Employees working in a job-rich area are faced with more potential competitors for housing, transportation, and other urban services. The situation may be often translated into traffic congestion and high housing prices in the vicinity. Some workers may have to look for appropriate places of residence farther from their places of work than otherwise. Employers also need a large geographical area for the labor pool because of more competitors. Meanwhile, the concentration of jobs, particularly customer-oriented activities such as retailing, provides non-work activity opportunities. Thus, employees of the workplace may make more activity stops than otherwise, resulting in lengthened travel times.

$H_{1.2}$: A workplace in a housing-rich area, measured by the amount, density, and variety in housing types around the workplace, is associated with shorter commute times. Most commuting trips take place between home and work. If a workplace is located in a housing-rich area, employees of the workplace have the opportunity to reduce commute times because they do not necessarily have to look for appropriate places of residence farther from their workplaces.

$H_{1.3}$: A workplace in close proximity to freeways (limited-access highways) is associated with shorter travel times, but a workplace in close proximity to bus transit is associated with longer travel times. It is obvious that highway facilities improve individual mobility, that is, the ability to move between different points. Thus, the accessibility of a workplace to freeways should shorten the times traveled by the employees. Although the relationship is less clear, the employees at a workplace with high transit accessibility may travel longer in times than otherwise because public transit is related to more transportation choices, rather than to better speed. Further, transit routes tend to serve busy activity corridors to secure some level of effective operation.

Hypotheses Related to Travel Mode

$H_{2.1}$: A workplace in a job-rich area, measured by the amount, density, and diversity of jobs around the workplace, is associated with less automobile commuting. While a workplace is a place of work to the employees, the workplace is also possibly the place of non-work activities (e.g., shopping, personal businesses) to others. If various activities were closer to each other, there would be more potential for using non-automobile modes (e.g., public transit, walking/bicycling) because activity mix requires less individual mobility by allowing people to accomplish multiple purposes with minimal stops. Traffic congestion that is often found on thoroughfares around activity concentrations may provide incentive for workers to turn to non-automobile modes. Public transit systems are likely to be more easily found in the major economic concentrations.

$H_{2.2}$: A workplace in a housing-rich area, measured by the amount, density, and variety in housing types around the workplace, is associated with less automobile commuting. If a workplace were in sufficiently close proximity to residences, there would be an incentive for the workers to use alternative modes to the automobile, such as public transit and walking/bicycling.

$H_{2.3}$: A workplace in close proximity to freeways (limited-access highways) is associated with more automobile commuting, but a workplace in close proximity to bus transit is associated with less automobile commuting. Overwhelming automobile dependence in suburban employment locations is related to ubiquitous highway systems but few alternative choices but to automobiles. If a certain level of service quality is maintained, public transit might become a viable option and thus lower the automobile dependence.

Hypotheses Related to Trip Chaining

$H_{3.1}$: A workplace in a job-rich area, measured by the amount, density, and diversity of jobs around the workplace, is associated with more trip chaining. A workplace rich in various urban activities, particularly retailing, may encourage workers to make more stops along the way on commuting trips because of the variety of activity opportunities and the vitality of street activities. It is important to note that certain activities such as manufacturing and warehousing rather discourage activity stops due to their negative features and less customer orientation.

$H_{3.2}$: A workplace in a housing-rich area, measured by the amount, density, and diversity of housing around the workplace, is associated with less trip chaining. Trip chaining is related to sequencing activities that compensate for less disposable time. If a workplace is located in a housing-rich area, and thus the employees shorten commute times and distances, activity stops made by the employees will be fewer because they are less exposed to activity opportunities during commuting trips.

$H_{3.3}$: A workplace in close proximity to both freeways (limited-access highways) and bus transit is associated with more trip chaining. The relationship of transportation provisions to trip chaining is less clear, but the improved mobility and more travel choices by transportation provisions area are likely to increase trip chains because they make activity sites more accessible. For example, highways shorten travel times between activity sites and thus increase the frequency of activity stops made during trips.

Table 2.1 summarizes the hypothetical relationships between workplace environs and commuting choices made by individual employees. It should be noted that, although the relationships below are highly simplified, detailed characteristics of workplace environs are likely to affect travel choices differently. The detailed specification of modeling each aspect of travel will be described in the analysis chapter.

Table 2.1 Hypothesized relationships

	Commute choices made by an employee		
Workplace environs	Time traveled	Automobile use	Trip chaining
Job (activity) opportunities	+	-	+
Housing opportunities	-	-	-
Transit accessibility	+	-	+
Highway accessibility	-	+	+

+ positive relationship; - negative relationship

CHAPTER III
LITERATURE REVIEW

This chapter reviews previous research on the spatial characteristics of workplaces, suburban workplaces, and their effects on travel pattern. The first part contains a review of theoretical explanations and empirical findings about the evolving metropolitan structure with respect to employment distribution. The second part reviews literature on the link between urban form and travel, emphasizing spatial characteristics of suburban workplaces. The third and final part evaluates methods and findings of previous research and draws lessons for this study.

Patterns of Employment Decentralization

With the massive suburbanization of population, especially after World War II, there has been a growing decentralization of commercial and industrial activities. The early stage of decentralization was led mainly by retail activities (Berry and Cohen 1973). Retailing moved out to the suburbs, home to middle- and upper-income customers. Retailers also found relatively cheaper land with good highway access for stores and parking. Strip centers stretched out along major arterial roads. More recently, regional super centers and power centers, typically anchored by three or more department stores or specialized chains, have developed in peripheral locations. These new types of large-scale retail centers tend to take advantage of highways and automobiles (Handy 1993a).

Manufacturing and distribution industries also moved to new industrial and business parks. In the pre-automobile era, industrial development was typically centered in the vicinity of railroads and waterfronts. However, crowded yards and streets in older inner city areas have increasingly hampered efficient operations. In suburban areas firms found larger but cheaper sites for plants and warehouses. The increasing reliance on highway trucking has contributed to the outward migration of industries (Fishman 1987).

While the concentration of high-rise office establishments in the central business district (CBD) defines the regional economic center in many metropolitan regions, there also has been a considerable decentralization of service and high-tech employment over the last three decades (Leinberger 1988; Cervero 1989a; Garreau 1991; Pivo 1990; Lang 2000). Technological advances have decreased the need for central city locations for businesses (Gordon and Richardson 1997). In the suburban areas, firms find attractive sites with park-like settings, spacious parking lots, quality neighboring residences, and good access to skilled workers (Gottlieb 1995). Many businesses now establish their new offices in suburban centers and business parks (Cohen 2000).

Fishman (1987) identifies three stages of the recent decentralization of high-tech industries and office businesses. The first is the establishment of "high tech" growth corridors, such as Silicon Valley, California and Route 128 outside Boston. The second phase concerns the decentralization of office bureaucracies, especially so-called back offices, from central city high-rises to suburban office parks. And, the final phase is the decentralization of production-service employment, such as accountants, lawyers, and skilled technicians. Now, the regional CBD is no longer a singular center maintaining the highest ranked businesses in many metropolitan areas.

Numerous scholars have developed models to explain urban structure. Among others, the "trade-off" model of urban land use, first developed by von Thünen for early nineteenth century agricultural land uses and modernized by urban economists during the twentieth century (Alonso 1964; Mills 1980), formulates an optimal land use pattern by evaluating a trade-off between transportation costs and land rents. Transportation plays a pivotal role in determining the location of an activity because an area's relative location is determined mainly by transportation systems. Although the urban location models have been developed mainly to explain residential location, they can also be applied to employment location.

In a simple term, employment decentralization is explained by a trade-off between transportation and economies of agglomeration (Shukla and Waddell 1991). Suppose that there is a city center in which production and distribution activities are concentrated.

Because the center is at a focal point of regional transportation networks, overall costs of commuting, goods transport, or face-to-face contact increase with distance from the center. Close proximity to other firms and services gives firms in the center the advantage of scale. Thus, firms tend to concentrate in the center.

Suppose further that transportation investments are made at the peripheral areas while distribution activities rely more on highway trucking. Transport costs of goods decline at the peripheral areas. Firms locate closer to workers to minimize commuting costs since the costs affect workers' effective wage rates. Decentralization would continue until firms reach the equilibrium between transportation cost savings and other advantages, such as economies of agglomeration at the center. Transportation investments at peripheral areas would have a decentralization effect by improving the relative locational advantage of the areas (Deakin 1991; Giuliano 1995).

While the prior part mainly explains employment decentralization by suburban "pull" factors, such as improved accessibility by highway improvements, there are also "push" factors in older centers. As a city center grows and ages, various negative externalities--congestion, insufficient parking, crime, and high rents--undermine economies of agglomeration (Gordon, Kumar, and Richardson. 1989). In suburban areas, firms may find better places with lower land values, better parking, and closer proximity to preferred housing.

Economic restructuring is an important factor in explaining recent metropolitan spatial restructuring. Communication and information processing technology is considered a fundamental force in restructuring production and distribution processes (Scott 1988; Castells 1989). New technology tends to weaken the advantage of agglomeration at older city centers. The transition to services and high-tech industries makes firms more mobile and more dependent on quality workers and environmental amenities (Gottlieb 1995).

Employment decentralization is related to widespread automobile availability, ubiquitous transportation systems, and the changing logic of production. It presumably gives rise to better access for suburban workers. Yet, the effect would be differential among social groups. As articulated by the "spatial mismatch" hypothesis (Kain 1992; Ihlanfeldt and Sjoquist 1998), the decentralization of jobs may negatively affect economic opportunities for low-income minorities that reside predominantly in the inner city and places opposite of growth axes. On the other hand, some negative features of urban growth--traffic congestion and environmental deterioration--may lead suburbanites to the anti-growth movement.

Polycentrism

Employment decentralization tends to take a polycentric form as firms cluster in a number of subcenters. Suburban employment centers are often characterized by concentrations of low- to mid-rise commercial buildings with extensive parking lots centered on a large shopping mall near highway intersections. Suburban centers have received much attention by scholars because of their increasing importance in metropolitan plans in terms of economic activities and traffic flows (Baerwald 1982; Leinberger 1988; Cervero 1989a; Hartshorn and Muller 1989; Giuliano and Small 1991; Garreau 1991; Pivo 1993; Fujii and Hartshorn 1995; Cervero and Wu 1997; Giuliano and Small 1999).

Suburban centers imply that agglomeration economies, in which firms benefit by locating close to each other, still play an important role in new locational and industrial settings. Business efficiency may be accomplished by a closer proximity to other firms in the same industry or by inter-industry linkages (Giuliano and Small 1999). For example, firms may economize the production process by disintegrating the process through external transactions among separate firms. New modes of production and industrial organization produce new types of spatial organization (Scott 1988; Castells 1989).

Suburban centers may also be explained by competition over locations with closer proximity to major regional transportation systems, especially to highway interchanges, which grant them better access to suburban workers, markets, and other firms (Deakin 1991; Shukla and Waddell 1991; Giuliano and Small 1999). The competition among firms for particular locations, in which production costs are low, may produce a number of business concentrations.

Size and function are different among suburban centers. Central place theory, first proposed by Walter Christaller in 1935, provides an explanation for a hierarchical organization of service and retail centers. In this model, the size, location, and function of centers are determined by market threshold and the consumer's willingness to travel. High-order goods and services, such as specialized services, are purchased less often and involve a higher cost of travel. Such services are offered in a few larger centers. Conversely, low-order goods and services, such as items offered by convenience stores, are purchased more often and regularly. Such activities are frequently found in community or neighborhood centers that are in close proximity to consumers. The earlier study by Berry (1967) applied central place theory to identifying specialization of market centers and a hierarchical pattern of retail distribution.

Related to the notion of central place theory, Giuliano and Small (1991) found that density and frequency of centers declined with distance from the downtown area in the Los Angeles region. Many of the centers were specialized by industry. Pivo (1993) found that the frequency of an office cluster type roughly decreased as size and density increased in the Toronto region. Each type of office cluster tended to be associated with a certain type of employment mix. McDonald and Prather (1994) found that in the Chicago urbanized area the density of suburban employment centers was influenced by distance to the CBD and three major employment centers (O'Hare Airport, Schaumburg, and central DuPage County). Cervero and Wu (1997) identified three tiers of hierarchical employment centers encircling downtown San Francisco in the Bay Area.

Historical background plays an important role in determining employment center type because of its tendency to provide both opportunities and constraints for development of a place. Technological level (e.g., transportation technology) and socioeconomic condition (e.g. income) in a certain period of time affect the way economic activities are spatially organized. Hartshorn and Muller (1989) use a generic longitudinal stage model of suburban economic-spatial development for the typology of suburban employment locations. They identify four stages of suburban development: "bedroom community (pre-1960)," "independence (1960-1970)" swept by decentralization of shopping malls and industrial and office parks, "catalytic growth (1970-1980)" leading to more mature suburban economic landscapes by surpassing the central city in total employment, and "high-rise/high-technology (1980-1990)" by which suburban downtowns surpass the CBD in office activity and expand high-technology corridors.

Leinberger (1988) uses historical background and physical characteristics of office spaces for the typology of what he calls "urban village cores". Three possible historical scenarios are identified: the "original downtown" of a metropolitan region, "suburban towns" that served local needs before decentralization swept them into the regional economy, and "new urban cores" that were developed from scratch and are generally car-oriented and campus-like. Similarly, Garreau (1991) identifies three types of "edge cities": pre-automobile "uptowns," "boomers" that are typically located at freeway intersections and centered on a large shopping mall, and "greenfields" that are developed often on master plans by private developers. The "boomers" are further classified into "strip," "node," and a "pig in the python" which is in between the two. Transportation plays a pivotal role in shaping edge cities.

Many studies have identified various types of employment centers by using physical and economic factors to foresee implications for metropolitan development and transportation. Baerwald (1982) identifies two general physical forms of suburban "downtowns" in Minneapolis: "clusters" which usually focus on a regional shopping center, and "corridors" which string out along axial freeways. He also identifies four general factors affecting cluster and corridor development: locational tendencies of different land uses, transportation systems in and around the concentration, historical factors and the timing of development, and other factors (e.g., social-demographic patterns, local government policies, and entrepreneurial prerogative).

Scholars have increasingly employed multivariate analyses to inductively identify types of employment centers. Using cluster analysis, Giuliano and Small (1991) identified five types of subcenters in the Los Angeles region: specialized manufacturing, mixed industrial, mixed service, specialized entertainment, and specialized service. As indicated by the names, the classification largely relied on the type of business activities and some spatial factors (e.g., distance from the CBD and employment density).

As traffic congestion grows on major thoroughfares around suburban centers, scholars have examined the location and land use characteristics of different types of suburban employment centers in order to relate them to transportation problems such as automobile dependence and traffic congestion. Using factor analysis and cluster analysis for America's 50 largest suburban employment centers, Cervero (1989a) identified six types of centers: office parks, office and concentrations centers, large-scale mixed-use developments, moderate scale mixed-use developments, sub-cities, and large-scale office growth corridors. The classification was largely based on detailed physical factors such as density, land use mix, floor area ratio, lot size, and many other factors. Pivo (1993) also used the urban form factors of size, density, distance from the CBD, and distance from highway, interchange, and subway station to determine the taxonomy of office clusters in the Toronto region. Using cluster analysis, he identified six office cluster types: common, interchange, outlying, secondary transit, primary transit, and major auto.

Meanwhile, many metropolitan regions like the greater Toronto and the central Puget Sound region utilized employment center strategies to better manage urban growth and transportation problems because urban centers are focal points in shaping urban growth. For example, the "Vision 2020," a long-range growth management plan for the central Puget Sound region (including Seattle as a major city), adopted an urban center strategy to encourage urban growth in compact, well-defined urban centers within the urban growth area (UGA). Urban centers were identified by density (employees, households), size, and transit service. Different strategies were employed for different types of centers: urban centers (further broken down into regional, metropolitan, and urban), town centers, and manufacturing-industrial centers. Strategic focus was mainly on better accessibility between jobs and housing and development of public transit systems.

An implication from the previous studies is the necessity of more comprehensive approaches to characterizing suburban employment centers. Studies need to take into account both physical and industrial dimensions of employment centers. In employing physical characteristics, studies also need to capture the urban context in a more comprehensive manner on both regional and local scale rather than relying on a limited number of simple local indicators, such as employment density.

Another implication concerns the potential transportation consequences of suburban centers. Suburban centers could become large enough to sustain a basis of public transportation such as light rail (Levine 1998). However, if they fall below a particular employment density or if land use patterns are highly automobile-oriented, the alternative transportation mode will make little economic sense. As suburban centers become large, they might also suffer from traffic congestion like their central-city counterparts.

Workplace Sprawl

While employment decentralization takes a polycentric form, scatteration is another important feature. Scatteration includes a large share of low-density small-sized individual employment locations spread throughout the suburban and exurban areas. Fishman (1987) proposes a neologism, "technoburb," to describe the new kind of urban sprawl. He describes it as "a hopeless jumble of housing, industry, commerce, and even agricultural uses." An important factor in explaining the new kind of urban sprawl is technology. Highway systems are now ubiquitous across metropolitan regions and beyond. The general reduction in transportation costs allows firms to locate farther from workers and customers without losing the market. In certain industries, the face-to-face contacts in business affairs are replaced with communication and information processing technologies.

In a comparative study of six metropolitan regions in Northern America, Pivo (1990) found that suburban office development patterns became more complex as the majority of office space was located outside the regional CBD with some scattered away from freeways. He suggested that the intrasuburban form of office development is better described as "a mélange of scatteration, clusters, and corridors." Giuliano and Small (1991) found that two-thirds of employment was outside any of 32 subcenters in the Los Angeles region in 1980. Gordon and Richardson (1996) found that the number of subcenters declined and that the proportion of regional jobs in subcenters was small and fell in the Los Angeles metropolitan region between the years 1970 and 1990. They suggested that the Los Angeles region could be more accurately described as a "dispersed" rather than as a "polycentric" metropolis. Most recently, Lang (2000) analyzed the location of office space in America's 13 largest metropolitan regions. He found that, while 38 percent of all office space in 1999 was located in a metropolitan region's traditional downtown, nearly the same amount, 37 percent, was found in highly dispersed, "edgeless" locations lacking well-defined boundaries and extending over vast areas of urban space.

Low-density scattered development patterns, particularly leapfrog patterns farther from both residences and major activity centers, give rise to the possibility of longer trip distance and more multidirectional and overlapping traffic flows. But, a major problem is the nature of total automobile dependence. Non-automobile modes such as public transit and walking are not a feasible option for commuters in such low-density dispersed land use patterns.

Link between Urban Form and Travel

There is an increasing interest in using location and land use policies to relieve urban transportation problems. Growing public concern about transportation condition and environmental quality has driven some to look at negative consequences of low-density dispersed urban settlements, notably urban sprawl. Many local and regional public agencies now adopt various proactive programs to manage community growth. Such programs include transit-oriented development, traditional town planning, jobs-housing balancing, and urban growth boundaries. Federal policies have also stimulated policymakers to employ land use strategies as a means of reducing automobile dependence and air pollution. The Intermodal Surface Transportation Efficiency Act (ISTEA), succeeded by the Transportation Equity Act for the Twenty-First Century (TEA-21), has made federal transportation funding more flexible for investments in alternative transportation systems to highways. Air quality requirements of the Clean Air Act (CAA) and the link to federal transportation funding are another important factor.

There has been lively debate over the influence of urban form on travel pattern over the last decade. This section reviews the large body of research, emphasizing the effects of suburban employment on commuting.

Metropolitan Structure and Commuting

On the metropolitan level, much research focuses on the impact of polycentric or dispersed urban structure, with respect to employment, on commuting. A comparative study on gasoline consumption by Newman and Kenworthy (1989) is perhaps one of the most controversial studies in triggering the debate over metropolitan structure because its conclusions require a radical transition of the way America's metropolitan regions have developed. Using data on land use and travel in the 32 large cities of developed world, Newman and Kenworthy found that average gasoline consumption per capita in U.S. cities was nearly twice as high as in Australian cities, four times higher than in European cities, and ten times higher than in Asian cities. The authors argued that the differences were primarily due to land use and transportation planning factors, rather than because of differences in income, gasoline price, or vehicle efficiency.

Another controversial study is the "jobs-housing balance" by Cervero (1989b; 1996a). Cervero (1989b) argued that continuing the lengthening of commuter trips and deterioration of traffic conditions were partly due to a widening imbalance between jobs and residences. In over 40 major suburban employment centers in the U.S., he found that suburban workplaces with severe jobs-housing imbalances tended to have low shares of workers walking and cycling to work and high levels of congestion on connecting freeways. In a gravity-based "push-pull" model, he also found that housing availability and prices in the vicinity of suburban job centers pushed workers toward longer commutes.

While the study by Newman and Kenworthy prescribes a radical reurbanization strategy that increases urban densities and transportation priorities to promote non-automobile modes, the "jobs-housing balance" by Cervero takes the nature of intermediary in policy recommendation by focusing on bettering the given suburban development in terms of transportation (Levine 1998). Yet, both studies require an active role of urban spatial policies to relieve the urban transportation problems of excess travel and automobile dependence.

The land use strategy to combat transportation problems raised a heated counterargument by the scholars that emphasize market forces as dominant factors while pessimistic about the effectiveness of physical planning. Critics argued that the market equilibrium process facilitates the "co-location" of firms and households in suburbs and thus reduce commute times (Gordon, Kumar, and Richardson 1989; Giuliano 1991; Gordon, Richardson, and Jun 1991; Levinson and Kumar 1994). According to this notion, market forces produce an efficient urban form, as the labor force attracts firms to the suburbs and as firms move to the labor force. Historical trends of urban development also appear to support the co-location hypothesis as the suburbanization of the labor force has been followed by the decentralization of businesses (Giuliano 1991).

Empirical studies provide evidence for the notion of co-location. Using the U.S. Geological Survey's LANDSAT data for 82 metropolitan regions, Gordon, Kumar, and Richardson (1989) found that polycentric and dispersed urban structure was associated with shorter commuting times. Low residential density and high industrial densities shortened commuting times, while high commercial densities lengthened commuting times. Using the 1985 American Housing Survey (AHS) for the 20 largest U.S. metropolitan regions, Gordon, Richardson, and Jun (1991) further confirmed that auto commute times either fell or remained stable. Levinson and Kumar (1994) also found that auto commute times remained stable despite the increasing trip distances and congestion in the Washington metropolitan region between 1968 and 1988.

In his subsequent jobs-housing balance study, Cervero (1996a) found that jobs-housing imbalance generally declined as many suburban bedroom communities attracted businesses. In a study of employment centers in the San Francisco Bay area in 1990, Cervero and Wu (1997) found that commutes made by employees of suburban centers were shorter in time than commutes made by employees in larger and denser urban centers. They also found that low-density, outlying centers had high shares of drive-alone commuting and low shares of public transit and walk/bicycle uses. As articulated by the "jobs-housing balance," high housing prices in and around centers were found to increase cross commuting, except for high-status professional workers in fast-growing, outlying centers. The authors suggested that polycentric development was related to "differentials" in urban and suburban commute patterns. This study implies that, although job-housing imbalance generally decline in the suburbs due to job decentralization, the effect may be uneven among social groups and subsections in a metropolitan region.

The individual case studies lend support to the co-location hypothesis, but larger national travel studies present slightly different pictures in overall commute patterns. As suggested by the co-location, the commute times appear to be stabilized by showing modest increases. According to the 1990 census data, the national average travel times increased from 21.7 minutes in 1980 to 22.4 minutes in 1990 (Pisarski 1996). The 1995 NPTS also shows that commute times increased from 18.2 minutes in 1983 to 20.7 minutes in 1995 (Hu and Young 1999).

Commute distance and automobile dependence appear to increase more than commute travel time. For example, the 1995 NPTS shows that average vehicle trip length to or from work increased from 8.6 miles to 11.8 miles between 1983 and 1995. The annual work-purpose VMT per household increased from 3,538 miles to 6,492 miles. The VMT for all purposes almost doubled from 11,739 miles to 20,895 miles due to massive increases in non-work trips over the same period. Nationally, the share of single-occupant vehicles increased from 64.4% in 1980 to 73.2% in 1990, while the share of carpooling declined from 19.7% to 13.4% (Pisarski 1996).

The previous commuting studies indicate that, though commute times have increased or decreased slightly depending on a particular case, commute distances and automobile uses have generally risen. Job decentralization in itself appears to shorten travel times, as low-density suburban locations make trip speeds increased, and people rely more on automobiles. With regard to gasoline consumption and air quality issues, the question whether travel times are shorter or longer might not be a main issue. Rather, the main issue of suburban jobs is overwhelming automobile dependence and longer trip distance.

The question of whether the decentralized urban form results in shorter commuting is also addressed by the studies of "wasteful" or "excess" commuting. According to the standard urban economic models, household location choice is expressed as a utility-maximizing problem, depending on land rent, commuting costs, and the costs of other goods and services (Alonso 1964; Mills 1980). An assumption is that workers prefer less commuting, all else being equal. Thus, job decentralization gives the opportunity to shorten commute because firms move into the suburbs where the majority of workers live. Using data from America's 14 cities, Hamilton (1982) examined the ability of the monocentric models to predict the mean commute distance. A required (or optimal) average commute distance was calculated by the locations of houses and jobs that resulted from the optimization rule of the standard monocentric models. He found that the actual mean commute distance was about eight times greater than the optimal commute distance predicted by the monocentric urban model in the 14 cities. Although there has been a heated debate over the portion of "wasteful" commuting (i.e., the difference between "optimized" and "actual" commuting), it appears that most studies agree to the presence of a large share of excess commuting (White 1988; Hamilton 1989; Suh 1990; Dubin 1991; Small and Song 1992; Giuliano and Small 1993).

The "wasteful" commuting studies indicate that there are many factors affecting residential choices and thus commuting. A possible question is which factors are important in shaping such a long journey to work.

Scholars point out fundamental causes of more traffic such as more workers, greater household income, low gasoline prices, and more automobile availability (Gomez-Ibanez 1991; Downs 1992). For example, higher incomes not only make automobiles more affordable to households but also make living farther from existing cities for more housing consumption possible. Along with the development of transportation and information technologies, firms move to urban peripheries in which space for offices and plants are more available. Decentralized jobs give rise to the possibility of further sprawl as they provide the opportunity for affluent suburbanites to move to exurbs without sacrificing a significant amount of travel time and cost.

Cervero (1989a; 1989b) suggests a location strategy putting jobs and housing close to each other by eliminating suburban exclusionary policies (e.g., large-lot zoning, growth controls) and by facilitating more compact land use patterns. Yet, Giuliano (1991) points out the overwhelming importance of economic and demographic factors that separate where people live and work, including neighborhood quality, school, racial and ethnic mix, relatively low travel costs, growing multiple-worker households, growing non-work trips, and so on.

Using a travel survey of workers at a major health care provider in Southern California, Wachs, et. al. (1993) found little evidence of an increasing imbalance between jobs and housing. According to the study, the increasing commute times were not due to increasing commute distances but to the increasing volume of traffic. The authors suggested that residential location choices of employees were based upon various factors including quality of neighborhood, schools, and perceived safety.

Using the method of "wasteful" commuting, Giuliano and Small (1993) examined jobs-housing balance by computing the excess commute at the given spatial patterns of housing units and job sites in the Los Angeles region in 1980. The authors found that actual commute times and distances were far in excess of what could be explained by jobs-housing imbalances. They suggested that policies that promote jobs-housing balance would have only small effects on commuting.

It should be acknowledged that economic and demographic factors play an important role in shaping travel patterns. Yet, the importance of transportation as a criterion for residential location choice may be different among different groups of people. This is particularly true when considering that not everybody enjoys free individual and residential mobility. Some people might not drive car because of economic incapability, physical handicap, or various reasons. Some low-income people may have difficulty in finding affordable housing nearby work. Some female workers may prefer the residence close to work because of difficulty with exclusive use of an automobile in their household and the responsibility of housekeeping. In a study of residential choice in Minneapolis, Levine (1998) found that commute time was an important determinant of residential location. He suggested that provision of affordable housing in the vicinity of employment concentrations could influence location decision for low-to-moderate income, single-worker households. He also suggested that a merit of job-housing balance is in "enhancing the range of households' choices about residence and transportation."

With regard to the effectiveness of location and land use policies for reducing transportation problems, economists tend to prefer non-spatial policy tools, such as road pricing and tax. Gordon and Richardson (1989) argue that, even if urban structure and public transit were key factors in reducing automobile dependence and gasoline consumption, a fuel tax would be "much simpler, faster, more effective, and cheaper" than rearranging metropolitan structure and building new rail systems.

Pricing policies look simpler and more effective in implementation than land use policies. However, enacting a pricing policy large enough to affect fewer and shorter automobile trips is in question because it may be politically unpopular. Pricing policies do not directly address the issue of widening the range of transportation choices. Further, road pricing involves equity issues as well as efficiency issues (Downs 1992). Newman and Kenworthy (1992) argue that American public policy tends to give income and price factors an overwhelming priority so as to override any role for physical planning, but no actual policy change toward better pricing of gasoline, road user charges, and subsidized sprawl occurs.

Some scholars suggest technological solutions rather than land use solutions to address transportation and air quality issues. Bae (1993) suggests that the automobile emission problem would be much more amenable to technological solutions than to transportation and land use measures. In her study of the 1991 Air Quality Management Plan in the Los Angeles Basin, the author found that the transportation and land use measures (e.g., alternative work schedule, mode shift, and growth management) aimed at reducing VMT had only a marginal impact on reducing automobile emission (e.g., reactive organic gases, nitrogen oxides, carbon monoxide, sulfur oxide, and particulate matter with a diameter of ten micrometers or less).

It appears that there is a difference in the language of "travel" that scholars are talking about in the debate. For example, critics of location approaches to urban transportation problems rely largely on the changes in travel times for their arguments, particularly travel times by automobiles; however supporters tend to emphasize physical trip distances (e.g., VMT) and non-automobile choices. These are difficult questions related to the level of acquiescence to automobile dependence. How do we assess job decentralization if it is related to shorter travel times but longer trip distances with greater automobile dependence? It may depend on the priority given to the type of travel costs (e.g., individual versus social) and policy purposes (e.g., mobility versus accessibility, and efficiency versus environmental sustainability). Commute time captures the influence of both individual mobility (e.g., automobile availability) and transportation services (e.g., highways). But, shorter travel times do not necessarily reflect social costs of urban infrastructure, air pollution, and public safety. Conversely, travel distance does not reflect different levels of transportation services and individual mobility. It is suggested that the indicator of VMT tends to be closely related to the air quality issue (Dunphy and Fisher 1996). But, there is also an argument that the reduction of VMT has only a modest influence on the reduction of air pollution (Bae 1993). An important point is that studies need to take into account a trade-off among different indicators of travel in their studies and their policy recommendations.

Local Land Use and Travel

There is a large body of research that focuses on the travel effects of physical characteristics of a subsection of metropolitan regions, such as neighborhoods and suburban employment centers. Research findings drawn from the studies of small-scale areal units can provide practical policy prescriptions for new suburban development or infill development.

Studies employ various indicators to characterize spatial features of local communities--density, activity mix, street design, and accessibility (Handy 1993b; Ewing, Haliyur, and Page 1994; Frank and Pivo 1994; Holtzclaw 1994; Cervero and Gorham 1995; Handy 1996b; Cervero 1996b; Cervero and Kockelman 1997; Boarnet and Sarmiento 1998; Crane and Crepeau 1998). Among others, density is probably the most frequently used measure to characterize land use features. Many studies report that density (e.g., higher residential density) affects travel behavior (e.g., shorter and fewer automobile trips). For example, Holtzclaw (1994) examined the effects of neighborhood characteristics on VMT and transportation costs per household for 28 communities in California. In his analysis, neighborhood characteristics were defined by residential density, transit accessibility, neighborhood shopping accessibility, and pedestrian accessibility. The analysis also included mean household income and household size as control variables. He found that residential density was a major variable in explaining the VMT and transportation costs. Density and transit accessibility together were found to lend the best statistical correlations. Household income, which had been considered an important variable in travel behavior, was not statistically significant in his study.

An issue concerning density is its relationship to economic and demographic characteristics. It has been argued that density is a surrogate for economic and demographic characteristics as low-income or small-sized households are likely to live in high-density communities (Dunphy and Fisher 1996; Levinson and Kumar 1997).

Using the 1990 Federal Highway Administration (FHWA) Highway Statistics and 1990 NPTS, Dunphy and Fisher (1996) found some negative relationships between residential density and travel patterns. But, they also found positive relationships between travel and demographic characteristics, such as household size and income. The authors suggested that economic-demographic characteristics were more important determinants of travel, as residents of higher-density communities were more likely to be those with lower travel needs. Similarly, Levinson and Kumar (1997) suggested that, at the interurban level, density served as a surrogate for city size, as markets reacted to raise density to compensate for high interaction costs in large metropolitan regions. According to these arguments, the independent effect of density could be more modest than usually found in studies. Therefore, studies need to analyze various spatial and non-spatial factors simultaneously to identify the independent effect of land use.

There are also the issues of threshold and offsetting effects in travel. Dunphy and Fisher (1996) found that higher densities began to have a significant effect on driving only beyond a certain level, indicating the presence of threshold in travel behavior change. Levinson and Kumar (1997) presented a threshold density in which speed and distance had offsetting effects on time, as higher density was associated with lower speed and shorter distance. These findings indicate that one needs to consider non-linearity in the relationship between land use and travel. Also, the effects of land use may be different due to the type of travel measured.

Along with density, land use mix has been considered an important dimension of land use because it represents the diversity of choices provided by a community. For example, using the Puget Sound Transportation Panel data, Frank and Pivo (1994) examined the impacts of mixed use, population density, and employment density on mode choice for work trips and shopping trips. Percentages of SOV, transit, and walking for each census tract were calculated while controlling economic and demographic factors. Density and activity mix were found to affect mode choice, yet some relationships were nonlinear, indicating the presence of thresholds. As density and land-use mix increased, transit usage and walking increased, whereas single-occupant vehicle usage declined.

Mixed land use development has potential for reducing traffic congestion and travel time as different types of activity have a tendency to make trips spread throughout the day and week (Cervero 1989a). Close proximity to various activities (e.g., restaurants, shopping, and banks) may facilitate non-automobile midday trips (Cambridge Systematics, Inc. 1994). A greater range of activity choices lends the quality of an area, but it may also gives rise to more trips, as people take advantage of the variety of choices (Crane 1996; Handy 1996b).

Compared to the measures of density and activity mix, detailed design characteristics, such as streetscape and building design, have been employed relatively less by studies because such measures typically require a large amount of detailed data. Such design features tend to have various qualitative facets, and are thus difficult to operationalize. While the importance in explaining travel behavior is a matter of empirical investigation, the street and building designs presumably affect travel behavior, particularly walking and cycling on a local scale, by providing perceived safety and an attractive environment (Parsons Brinkerhoff Quade and Douglas Inc. 1993; Cambridge Systematics, Inc. 1994; Handy 1996b; Cervero and Kockelman 1997).

The study by Cambridge Systematics, Inc. (1994) presents a comprehensive characterization of land use and design characteristics of employment sites. Using data for 330 employment sites in Los Angeles County, the analysis characterized surrounding land use and design features of each work site at three distinct levels: general environs ranging from one-half square mile to two square miles from each work site, the area within one-quarter mile of the workplace, and the work site itself. The variables covered an extensive range of detailed design features, including presence of graffiti, trees and shrubs in the sidewalk zone, width of sidewalks, and building setback. Using principal components analysis, 24 variables were grouped into 5 composite variables: land use mix, availability of convenience services, accessibility of services, perceived safety, and aesthetics. The idea was that, rather than an individual characteristic, the general quality or ambiance of a work site would be more important in influencing mode choice. The study also included measures of transportation demand management (TDM) incentives to examine a joint effect in influencing commute mode choices. Overall, the effectiveness of programs of TDM measures increased at those locations where supportive land use and design characteristics existed.

A majority of studies of the link between urban form and travel are based on spatial characteristics of neighborhoods. However, scholars increasingly take an interest in the effects of employment centers. Large employment concentrations have potential for operating public transit services by increasing workers with common destinations. They may increase carpooling and thereby reduce single-occupant auto trips. Close proximity to various activities (e.g., restaurants, shopping, banks) may facilitate non-automobile trips (Cambridge Systematics, Inc. 1994).

However, the suburban reality is not so easy. Public transit systems in many metropolitan regions focus primarily on radial services to and from the regional CBD and poorly serve suburban centers and residences (Fujii and Hartshorn 1995). Thus, a "transit-oriented center" could suffer from its poor connectivity to other suburban centers and residences. As employment centers become denser and larger, they could lengthen commute time and distance due to increasing congestion. Although workers of suburban centers tend to have shorter commute times than the older CBD, workers of low-density centers are highly dependent on automobiles for commuting (Pivo 1993; Cervero and Wu 1997). Further, in order for a suburban center to be successful, job clustering needs to be accompanied by other policies such as regional cooperation, ridesharing programs, high occupancy vehicle (HOV) lanes, and employer-based TDM incentives (Downs 1992).

Cervero (1989a) presents a comprehensive analysis of the influence of land use and design characteristics of suburban centers on the travel choice of workers in over 50 of America's largest suburban employment centers. Land use was characterized by numerous measures, including size, density, composition, site design, jobs-housing balance, land ownership, and parking provisions. Overall, he found that development characteristics of suburban centers affected the mode choice of workers and traffic conditions. For example, high employment densities were associated with low traffic speed, low drive-alone commutes, and low levels of parking supply. Land use mix had the greatest influence on commute mode choices such as ridesharing, walking, and bicycling. Size of centers influenced traffic conditions and mode choice. The balance between jobs and housing was associated with higher shares of walking and bicycling and less congestion.

Filion (2001) examined land use patterns and their impacts on activity patterns of workers in three suburban mixed-use centers in the greater Toronto area. The author found that the centers were not too distinct from typical low-density dispersed suburban centers although they achieved some level of high-intensity, mixed-use development, midday activities, and transit uses. He suggested that a finer grained mixing of land uses within centers (e.g., pedestrian-oriented design features) would relieve the heavy reliance on automobiles for journeys within centers. Also, the creation of corridors concentrating medium- to high-density residential areas along major transit routes was suggested for transit uses, leading to less automobile use.

One of hottest issues in planning and transportation in recent years is perhaps new urbanism, including a group of new urban design approaches, such as transit-oriented development (TOD) and traditional neighborhood design (TND). These new design approaches purport to reduce motorized trips and air pollution by enhancing physical accessibility. Many studies have explored the effectiveness of these new proposals and their important spatial features by examining alternative neighborhood types.

Ewing, Haliyur, and Page (1994) compared household travel patterns for six communities in Palm Beach County, Florida. Location and land use were determined using residential density, employment density, jobs-housing ratio, percentage of multifamily dwellings, residential accessibility for work trips, destination accessibility for nonhome-based trips. The authors found that, although households in a sprawling suburb generated more vehicle hours of travel per person than comparable households in a traditional city, the difference was small when considering the greater difference in accessibility. Importantly, sprawl dwellers were found to compensate for poor accessibility by linking trips of household members. They suggested that concentrating various activities in activity centers would facilitate efficient automobile trips.

Handy (1996b) presents a detailed characterization of urban form in a comparative analysis of alternative neighborhoods. Based on a quasi-experimental scheme, two "traditional" and two "modern" neighborhoods were selected in the San Francisco Bay area. Urban form was evaluated in terms of accessibility. Both quantitative and qualitative measures of accessibility were applied to characterizing street networks (e.g., intersections, cul-de-sacs), proximity and diversity of activity sites (e.g., groceries, shops, restaurants, banks) in each neighborhood, the accessibility to regional centers (e.g, supermarkets), and detailed design features (e.g., sidewalks, setbacks, housing design). Among others, the author found that higher accessibility in terms of trip distances and variety in potential destinations was associated with longer trip distances and higher trip frequencies, indicating that the accessibility-enhancing policies to reduce total travel would be partially offset by more trips. Contrary to general belief among urban designers, residential design features such as front porches and building materials were less important factors in a person's decision to walk.

Using the 1990 San Francisco Bay Area Travel Survey (BATS) data, Cervero and Kockelman (1997) evaluate the influences of neighborhood built environment on VMT and mode choice, mainly for non-work trips. A number of variables were employed to characterize three important dimensions of built environment: density (e.g., population density, employment density, accessibility to jobs), diversity (e.g., dissimilarity index, entropy index, vertical mixture, activity center mixture), and design (street pattern, pedestrian/cycling provisions, site design). Factor analysis was used to derive composite variables for each dimension of built environment. Overall, the authors found that density, land-use diversity, and pedestrian-oriented designs (e.g., sidewalk, street light, block length, planted strips) reduced trip rates and automobile travel in a statistically significant way while the influences were modest. Neighborhood characteristics were found to be more important in explaining mode choice for non-work trips than for commute trips. More appreciable impacts were found with the synergy of the three dimensions rather than with one individual dimension. The authors concluded that the research findings lent some credibility to new urbanist approaches to attaining transportation objectives, such as reducing automobile dependence and air pollution.

While studies increasingly employ more sophisticated and comprehensive approaches in characterizing communities, a majority of the studies rely heavily on the local spatial measures but give little attention to the larger spatial context, such as the relative location of an individual community in the metropolitan region. The effectiveness of new urbanist town planning may be different by the larger spatial context in which the community is located.

Handy (1993b) evaluated the effects of alternative urban forms of development on non-work travel patterns in the San Francisco Bay area. One of notable features is its contextual approach to characterizing urban form by using the concept of "local" and "regional" accessibility. Local accessibility depends on close proximity to locally oriented centers of activity, while regional accessibility depends on good transportation links to regional centers of activity. Gravity-based accessibility measures were used to calculate both types of accessibility. Overall, she found that higher levels of both local and regional accessibility were associated with shorter trip distances. Total travel was less in the areas with higher levels of both local and regional accessibility because of slight difference in trip frequency. There were offsetting effects, as the effect of each type of accessibility on travel was most significant when the other type of accessibility was low. The study results provide implications not only for local land use policies but also for regional policies in coping with transportation problems.

Cervero and Gorham (1995) compared commuting characteristics of transit-oriented and auto-oriented suburban neighborhoods in the San Francisco Bay Area and in Southern California. Similar neighborhoods in terms of incomes and transit service levels were matched with one another. Transit neighborhoods showed higher levels of walking and bicycling and lower levels of drive-alone trips. The level of transit commuting was higher in transit neighborhoods in the Bay Area, but there were no clear patterns in transit commuting in the Los Angeles region. The authors suggested that transit-oriented neighborhoods would have negligible effects on commuting patterns within the regional context of highly automobile-oriented suburbs.

Meanwhile, a group of scholars have tried to set the link between urban form and travel behavior on a microeconomic basis (Boarnet and Sarmiento 1998; Crane and Crepeau 1998). Based on travel demand models, trip generation is explained as a function of price or cost that is related to land uses and economic-demographic characteristics. For simplicity, time costs are often surrogated by trip distance, time, or accessibility in the models.

Using a household travel diary data for San Diego, Crane and Crepeau (1998) studied the influence of neighborhood design on non-work trips. Land use features were represented by street pattern, street network density, mixed use, and so on. Overall, the trip frequency and mode split were very weakly explained by the demand model. The connected street pattern (i.e., grid versus cul-de-sac), which was considered as an important feature for distinguishing new urbanist communities from modern suburban neighborhoods, was not statistically significant in their model.

Using a 2-day travel diary for southern California residents, Boarnet and Sarmiento (1998) examined the link between neighborhood land use pattern and non-work automobile trip-making. While Crane and Crepeau (1998) included trip length and speed in their model as the variables for time costs, the authors treated time costs differently in the model by assuming that time costs were reflected in the accessibility linked to land use patterns. Land use variables were measured at two levels of geographical scale: neighborhood and zip code level. Land use variables included population density, percentage of street grid, retail employment density, and service employment density. Overall, land use variables were not statistically significant in explaining trip frequency for non-work. The authors pointed out that choice of measurements and specification of methodology could lead to different results and conclusions.

The studies based on travel demand frameworks have an advantage in explaining individual trip-making by connecting it to the concepts of price or cost. The studies typically focus on the effects of neighborhood design components on trip frequency. An interesting point is the relationship between accessibility and tripmaking. From a theoretical point of view, better physical accessibility between points is expected to generate more trips because of lower trip costs. Thus, neotraditional communities that purport to improve physical accessibility among activity sites are likely to generate more trips rather than reduce trips (Crane 1996). An important consideration is their impacts on total automobile trips and air quality. The question whether greater trip frequency over shorter distances actually reduced total trips by substituting non-motorized local trips for long distance trips is a matter of empirical study (Handy 1993b; Handy 1996b). Therefore, studies need to examine potential complementary or substitutive relationships among various trip indicators rather than to rely on single indicator.

Some Issues in Methodology and Measurements

This part discusses some methodological and measurement issues in the study of the relationship between urban form and travel. First, there are various types of methodology employed in analyses (Crane 1996; Handy 1996a; Burchell, et. al. 1998). Perhaps the most frequently used analytical method would be a group-comparison analysis based on quasi-experimental design (Ewing, Haliyur, and Page 1994; Cervero and Gorham 1995; Handy 1996b) and regression-type analysis (Frank and Pivo 1994; Holtzclaw 1994; Boarnet and Sarmiento 1998; Crane and Crepeau 1998). Each method has its own advantages and disadvantages. Studies using group-comparison schemes make a grouping (e.g., "traditional" versus "modern" neighborhoods) based on certain criteria (e.g., accessibility, land use, or design) that distinguish them from one another. Similar cases are matched in terms of potentially important confounding factors, such as economic-demographic characteristics in order to control confounding effects. This type of study tends to weakly address the issue of internal validity by loosely controlling a limited number of confounding factors. By lumping individual spatial elements together within a community, it is difficult to identify the independent effects of each specific spatial component (Crane 1996). However, this type of methodology is not always inferior in exploring land use-transportation issues. Randomization is often difficult to implement in real world studies because of the cost of data gathering and insufficiency in real world cases. Group-comparison studies can also identify the synergy of various individual spatial elements since the effects of urban form tend to be more significant by the general quality of a community rather than by an individual spatial element (Cambridge Systematics, Inc. 1994).

Regression-type analyses have a methodological advantage in terms of randomization. Typically, studies are drawn from large travel survey data through random sampling. The studies do not involve intentional processes of case selection and assignment to secure internal validity. They can be a useful approach to identifying the independent effects of each specific spatial feature on travel behavior. Yet, due to the nature of randomization, the studies have to include a number of potentially important variables in the analytical model to control the confounding effects. Many real-world studies tend to control only a limited number of confounding variables due to a lack of data availability. Further, studies tend to lack the consideration of the interaction effects among independent variables (e.g., combined effects of land use diversity and pedestrian-friendly design).

Some studies take a kind of middle-ground approach by creating composite variables in either the comparison model or regression model (Cambridge Systematics, Inc. 1994; Cervero and Kockelman 1997). For instance, a small number of composite variables having similar characteristics are derived from a large number of initial variables. Factor analysis or principal components analysis is often used to identify the important spatial dimensions or characteristics. The composite variables may be used for regression or the analysis of variance, depending on the analytical method in a particular study. Composite variables can also be used in cluster analysis to classify workplaces or neighborhoods (Cervero 1989a). This type of study has some advantages in reducing the complexity of spatial characteristics and in overcoming multicolinearity among independent variables. However, the process is not always straightforward. Derived composite variables often consist of various heterogeneous variables in various ways (i.e., strength and direction). This gives rise to a difficulty in defining the variables and interpreting their effects.

In measuring urban form, studies use various indicators, such as density, land use mix, and design. Density is perhaps the most widely used indicator in characterizing urban form because of its simple but clear representation. Density is considered among the focal concepts in the debate of "compact city versus sprawl" (Burchell, et. al. 1998). It also has policy relevance because land use controls typically employ density as a key apparatus. But, density is a very poor measure of urban form from the analytical standpoint because it does not capture the variation of land uses that are crucial to examining activity patterns and thus travel (Handy 1996a). The problem would be particularly true in the case of local trips. In spite of the problems associated with measuring density, some type of travel, such as regional commuting trips, may be less seriously vulnerable to the arbitrariness and aggregation problems.

In order to complement the drawback of density measures, many studies employ some land use diversity measures such as the share of commercial land uses (e.g., shops, groceries, and banks), entropy index, or dissimilarity index within an areal unit (Cervero 1989a; Frank and Pivo 1994; Handy 1996b; Cervero and Kockelman 1997). However, the share of a certain activity is a weak indicator of diversity because it does not exactly take into account the compositional variation among various activities within the spatial unit.

The entropy index appears to have advantage in representing the variety of activities or land uses by providing a simple numeric indicator of distributional evenness. The entropy index assumes that the maximum entropy be attained by the same proportions of distribution over the classified items. However, this assumption is valid only when the general distribution (e.g., at the metropolitan level) over the classified items tends to have similar proportions. In reality, certain land uses (e.g, commercial land use against residential land use) tend to have systematically lower shares across the area. Further, the entropy index does not account for which land use takes a particular proportion within an areal unit, although the implication of each land use on travel may be different one another (Krizek, forthcoming). Thus, studies need to employ various complementary indicators to overcome drawbacks coming from the reliance on a single measure of land use diversity.

The spatial unit of local measures also needs some attention. Studies often have to rely on an arbitrary spatial unit to measure urban form indicators due to data availability. Most housing and employment data are gathered from government sources, and are often aggregated on census geography, such as census tracts or block groups. A problem is that these areal units do not necessarily guarantee the homogeneity and functional integrity for a particular research purpose. This is known as the "modifiable areal unit problem" in geographical studies.

Land use diversity measures are particularly vulnerable to the arbitrariness of government geographies. For example, census tracts tend to increase in areal size with distance from the regional core, which have the possibility for exaggerating land use diversity in outer areal units. The technology of geographic information systems (GIS) gives researchers the opportunity to overcome this kind of problem by providing various functions to compute spatially referenced data by "customized" geographies defined the researcher on a particular topic. Now many local governments and regional organizations in the US provide various fine-grained data sources in GIS formats.

Measures of jobs-housing balance also deserve some attention. Jobs-housing balance is typically computed as the ratio of jobs to employed residents or the ratio of residents working locally to residents working outside within each subsection (e.g., municipal boundaries) in a metropolitan region (Cervero 1989b, 1996a). In a sense, jobs-housing balance measures are a kind of cumulative opportunities measures of accessibility, considering both demand- and supply-side. Local municipal boundaries, as a spatial unit, have policy relevance because land use controls are largely under the control of local governments. Many local governments, especially those in California, are applying jobs-housing balance measures as a planning indicator.

In spite of the policy appeal of jobs-housing balance, it could be a weak indicator of transportation and air quality impacts when applied on the local basis. First, it does not take into account the effects of regional labor and housing markets (Giuliano 1991; Levine 1998; Levinson 1998). Today, an individual local jurisdiction is often located within the larger metropolitan region. Besides the difficulty in matching the economic capability of workers with affordable houses, it has limits in addressing the broader regional context. Second, the local jurisdiction boundary, as a unit of catchment area, does not necessarily coincide with the "indifference zone" in commuting behavior. Giuliano and Small (1993) suggest that a local jurisdiction as a catchment area tends to be too small to address the jobs-housing imbalance problem.

Levinson (1998) suggests that gravity-based accessibility measures would be more appropriate to measuring jobs-housing balance than jobs-housing ratio measures because such measures capture the regional context and overcome the catchment area problem. In his case, the jobs-housing balance, based on the local scale, is replaced with the accessibility between jobs and housing, based on the regional scale.

The fundamental concept driving the study of the link between urban form and transportation is perhaps accessibility (Hanson 1995; Handy 1996b; Salomon and Mokhtarian 1998). Accessibility as an urban form measure has been long employed by a group of scholars (Hansen 1959; Wachs and Kumagai 1973; Hanson and Schwab 1987; Handy 1993b; Handy and Niemeier 1997). As shown in gravity-based accessibility measures, accessibility is measured in terms of the distribution of opportunities (e.g., jobs) and transportation systems to get there. Its apparent basis on travel demand models gives it potential to support the link between urban form and travel (Handy 1993b; Handy 1996b). Further, an accessibility measure can function as a composite indicator to characterize urban form and quality by implying various dimensions of urban form, such as size, density, diversity, and proximity of land use activities on both local and regional scale.

Lessons

Scholars have tried to identify the relationship between urban form and travel. The goals are to identify important dimensions of urban form that affect travel patterns and to suggest policy implications for making urban development better. This body of research is currently a field of vital debate. Although many empirical studies lend support to urban form as an important factor in making travel patterns different, the findings are not conclusive enough to provide definite evidence for urban policies. Below summarizes some lessons from previous research.

First, the research focusing on the relationship between characteristics around individual workplaces and commuting is less vital compared to the research on the relationship between neighborhood characteristics and travel, especially non-work travel. Employment-based commuting studies are mainly macro-scale ones using aggregate travel data. In the residential-based research, the spatial characteristics of work sites tend to be treated as a residual dimension. Research based on the locations of employment is also important because of major urban activities and traffic attractions. Further, new urban design approaches such as high-density, mixed-use, or transit-oriented suburban development patterns have more potential to be economically successful in the vicinity of large employment concentrations because land values and access to activities tend to facilitate more compact development patterns. The link between residential and non-residential activities is an important land use consideration in new urbanist approaches.

Second, studies need to more fully characterize the spatial context in which an individual tripmaker makes activities. Although there are some exceptions, studies usually rely on urban form characteristics on either a local or regional scale. While the studies focusing on regional measures tend to miss specific features of land use that affect travel behavior, the studies focusing on local land uses miss a larger urban context that might be important in shaping the effectiveness of local features and, in turn, thus travel patterns. Thus, studies need to take into account both the regional and local spatial context. In some cases, however, a kind of "multilevel model" is required in the analysis because individuals (i.e., trip-makers) are nested within larger spatial clusters, and they cross over among spatial units.

Third, one issue of heated debate is the relative importance of urban form factors compared to economic and demographic factors. There may be two outlooks: urban structure as a collective product of the behavior of individuals and urban structure as a conditioner shaping an individual's behavior. Obviously, individual needs and resources fundamentally determine the demand for travel and land use. But, the travel demand is also conditioned by opportunities and constraints in place. In the long term, there may be a dynamic equilibrating process between urban form constraints and individual travel choices. While no one would dispute against considering both urban form and non-urban form factors, actual empirical studies tend to weakly control either side of factors. Thus, studies need to take into account various complementary effects of urban form factors and economic-demographic factors on travel, rather than emphasizing either factor.

Fourth, studies need to more explicitly show how urban form factors affect travel choices. As Handy (1996a) points out, many studies are carried out by an implicitly assumed relationship between urban form and travel. Even though a study finds a statistically significant association between the variables, it lacks a theoretical basis of why and how such urban form factors affect travel behavior. As suggested by some travel demand studies, microeconomic theories based on utility maximization principles could be a useful basis to set up the conceptual framework. Different types of urban form constitute different opportunity distributions and thus different prices for people to participate in activities.

Fifth, studies need to apply diverse analytical methods, rather than relying on a single method. For example, a comparative analysis based on grouping may be a useful approach to capture the overall characteristics of a site and the synergy effects on travel, while a regression-type analysis may be a useful tool to identify independent effects of each spatial indicator. By employing both analytic methods, the relationship between urban form and travel could be more richly understood.

Sixth, different indicators of urban form may lead to different results and conclusions. Also, an urban form factor may have different meanings as an indicator of travel. For example, suburban employment centers might help reduce commute times but increase trip distances and automobile uses. Walking/bicycling provisions can either substitute or complement automobile uses. Social costs and benefits resulting from travel patterns may be extremely difficult to calculate. There is always a problem of selection among the various indicators of urban form and travel. An important point is that studies need to take into account such complementary and conflicting effects by analyzing diverse indicators.

Seventh, the level of data aggregation may affect the research results. It appears that disaggregate models of travel behavior in general show very low relationships (e.g., low R-squares), compared to aggregate models. Part of the reason may be that the level of data aggregation affects not only the range of possible measurements but also the methodology employed. Studies based on aggregate data have methodological weakness inherently because of the possibility for the "ecological fallacy" that results from drawing conclusions about individual travel behavior based on observations from aggregated data. Also, these studies are under threat from the "modifiable areal unit problem" that results from the aggregation of data into arbitrary areal units for geographical analysis.

Eighth, each urban form indicator has its own assumptions in representing a certain dimension of urban form. Before using a particular indicator, studies need to take into account such underlying assumptions to avoid the possibility for reaching misleading conclusions. Related to problems of data aggregation, some urban form indicators are vulnerable to the arbitrariness of spatial aggregation. GIS can be a useful tool to overcome or reduce such problems.

CHAPTER IV
METHODOLOGY

This chapter describes the methodology used for empirical analysis to address this study's research questions. An emphasis is given to addressing the lessons from literature review in the previous chapter. First, data sources for the case study are introduced. Second, the operationalization process for a number of measurements is specified to represent each concept identified in the research hypotheses. Finally, analytical methods are described.

Data Sources

Most data sources for this study were obtained from the North Central Texas Council of Governments (NCTCOG), a metropolitan-wide association of local governments for regional planning of the Dallas-Fort Worth area. Travel data were obtained from the 1994 NCTCOG Workplace Survey. This survey includes the information of 278 sampled work establishments and the travel and personal-household characteristics of the 7,336 employees surveyed (for details of survey design, see the *1994 Workplace Survey: Dallas/Fort Worth Metropolitan Area*, Barton-Aschman Associates, Inc., 1995).

In the original survey, the sample size of 278 work establishments was set with a consideration of statistical representativeness. The sample was also "stratified" by type, size, and geographical location to assure the reliability. In each stratum, random sampling was conducted. Once the 278 sites had been sampled and surveyed, the employee survey, including socio-economic and travel characteristics of individual employees, was conducted for the 21,000 employees who work in the 278 sites. The 7,336 employees actually completed and returned the employee survey forms.

The 1994 NCTCOG Workplace Survey provides various trip characteristics of 7,336 workers, such as travel mode, time of day of the trip, midday travel, and trip chains made during commuting trips. But, it does not provide the information of travel time to work. Thus, this study used the 1995 NCTCOG Roadway Network data in TransCAD data format to compute the time traveled between home and work of each employee. The roadway network data contain the estimated peak and off-peak travel times of each coded network segment. The detailed process of travel time calculation based on the shortest network path will be presented in the section of measurements.

The 1995 NCTCOG Land Use GIS data were used to capture local land use characteristics around each work site. The data provide the spatial distribution of 19 land use categories. Various GIS techniques were used to compute land use characteristics (e.g., clipping a half-mile radius from each workplace point and then calculating the acres by land use category to compute land use composition).

The 1995 NCTCOG Employment Estimates were used to capture the job distribution around each work site, such as employment density per acre and regional accessibility of a workplace to other workplaces. The employment estimates are available in the gross numbers of employment at the TSZ level. Thus, the type of industry or occupation cannot be identified.

Some housing data were obtained from the 1990 Census (STF3A) from the U.S. Bureau of the Census. Housing estimates on the small areal scale such as census tracts or TSZs were not available from the NCTCOG GIS database.

In addition to the major data sources above, this study used various data in GIS-format, including the 1990 Census TIGER-Line files (used for address-matching) from the Census Bureau, freeway routes (used for highway accessibility) from NCTCOG, and bus transit routes (used for transit accessibility) from the Dallas Area Rapid Transit (DART) and the Fort Worth Transportation Authority (the-T).

Table 4.1 summarizes major data sources used for empirical analyses.

Table 4.1 Summary of data sources

Data source	Description	Use
1994 Workplace Survey data from NCTCOG	• 278 records for work establishments surveyed • 7,336 records for employees surveyed	• Employer characteristics: number of employees, type of business, etc. • Travel characteristics of each employee: trip mode, trip chains, etc. • Personal and household characteristics of each employee: age, gender, income, household type, etc.
1995 Roadway Network data from NCTCOG	• Peak and off-peak travel time by coded roadway segment • GIS data format	• Time and distance traveled based on the shortest network path between home and work of each employee
1995 Land Use data from NCTCOG	• 19 land use categories • GIS data format	• Local land use characteristics: land use mix, amount and proportion by land use category, etc.
1995 Employment Estimates data from NCTCOG	• Gross employment estimates in each TSZ for 1990, 1995, and 1998	• Local employment density and jobs-housing ratio, regional accessibility of each workplace to other workplaces, etc.
1990 Census data from U.S. Census Bureau	• 1990 housing in each census tract	• Local housing density, types, price, jobs-housing ratio, and regional accessibility of each workplace to housing, etc.
Various	• 1995 TIGER-Line data from U.S. Census Bureau • NCTCOG GIS database • Public transit routes from DART and the-T	• Address-matching for home and work of each employee • Delineating freeways, TSZs, counties, cities, etc. • Delineating bus transit routes

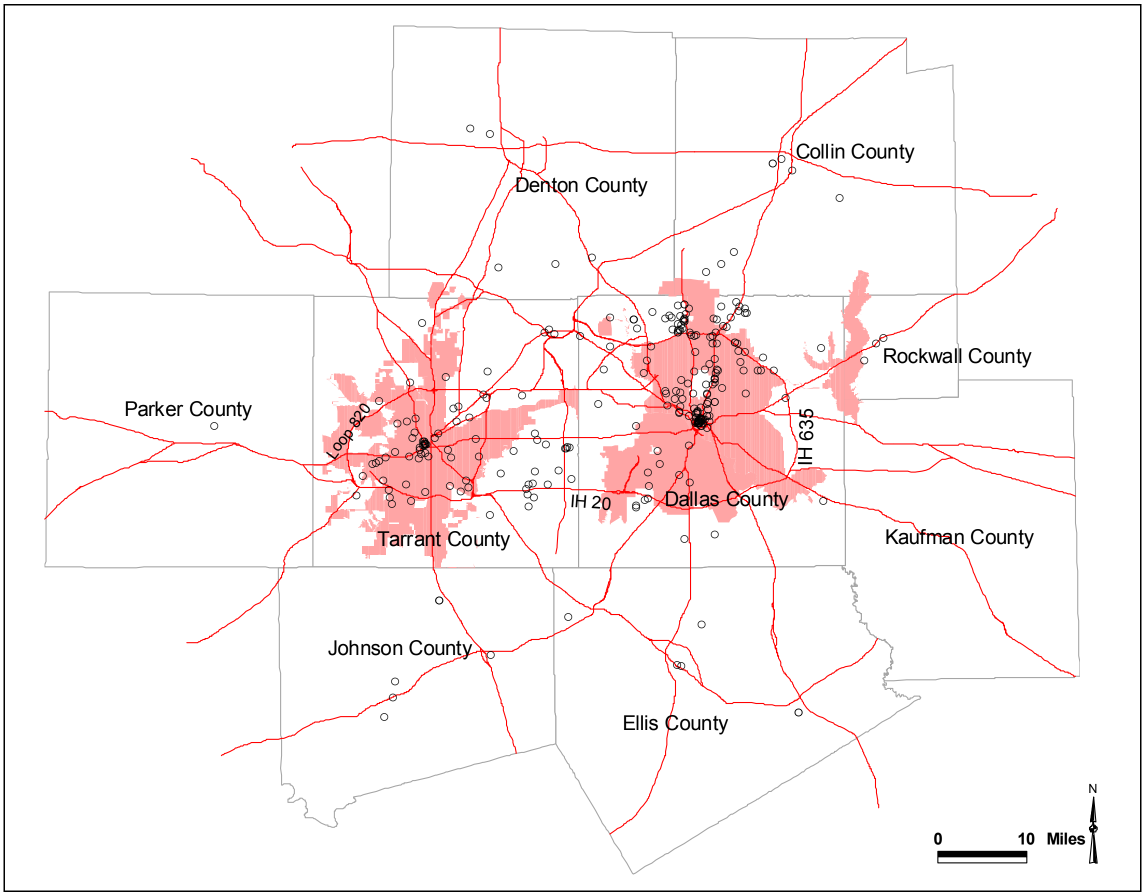

Figure 4.1 Location of 278 work establishments from the 1994 NCTCOG Workplace Survey

Study Cases

Although the 1994 NCTCOG Workplace Survey was conducted for 278 establishments, this study confines the analyses to 270 establishments because some GIS data do not cover all of the 278 sites. Further, this study confines commute sheds to capture homes of surveyed employees to the Dallas-Fort Worth Metropolitan Planning Area (MPA), which is designated for the regional transportation planning by NCTCOG, because some residences of the 7,336 employees are outside of GIS data coverage.

Given that most commuting occurs between home and workplace, the coverage of GIS data should encompass not only the workplace but also the home of each employee. If a workplace is outside of GIS coverage, the workplace is excluded from the analysis because we cannot measure spatial characteristics of the workplace. Or, if the residence of an employee is outside of GIS coverage, the employee is also excluded from the analysis because we cannot measure travel time and distance between home and work made by this employee.

The MPA, as commute sheds for this study, includes all of Collin, Dallas, Denton, Tarrant, and Rockwall counties and some portions of Ellis, Johnson, Kaufman, and Parker counties. Theses counties surround Dallas and Fort Worth as primary cities. Of the 9 counties, 6 counties are in the Dallas Metropolitan Statistical Area (MSA) while 3 counties are in the Fort Worth MSA. The MPA boundaries appear large enough for the analysis since they cover most locations of work and home in the Dallas-Fort Worth area.

Variables and Measurements

This section specifies variables to measure various concepts that were identified in the conceptual framework and hypotheses. As mentioned earlier, major components for the analysis are: travel choice (measured by travel time, travel mode, and trip chaining), worker (decision-maker who makes a travel choice), employer (workplace itself where a worker is employed), and workplace environs (local and regional distributions of jobs, housing, and transportation provisions around each worksite). Travel choices made by each individual worker for commuting constitute dependent variables. Given the research objectives of this study, variables representing workplace environs constitute independent variables, while variables representing the personal and household characteristics of each worker and the employer characteristics in which each worker is employed constitute confounding variables.

It should be noted that travel behavior models for different trip attributes require different sets of variables. For example, travel mode models include trip distances to capture the effect of spatial friction. Trip chaining models include both trip distance and trip mode to capture the effects of spatial friction and mobility constraint (i.e., flexibility in moving between activity sites) by trip mode on activity patterns. The specific relationship between a spatial factor and a trip attribute will be explored in the actual analyses.

Dependent Variables

Dependent variables comprise travel time, travel mode, and trip chaining made by individual workers during commuting trips. First, travel times are measured by home-to-work vehicle minutes traveled in a personal vehicle (car, pickup, truck, or van) by each worker. Since the 1994 NCTCOG Workplace Survey does not provide the information about times traveled by each surveyed worker to work, this study uses estimated vehicle travel times by a shortest network path algorithm. Second, given that automobile dependence is overwhelming, travel mode is measured by a binary distinction: whether an individual worker commutes by a single-occupant vehicle or not. Third, trip chaining is also measured by a binary distinction: whether an individual worker makes at least one stop or not one the way home after work. Although activity stops may also be introduced before work and during work, the choice model is set up only for activity stops on the way after work because the majority of non-work activity (e.g., shopping, personal business) occurs on the way home after work.

Table 4.2 Dependent variables and measurements used for travel behavior models

Variable	Type	Measurements
Travel time	Continuous	Vehicle minutes traveled in personal vehicle by a worker for home-to-work trip through the shortest network path
Travel mode	Discrete	Whether a worker uses a single occupant vehicle for home-to-work trip or not (1=yes, 0=no)
Trip chaining	Discrete	Whether a worker makes at least one stop on the way home after work or not (1=yes, 0=no)

Vehicle Times Traveled: Address Matching and Shortest Network Path

In order to calculate home-to-work vehicle travel times through shortest network paths, origin points (homes) and destination points (workplaces) should be located first. First, address matching with GIS tools was conducted by using the information of geographic coordinates (for workplaces) and addresses or street intersections (for residences). The 1990 TIGER-Line street map was used as a base map for address matching. Due to missing and incomplete information of addresses in the original survey, address matching was successful only for 5,015 records of the 7,336 records (surveyed employees).

Second, vehicle travel times through the shortest network path between home (origin point) and workplace (destination point) of each worker were computed using the 1995 NCTCOG Roadway Network data, which contain estimated peak/off-peak travel times for each coded roadway segment. Peak travel times were applied if the time of arrival at work was between 6:30 a.m. and 8:29 a.m. A customized ArcView Avenue script running in the Network Analyst environment was used for the repeated calculation (i.e., loops of calculation for the 5,015 records). After intensive computation using GIS tools, 270 workplaces and 4,880 surveyed employees remained valid because some workplaces and homes were outside of the GIS data coverage. Table 4.3 shows data breakdown during the GIS process.

Table 4.3 Data breakdown during address matching and network travel time calculation

Data step		Changes in data records	
		Workplaces	Employees
1	Original data	278	7,336
2	Address matching	278	5,015
3	Network travel time calculation	270	4,880

Several drawbacks of using the home-to-work vehicle travel times through the shortest network algorithm should be noted. First, the NCTCOG Roadway Network data do not provide travel times by trip mode. Public transit has its own fixed routes. Therefore, the estimated network travel times are used only for the analysis of automobile travel. Second, the travel times are likely shorter than the actual travel times made by workers because they do not take into account access times (e.g., times from parking to office) and stops made on the way of commuting trips. Third, the assumption that people minimize their travel in terms of duration would be idealistic. People may have imperfect information about the traffic conditions of the alternative routes. Some people may habitually use certain routes even though the routes require longer travel times than an alternative route.

In addition to the network vehicle travel times, travel distances through the shortest path were computed. The models of mode choice and trip chaining include home-to-work distance of each work as a control variable. The shortest network vehicle travel times above cannot be used as a control variable because they are more appropriate to automobile commuting trips, but not to public transit and non-motorized trips (e.g., walking, cycling).

Independent Variables

Characteristics of workplace environs are measured by local and regional distributions of jobs, housing, and transportation provisions around each workplace. Theses characteristics reflect the magnitude, density, variety, and proximity of the opportunity. The phrase "around each workplace" is implemented by using "customized" spatial units centering around each worksite, depending on the spatial object (i.e., jobs, housing, and transportation) and scale (i.e., local or regional). First, regional measures for each workplace, such as the regional accessibility to housing and other workplaces, are based on the metropolitan region (i.e., MPA boundaries) in order to capture the opportunities in destinations. Second, local measures of job distribution (i.e., activity sites) are based on a half-mile radius from each workplace. Third, local measures of housing distribution are based on one-mile radius from each workplace. Fourth, local measures of public transit accessibility are based on whether the nearest transit route is within a quarter-mile radius from each workplace, assuming a quarter-mile to be a walkable distance. Finally, local measures of highway accessibility are based on the distance to the nearest controlled-access highway from each workplace.

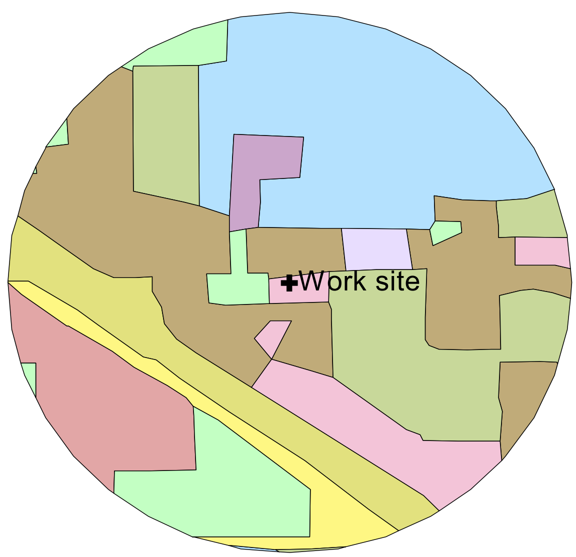

Figure 4.2 Illustration of measuring local land use characteristics in GIS: a half-mile radius from a worksite

Customized geographies (e.g., a half-mile radius or one-mile radius from each workplace) defined by the researcher have an advantage over census geography, such as census tracts or TSZs, because census geographies exhibit wide spatial variations in areal size, making it difficult to apply consistent standards to measuring land use characteristics. Further, customized geographies considerably overcome the aggregation problem by clarifying the difference in land use characteristics even if two workplaces are neighboring. Using TSZs or census tracts were used as areal units assumes that the workplaces within the same zone share the same land use characteristics. This assumption is less realistic because two workplaces within a large zone are often located in different environs. Therefore, the land use characteristics measured should be specific to each site.

Various GIS tools were utilized to customize repeated calculation processes for a large amount of spatially referenced data. For example, computing the entropy index of land use mix for each workplace involves capturing a half-mile buffer from each workplace and then calculating the areal size by each land use category. GIS customization makes the repeated process simple and rapid.

Due to data constraints, this study does not fully capture spatial characteristics around individual workplaces. First, some indicators such as employment density and housing density were based on TSZ and census tract data respectively because those data (housing units and jobs) were available only at a particular census geography scale. Second, in measuring activity mix, this study does not include indicators of vertical activity mix, in which different types of activity are distributed vertically on one site (e.g., multi-use buildings). Third, the analysis does not include design factors such as street patterns (e.g., intersections and block size) and pedestrian amenities (e.g., sidewalks, bicycle trails, and ease of street crossing) because measuring such design factors for the sampled work establishments requires considerable amount of time and costs. Third, for public transit provisions, this study does not include fares, times, and quality of services (e.g., operation schedules). Further, DART (Dallas Area Rapid

Transit) light rails are not included for public transit accessibility because the 1994 Workplace Survey and 1995 GIS database by NCTCOG are prior to its operation.

Table 4.4 Independent variables and measurements

1. Job distribution around each workplace: local level
    - % Land for employment uses within a half-mile radius from each workplace
    - Employment density: the number of employees per non-residential developed acre (excluding residential, vacant, parks, water, and dedicated) in the TSZ in which each workplace is located
    - Entropy index of land use mix (office, retail, institutional, and industrial) within a half-mile radius from each workplace
    - % Retail land of the total developed land within a half-mile radius from each workplace
    - % Office land of the total developed land within a half-mile radius from each workplace
    - % Industrial land of the total developed land within a half-mile radius from each workplace
    - 1 if a workplace is inside of any major employment center; 0 otherwise

2. Job distribution around each workplace: regional level
    - Regional accessibility of each workplace to other workplaces: the gravity-based accessibility index
    - Straight-line distance from each workplace to CBD in miles: downtown Dallas (city hall) if in Dallas MSA, downtown Fort Worth (Hyde Park) if in Fort Worth MSA

3. Housing distribution around each workplace: local level
    - % Residential land (single-family, multi-family, and mobile home) within one-mile radius from each workplace
    - Ratio of housing to jobs within four-mile radius from each workplace
    - Housing density: the number of housing units per residential acre in the census tract in which each workplace is located
    - % Multi-family residential land within a one-mile radius from each workplace (a proxy for housing diversity)
    - Median price of owner-occupied housing units in the census tract in which each workplace is located

4. Housing distribution around each workplace: regional level
    - Regional accessibility of each workplace to housing: the gravity-based accessibility index

5. Transportation provisions around each workplace
    - Public transit accessibility: 1 if within a quarter-mile from the nearest bus transit route (DART in Dallas and the-T in Fort Worth); 0 otherwise (not including the DART Light Rail and the feeder bus lines to rail stations because the light rail first opened in 1996 after this survey)
    - Highway accessibility: straight-line distance to the nearest controlled-access highway in miles

While Table 4.4 summarizes the independent variables used in this study, the operationalization process for some variables will be further specified because they raise various issues to be addressed in calculation.

Regional Accessibility to Housing and Jobs: Gravity-Based Accessibility Index

This study uses gravity-based accessibility measures to represent the accessibility levels of an individual workplace to housing and other workplaces in the metropolitan region. Accessibility is defined using the equations below:

$$A_{iR} = k \sum_{j} R_j * f(t_{ij})$$

$$A_{iW} = k \sum_{j} W_j * f(t_{ij})$$

where

A_{iR} = accessibility of worksite i to houses within the region

A_{iW} = accessibility of worksite i to other workplaces within the region

R_j = number of houses in zone (TSZ) j

W_j = number of employment in zone (TSZ) j

$f(t_{ij})$ = function of travel time between workplace point i and zone j

k = 1/1,000 (scaling factor).

The parameter of impedance function was estimated using the 1994 NCTCOG Workplace Survey including 4,880 work trips. The trip frequency distribution by a five-minute travel time cohort was used for the parameter estimation.

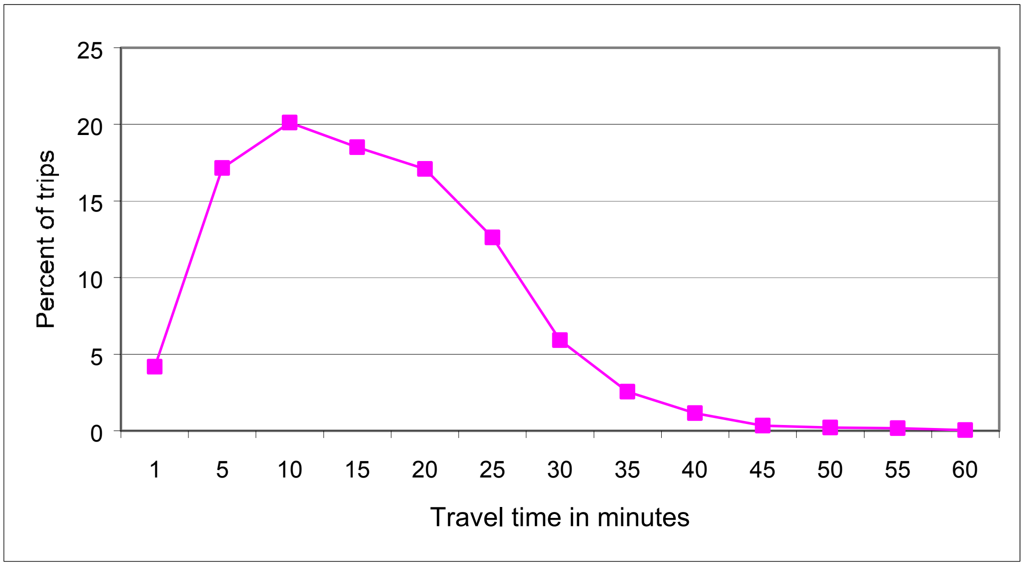

Figure 4.3 Distribution of work trips by travel time

An exponential form, which is perhaps most widely used in recent studies, was applied to the equation:

$$P(t) = c * \exp(-\beta t)$$

where P(t) is the number of trips in each five-minute travel time cohort divided by the number of total trips, and c and β are parameters to be estimated. After the natural log transformation, the following regression equation was generated:

$$\ln P(t) = 7.6694 - 0.1034 * t \quad (R^2 = 0.8564, N = 12)$$

The impedance function used in the accessibility equations takes the following form:

$$f(t_{ij}) = \exp(-0.1034 * t_{ij})$$

To calculate the accessibility of each workplace point, one needs to first calculate travel times of each pair of workplace point and destination zone (TSZs). Centroid point (geometric center) was used as a representative point for each destination zone. The 1995 NCTCOG Roadway Network GIS data were used for the point-to-point calculation of peak travel times through the shortest network path.

Several problems need to be pointed out in using the simple accessibility measures above. First, a more ideal measure would take into account the different levels of mobility by trip mode (e.g., auto, transit, and walking). Second, while this study employs a negative exponential form for the impedance function, the actual trip frequency tends to increase over short travel times from each workplace but then decrease thereafter. The actual trip distribution contributed to lowering the slope of impedance function. From the theoretical point, the estimation of spatial friction based on actual trip data may not be the most desirable method because actual trips are not necessarily the same as what people prefer or the subjective disutility of travel (Handy and Niemeier 1997). Yet, exploring underlying travel preferences requires a new type of survey. Third, the accessibility measures only take into account the quantity of opportunities such as the number of houses or jobs. A more sophisticated measure would be to include qualitative aspects of opportunity such as the match between housing prices in residential zones and workers' affordability.

Workplace-Based Housing-Jobs Ratio

To measure jobs-housing ratios, most previous studies have used a fixed sub-regional geography such as local municipalities (Cervero 1989, 1996). If a community has more jobs than houses, the community is likely to import workers. Else, if a community has fewer jobs than houses, the community is likely to export workers. Thus, a balanced community (i.e., jobs-housing is 1:1) is likely to minimize commuting trips.

This study is slightly different from previous studies in the way jobs-housing ratio is measured. Housing-jobs ratio is measured from the standpoint of the individual workplace. A workplace-based housing-jobs ratio is computed based on the concept of cumulative opportunity measures (Handy and Niemeier 1997). Specifically, the ratio of housing to jobs is computed by counting jobs and housing units within a given distance from each workplace. If a workplace had the housing-jobs ratio above 1, the workplace is in a housing-surplus area and thus commuting trips made by the employees are likely shorter. Else, if a workplace had the housing-jobs ratio below 1, the workplace is in a job-surplus area, and thus commuting trips made by the employees are likely longer.

Several problems should be solved when computing the housing-jobs ratio for each individual workplace. First, a cutoff distance should be chosen. There are no absolute standards on how to make this choice. The longer the cutoff distance, the more likely the jobs-housing balance, and vice versa. Handy and Niemeier (1997) suggested that frequency distributions of travel distances (or times) could help with the decision on where to cut. Cervero (1989) used a three-to-four mile radius for his aggregate model of residential location in a jobs-housing balance study. This study uses a four-mile radius as a cutoff distance.

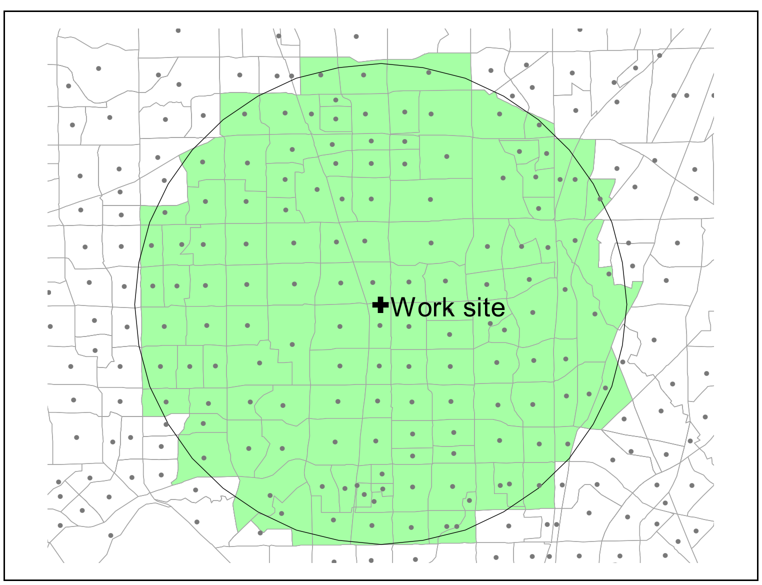

Figure 4.4 Illustration of measuring workplace-based housing-jobs ratio

Second, given that housing and employment data are aggregate at census geographies, this study needs to decide how to treat those areal units stretched over cutoff boundaries. The choice is to include an areal unit in the computation if its centroid point is within the boundary. The areal unit for housing and employment are based on TSZs.

Land Use Mix: Entropy Index and Land Use Composition

There are various indicators to measure diversity or segregation of land use, such as the ratio of commercial land uses, dissimilarity index, and entropy index. Among others, the entropy index, also known as the information index, has been widely used by studies (Cervero 1989a; Frank and Pivo 1994; Cervero and Kockelman 1997; Giuliano and Small 1999). The entropy index of land use mix for an areal unit can be computed as

$$E_i = [-\sum_k p_{ik} \ln(p_{ik})]/\ln(K)$$

where E_i is the entropy index of land use mix for workplace i, p_{ik} is the proportion of land use category k of the nonresidential developed acres within a half mile radius from workplace i, and K is the number of land use categories (K=4, office; retail; institutional; and industrial in this study). The index varies from zero to one: zero for a complete single land use, and one for equal distribution of each land use category.

The entropy index assumes that the maximum entropy or perfect land use mix is attained by equal distributions over different land use categories. This assumption is less realistic since a certain land use category can systematically have a low share in the region. Furthermore, by simply calculating the degree of evenness in land use distribution, it fails in addressing the problem of compositional difference in land use. In other words, it does not tell us what land uses are there. The impacts of different land uses on travel may be quite different.

In order to make up for the drawback of entropy, this study also uses each share of retail, office, and industrial land uses within a one half-mile radius from each workplace.

Commercial and industrial land uses are important in facilitating or discouraging non-work activities. For example, retail land uses (e.g., shopping) are likely to facilitate non-work activities. Industrial land uses (e.g., plants and warehouses) are likely to discourage non-work activities. Further, the proportion of land uses surrounding each workplace helps define the type of employment district in which the workplace is located.

Major Employment Centers: Density and Size

While some local indicators (e.g., employment density and share of employment land uses around each workplace) may provide a clue for the degree of employment concentration around the 270 work establishments in the survey, this study also needs to identify major employment centers .(i.e., independent of the 270 surveyed sites) across the Dallas-Fort Worth region in order to examine the overall metropolitan structure (e.g., polycentrism) and to identify if the 270 workplaces are located in the major centers. Scholars have used various criteria to identify relatively large employment concentrations (Dunphy 1982; Cervero 1989a; Garreau 1991; Giuliano and Small 1991; McDonald and Prather 1994; Fujii and Hartshorn 1995; Cervero and Wu 1997). The criteria to delineate employment centers tend to be dependent upon the type of data as well as the research interests in a particular study.

This study adopts the criteria of employment density and size suggested by Giuliano and Small (1991) because the criteria are simple but widely used by other studies. Like their study, this study also uses TSZ geography to delineate employment centers.

A problem with identifying centers is that there are no absolute standards to decide cutoff density and size. Giuliano and Small (1991) used a density cutoff of 10 employees per acre and a minimum total employment of 10,000 for the Los Angeles region. While using criteria of density and size, Cervero and Wu (1997) applied 7 employees per acre as a cutoff density for the San Francisco Bay Area.

In order to determine appropriate criteria, this study used two methods interchangeably: finding a critical break ("elbow" point) in the employment density distribution and applying density and size criteria enough to capture well known employment centers (e.g., Galleria, Las Colinas, Telecom Corridor, Legacy, etc.) in the metropolitan region. As a result, this study defines employment centers as a contiguous set of TSZs with a minimum density of 10 employees per developed acre in each TSZ and a minimum total employment of 10,000 (including also those zones below the cutoff density but completely enclosed by the zones above the cutoff density).

Confounding Variables

Confounding variables consist of the variables related to individual employees, employers, and other control factors for travel estimation.

Workers (Employees)

The 1994 Workplace Survey provides some variables related to socioeconomic characteristics of 7,336 workers (employees), such as age, gender, income, and household size. In addition to the survey information, several variables were included to further capture the characteristics of each worker. Residential location, measured by the distance from home to CBD, captures the degree of suburbanization. While the Dallas-Fort Worth region is a large consolidated metropolitan area, the Dallas area and the Fort Worth area somehow construct different urban realms. This study controls the case specific factor by including a variable of whether a particular residence is located in the Dallas MSA or in the Fort Worth MSA. Some seemingly important variables, race-ethnicity for example, are not provided from the survey.

Several travel-related control factors are also included in travel behavior models. First, the time period of trip (e.g., morning/evening peak or off-peak hours) by each worker is included to control the effects of traffic conditions on travel choices and activity patterns. Second, the trip distance between home and work for each worker is included in travel mode and trip chaining models to control spatial friction effects. Better measurements may be mode-specific service characteristics (e.g., travel times or costs for each mode). The shortest network vehicle travel times in the previous section cannot be used because they are more appropriate to automobile commuting trips, but not to public transit and non-motorized trips (e.g., walking, cycling). Third, while the study estimates travel modes made by individual employees, trip mode may also affect trip-chaining behavior. Hence, the trip-chaining model includes trip mode to capture the effects of individual mobility on activity patterns.

Table 4.5 Confounding variables and measurements

1. Worker (employee)

A. Socioeconomic characteristics

- Individual characteristics: age, gender, full-time or part-time
- Household characteristics: number of members in household, number of workers in household, annual household income, total vehicles per licensed driver in household
- Straight-line distance from home to CBD in miles: downtown Dallas (city hall) if in Dallas MSA; downtown Fort Worth (Hyde Park) if in Fort Worth MSA
- MSA of residence: 1 if in Dallas MSA; 0 if in Fort Worth MSA

B. Trip-related control factors

- Period of commuting: peak or off-peak (morning peak: 6:30 a.m. to 8:29 a.m., evening peak: 5:01 p.m to 7:00 p.m.)
- Trip distance: shortest network distance in miles between home and work (used for travel mode and trip chaining models)
- Trip mode: drive-alone; carpool; public transit; walk/bike; or other (used for trip chaining models)

2. Workplace (employer)

- Type of business: retail (general merchandise, restaurant, gas station, etc.); service (banks, insurance, real estate, health, education, amusement, etc.); or basic (agriculture, manufacturing, wholesale trade, transportation, communication, utilities, etc.)
- Size of workplace: number of employees
- MSA of workplace: 1 if in Dallas MSA; 0 if in Fort Worth MSA

Table 4.6 Summary statistics on personal and household characteristics of workers

Variable	Class	Percent	Mean (Standard deviation)
Age (N=7,013)			36.9 (11.1)
Gender (N=7,276)	Male	50.7	
Attachment to job (N=7,243)	Full-time	91.3	
Persons in household (N=7,319)			2.9 (1.4)
Workers in household (N=7,251)			1.9 (0.8)
Annual household income (N=5,832)	Under $15,000	8.0	
	$15,000 to $24,999	11.8	
	$25,000 to $34,999	33.3	
	$35,000 to $49,999	14.8	
	$50,000 to $74,999	17.1	
	$75,000 and higher	15.0	
Licensed drivers in household (N=7,234)			2.1 (0.8)
Vehicles per household (N=7,192)			2.1 (0.9)
Vehicles per licensed driver in household (N=7,192)			1.0 (0.4)
Location of residence (N=5,015)*	Central-city	28.4	
	Suburban	71.6	

* Central-city if within 9 miles from the Dallas CBD or within 6 miles from the Fort Worth CBD; suburban otherwise

Workplaces (Employers)

The 1994 Workplace Survey provides some variables specific to each of 270 work establishments (employers), such as industry type and size (number of employees). The industry type of a particular workplace needs to be included in travel models since different types of business have a different location propensity and thus dictate different travel patterns of the employees. The size of workplace can also affect travel patterns of employees. For example, workers of major employers might easily find the partners for carpooling within their workplaces. Major employers can play a significant role in operating workplace-based TDM strategies. Regarding the workplace itself, some seemingly important variables are not provided from the survey, such as parking availability and employer-based TDM programs (Cambridge Systematics, Inc. 1994).

Note that the distinction between confounding variables and independent variables is based on the distinction between a workplace itself and its environs. Thus, the industry type of a workplace is not treated as a spatial characteristic of the workplace and thus not an independent variable in this study. But, a certain land use characteristic surrounding the workplace (e.g., the share of retail land uses within a half-mile radius from the workplace) is treated as an independent variable.

Table 4.7 270 workplaces by industry type and size

	Number of establishments	(percent)
Industry type		
Retail (general merchandise, restaurants, etc.)	111	(41.1)
Service (banks, insurance, real estate, health, etc.)	115	(42.6)
Basic (manufacturing, wholesale trade, etc.)	44	(16.3)
Number of employees		
Under 10	27	(10.0)
10-49	131	(48.5)
50-99	51	(18.9)
100-199	37	(13.7)
200-299	13	(4.8)
600 and above	11	(4.1)
Total	270	(100.0)

Analytical Methods

The analysis begins with an overview of the metropolitan structure with respect to employment in the Dallas-Fort Worth area. It provides an overall perspective on the urban structure of the study area. Employment distribution can have various dimensions such as centralization, concentration, clustering, and evenness. Among others, this study looks at the overall urban structure in terms of decentralization, polycentrism, and scatteration with respect to employment. Decentralization is analyzed by looking at temporal and spatial patterns of job growth. Polycentrism, in which businesses cluster in a number of concentrations, is measured by identifying major employment centers by using the criteria of size and density. After delineating employment centers, the study analyzes some of their basic profiles. A discussion of the scattered job distribution is intertwined with polycentrism.

Using the NCTCOG 270 workplace sample, the analysis evaluates the spatial characteristics of workplace locations. Using the initial variables representing distributions of jobs, housing, and transportation provisions around individual workplaces, the analysis conducts a factor analysis to obtain a small number of composite variables or spatial factors of workplaces. The idea is that the concerted effects by various individual spatial elements may be more important in shaping travel patterns rather than by individual elements (Cambridge Systematics, Inc. 1994; Cervero and Kockelman 1997). The newly generated composite variables (spatial factors) are then used for the subsequent analysis.

Spatial characteristics of workplaces are compared by the combination of two locational dichotomies: central versus suburban, and inside versus outside of major employment centers. Factor scores estimated from the factor analysis are used for the comparison of spatial characteristics.

As a special case, the analysis examines the spatial characteristics of three suburban employment centers: Galleria (Dallas), Las Colinas (Irving), and Telecom Corridor (Richardson), which represent suburban downtown, master planned business and residential community, and high-tech corridor respectively. By definition, this study refers to "suburban downtown" as a downtown-like suburban center in terms of density and activity composition. The "master planned community" refers to a large-scale development by a master developer, planned to contain a mix of jobs and housing. The "high-tech corridor" refers to a concentration of cutting-edge technology-based industries along major highways. The three case areas are among the fastest growing centers in the northern Texas. Factor scores from the factor analysis are used for comparison.

Using cluster analysis, 138 suburban workplaces are categorized in terms of their surrounding spatial characteristics, and then compared to each other. Again, factor scores from the factor analysis are used for classification and comparison.

After evaluating the spatial characteristics of workplaces, the next stage is to relate the spatial characteristics to commuting patterns of employees who work there. Commuting patterns are analyzed in terms of travel time, travel mode, and trip chaining. Two methods are used: group comparisons and regression-type travel models.

Group comparisons are based on the same workplace categories used for the analysis of workplace environs: location types (central versus suburban, and inside versus outside of major employment centers), selected suburban centers (Galleria, Las Colinas, and Telecom Corridor), and suburban workplace types classified by the previous cluster analysis. A major question is how workplaces differ from one another in terms of commuting characteristics.

In order to explore the factors affecting commuting behavior of individual workers, statistical models are used: an ordinary linear regression for commute travel times, and binary logit models for travel mode and trip chaining. Each model includes both the socioeconomic characteristics of individual workers making travel choices as well as the characteristics of workplace environs. Factors scores representing the characteristics of workplace environs are used again for the travel models.

Figure 4.5 summarizes the process of analysis.

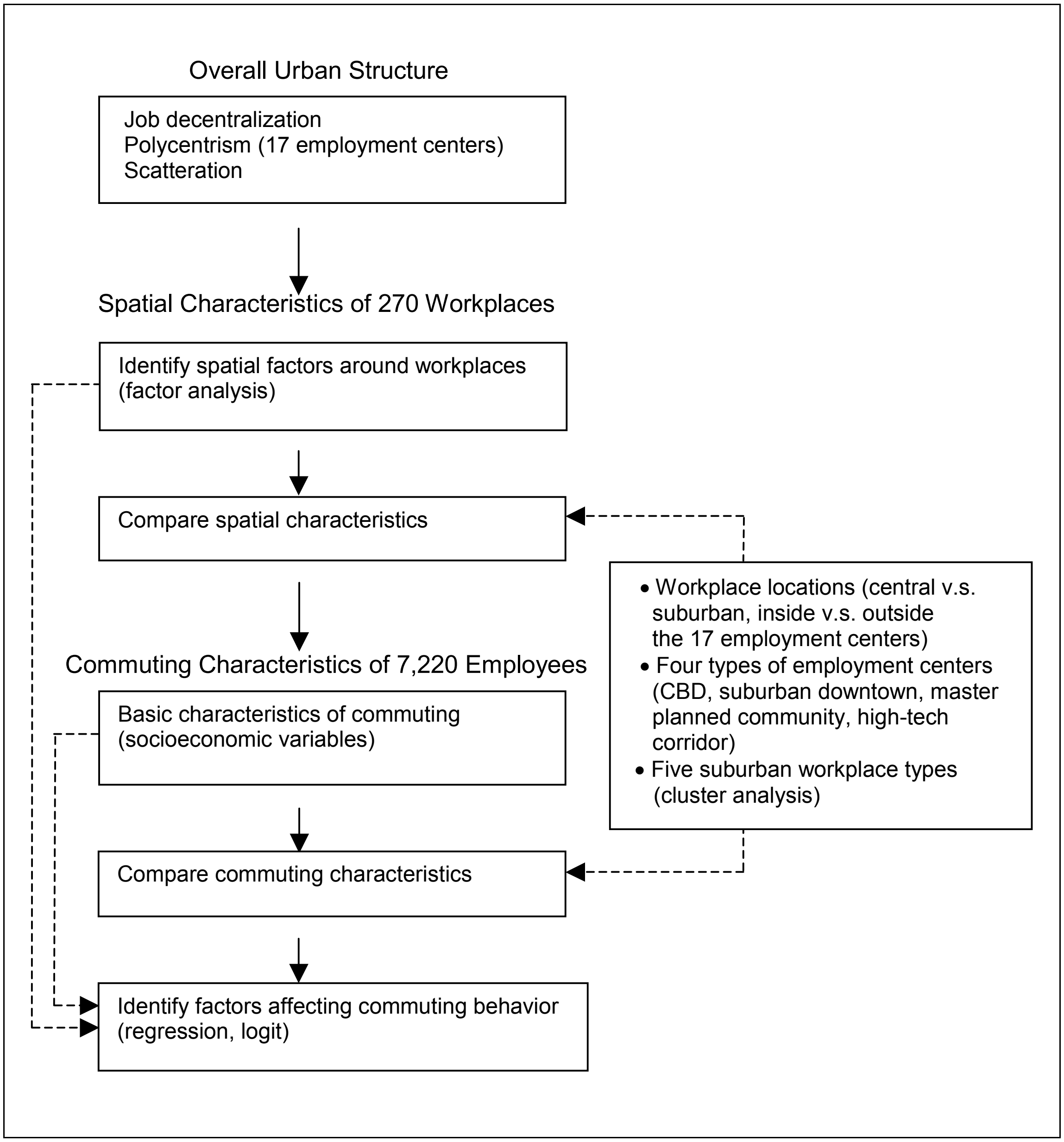

Figure 4.5 Process of the empirical analysis

Several methodological weaknesses of the empirical analysis should be noted. First, there is a limit in securing internal validity. For example, this study does not capture design factors (e.g., sidewalks, intersections, building setback, etc.). Design features are presumably important spatial factors, particularly for walking and cycling.

Since this study is workplace-based, the land use characteristics of neighborhoods in which individual workers reside are not captured. Second, there is also a limit in securing external validity. Since this is a case study at one period of time, there is a limit to generalize the findings to elsewhere. Third, the analysis using the cross-sectional data has an inherent weakness in inferring causality.

CHAPTER V
CHARACTERISTICS OF WORKPLACE ENVIRONS

This chapter evaluates spatial characteristics of workplace locations. The analysis begins with an overview of metropolitan structure in terms of employment distribution. Emphasis is given to employment decentralization and its form: polycentrism and scatteration. The analysis is followed by the characterization of workplace environs in terms of the distribution of jobs, housing, and transportation provisions around individual workplaces. The 270 sampled workplaces from the 1994 NCTCOG Workplace Survey are used for analysis. First, factor analysis is used to capture important spatial factors of workplace environs. Second, spatial factors are then compared by several spatial references: workplace location types (central versus suburban, and inside versus outside of major employment centers), four employment centers (primary downtown, suburban downtown, master planned community, and high-tech corridor), and suburban workplace types that are classified by cluster analysis for 138 suburban workplaces.

Overall Urban Structure

Like many other urban areas in the US South, the Dallas-Fort Worth region has accomplished steady job growth over the last decade. According to the estimates by NCTCOG, total non-construction jobs in the metropolitan planning area (MPA) grew from 2,056,060 in 1990 to 2,507,740 in 1998, with the addition of 451,680 new jobs. A simple decentralization indicator is applied to see if the job growth is related to job decentralization. The most widely used method is perhaps to compute a density gradient from the regional center. The employment density gradient in a negative exponential form is written

$$D_x = D_0 \exp(-gx)$$

where D is employment density measured in number of employees per developed acre in each census tract, x is the straight-line distance from the geometric center of each census tract to the CBD in miles, D_0 is employment density at distance zero (i.e., downtown Dallas in Dallas MSA and downtown Fort Worth in Fort Worth MSA), and g is the density gradient. Lower values of g indicate the greater decentralization of workplaces.

Table 5.1 presents changes of employment density gradient in the Dallas-Fort Worth over three-year points: 1990, 1995, and 1998. Although one needs to consider a longer term to see clear changes, the indicator demonstrates that job distribution has taken a more decentralized form since the estimated density gradients are lower in recent years.

Table 5.1 Changes in employment density gradient

Year	g	R^2	Non-construction employment
1990	-0.1084	0.251	2,056,057
1995	-0.1003	0.258	2,245,722
1998	-0.0981	0.250	2,507,743

In order to see which part of the region added new jobs over the last decade, Table 5.2 presents employment growth in the top ten cities that capture the largest share of jobs in the region. Two central cities, Dallas and Fort Worth, continue to dominate economic activities in the region by accounting for the largest shares of employment. However, the highest job growth rate is shown in a number of suburban cities, particularly in affluent northern suburban cities such as Plano, Irving, and Richardson. Suburban cities have gained the greater share of new jobs. Interestingly, the three suburban cities with the leading job growth rates in the region contain high-quality master-planned business parks (Legacy, Plano and Las Colinas, Irving) or concentrations of high-tech and producer-service information industries (Telecom Corridor, Richardson).

Table 5.2 Changes in employment in top ten cities

Rank	City name	Non-construction employment			Percent change		
		1990	1995	1998	1990-95	1995-98	1990-98
1	Dallas	809,650	854,400	930,700	5.5	8.9	15.0
2	Fort Worth	330,350	339,800	375,450	2.9	10.5	13.7
3	Irving	106,600	124,950	149,450	17.2	19.6	40.2
4	Arlington	90,100	101,600	109,850	12.8	8.10	21.9
5	Plano	54,450	71,100	87,250	30.6	22.7	60.2
6	Richardson	57,750	63,300	78,050	9.6	23.3	35.2
7	Garland	62,300	67,600	75,200	8.5	11.2	20.7
8	Farmers Branch	50,150	55,100	61,350	9.9	11.3	22.3
9	Grand Prairie	51,800	54,150	59,250	4.5	9.4	14.4
10	Carrollton	45,250	48,050	53,400	6.2	11.1	18.0

Source: North Central Texas Council of Governments, 2001

Figure 5.1 presents the spatial variation in employment density across the region in 1995. Again, greater job concentrations are shown in the part of the Dallas area. Employment decentralization appears to have directionality, by showing that job concentrations are selectively stretching out to the northern suburbs of Dallas. Job concentrations create a combination of clusters and corridors, which implies that major transportation nodes and strips are an important factor in job growth.

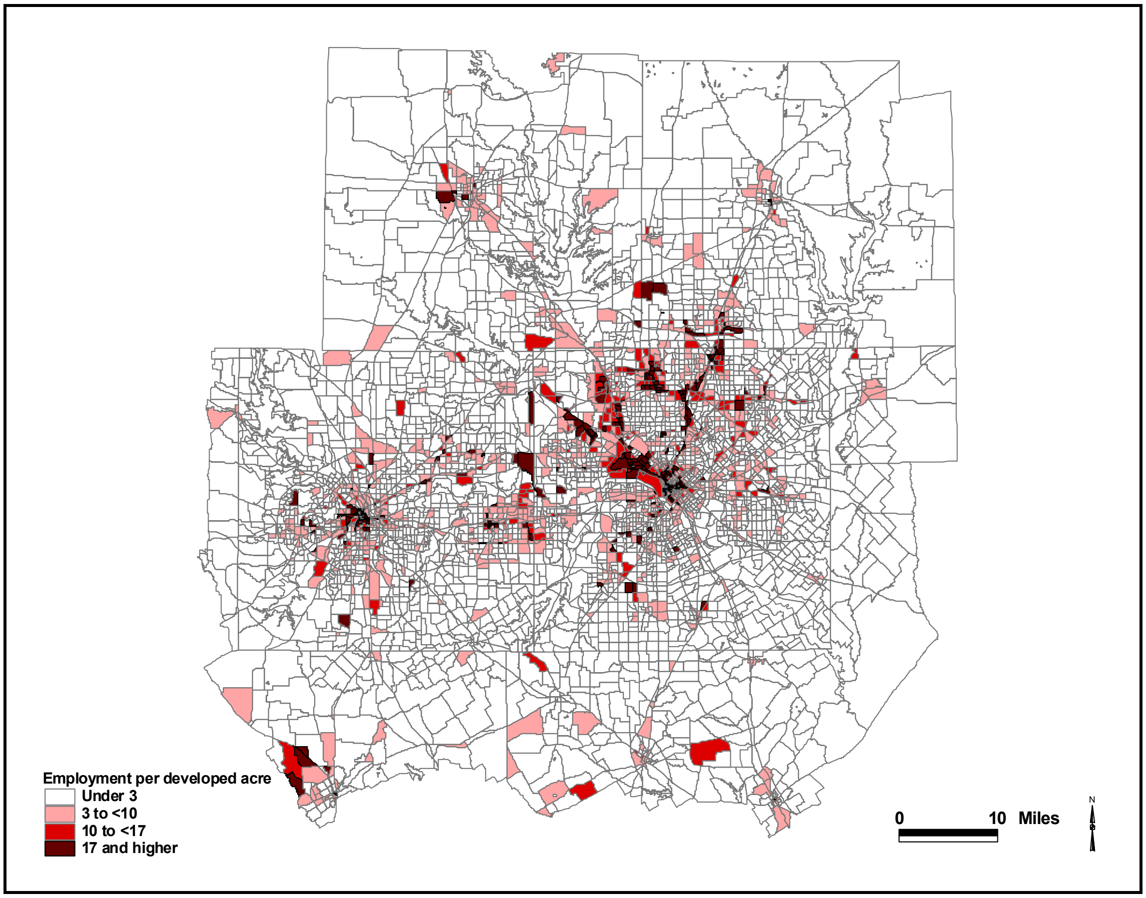

Figure 5.1 Spatial variation of employment density by TSZ, 1995

Polycentrism

Employment decentralization tends to take a polycentric form. In order to examine the characteristics of metropolitan structure, major employment centers in the region are identified by the criteria of a minimum density of 10 employees per developed acre and a total employment greater than 10,000 in 1995, as discussed in Chapter IV. Table 5.3 presents a basic profile of 17 major centers.

Downtown Dallas and its radial corridors, such as Stemmons Corridor (IH 35 E) and North Central Expressway Corridor (US 75), dominate economic activities in the region. Downtown Fort Worth constitutes a regional center. But, its dominance appears to be much smaller than downtown Dallas.

Table 5.3 Basic profile of major employment centers by rank

Rank	Location	1995 Employment	Area (acre) *	Employment density (per acre)	Distance from CBD (miles) **
1	Downtown Dallas	196,105	2,542.1	77.1	-
2	Stemmons Corridor (Dallas)	147,790	5,927.4	24.9	1-6
3	Downtown Fort Worth	101,652	2,195.8	46.3	-
4	North Central Expressway Corridor (Dallas)	87,659	2,476.7	35.4	3-10
5	Galleria (Dallas)	81,867	2,725.3	30.0	10-13
6	Las Colinas (Irving)	59,465	2,350.3	25.3	9-15
7	Arlington	52,092	3,119.4	16.7	11-16
8	North Stemmons Corridor (Dallas)	50,698	2,702.3	18.8	7-10
9	Telecom Corridor (Richardson)	42,276	1,867.4	22.6	10-15
10	Garland	36,679	2,321.1	15.8	7-12
11	Farmers Branch	24,770	1,520.0	16.3	10-13
12	Plano on the North Central Expressway (Plano)	24,678	1,318.0	18.7	15-18
13	Carrollton	22,109	1,198.4	18.4	11-14
14	Dallas-Fort Worth Airport	19,666	791.2	24.9	19-20
15	Dallas-Fort Worth Airport: Entrance	17,976	802.0	22.4	15-16
16	Legacy (Plano)	13,615	660.0	20.6	19-20
17	Naval Air Station (Fort Worth)	10,826	428.2	25.3	7-8
Totals of 17 centers		989,923	34,946	28.3	-

* Excludes residential, vacant, parks, and dedicated lands.

** Applies the distance from Fort Worth CBD for Arlington and Naval Air Station.

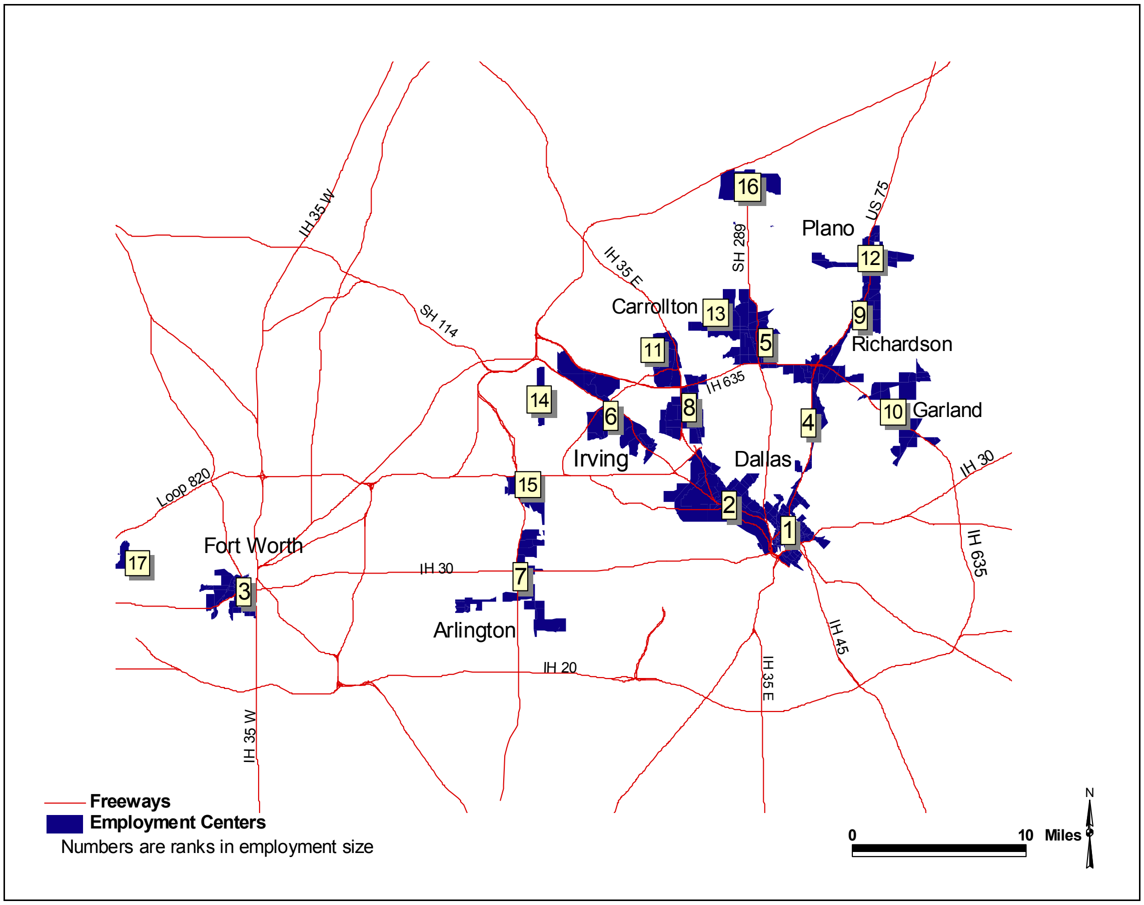

Figure 5.2 Location of major employment centers

While a few older and larger centers in the central city account for the largest share of employment, a majority of centers are medium-sized suburban centers, approximately 7 to 20 miles away from the CBD. Most suburban centers are located in the northern part of Dallas. Some suburban centers such as Arlington are those which once served as a town center before the decentralization absorbed them into the regional economy. Yet, many suburban centers, such as Las Colinas (Irving), Telecom Corridor (Richardson), and Legacy (Plano), are new suburban business parks that came from "greenfields". Like the Galleria area, relatively matured mixed-use suburban centers are also shown. Airports and their surrounding areas are another type of suburban center, like Dallas-Fort Worth Airport and Naval Air Station.

Employment density tends to rapidly decline over short distances from the CBD, and then decline modestly or remain stable thereafter. Compared to the downtowns of both Dallas and Fort Worth, most subcenters show much lower levels of employment density. Older subcenters, other than CBD, in the central city are not much different in land use density from suburban centers.

Major regional highways and the interchanges play an important role in employment development. Radial arteries from the CBD form business corridors, as shown in the cases of the Stemmons Corridor (Dallas) along the IH 35 E and the North Central Expressway Corridor (Dallas), the Telecom Corridor (Richardson), and Plano along the US 75. Regional beltways are also important in the formation of suburban centers as shown in a number of business corridors on the northern part of IH 635 (L. B. Johnson Freeway).

In his popular book, Garreau (1991) identified seven "edge cities" in the Dallas-Fort Worth area. While his criteria and spatial divisions are different, the location of edge cities identified by Garreau mostly corresponds to the location of centers identified in this study. In addition to Garreau's edge cities, this study captures other centers, including Garland, Arlington, Carrollton, and Farmers Branch. Some are satellite city centers or concentrations of conventional industries. The Dallas-Fort Worth Airport and Naval Air Station listed in this study are a type of special generator, but are not edge cities in Garreau's concept.

Scatteration

Along with polycentrism, scatteration is another important feature of job decentralization, in which large shares of individual employment sites are spread out throughout suburban and exurban areas. Table 5.4 presents the share of employment between the inside and the outside portions of the major centers in order to see the degree of scatteration.

Table 5.4 Employment by inside versus outside of 17 employment centers, 1995

	Employment		Area (acre)*		Employment density (per acre)
Inside center	989,923	(43.9)	34,946	(13.7)	28.3
Outside center	1,266,811	(56.1)	219,641	(86.3)	5.8
Total	2,256,734	(100.0)	254,587	(100.0)	8.9

* Excludes residential, vacant, parks, water, etc.

The seventeen centers account for about 44 % of employment in the region, leaving 56 % of the jobs outside the centers. In other words, more than half of the total jobs are located in low-density small-sized scattered employment sites in the region. Yet in terms of land area, the 17 centers account for only 13.7 % of the total amount of non-residential land uses.

The scatteration indicator does not directly tell us the absolute extent to which workplaces are dispersed. Other similar studies might help draw some clue. In the Los Angeles region, where urban structure is considered to be highly "dispersed", Giuliano and Small (1991) found that about 68% of total employment was outside any of the 32 centers. In a recent study, Lang (2000) found 34.6% of office space was outside of downtowns and edge cities in the Dallas area. He suggested that office development patterns in the Dallas area tend to be "dispersed". Employment development patterns in the Dallas-Fort Worth area may not be as extreme a case of workplace sprawl. It seems more reasonable to describe it as "dispersed".

Identifying Spatial Dimensions around Workplaces

Based on the 270 sampled worksites of the 1994 NCTCOG Workplace Survey, this section identifies important spatial dimensions that define different workplace locations. Spatial characteristics are figured out by calculating distributions of jobs, housing, and transportation provisions around individual worksites. Table 5.5 presents summary statistics on the spatial characteristics around the 270 workplaces.

Table 5.5 Summary statistics on the spatial characteristics for 270 workplace locations

	Mean	Standard Deviation	Range	
			Minimum	Maximum
Job distribution around workplaces				
% Employment land uses (within a half-mile radius)	39.90	22.67	2.60	89.80
Employment density (per non-residential developed acre in TSZ)	87.76	296.16	0.64	3,083.21
Entropy index of land use mix (within a half-mile radius)	0.59	0.19	0.00	0.96
% Retail land uses (within a half-mile radius)	15.08	11.58	0.00	57.54
% Office land uses (within a half-mile radius)	12.03	15.10	0.00	58.10
% Industrial land uses (within a half-mile radius)	15.57	21.25	0.00	99.95
Regional accessibility index to other workplaces	300.74	119.95	61.52	526.84
Distance to CBD (in miles)	8.56	7.25	0.15	42.21
Housing distribution around workplaces				
% Residential land uses (within a one-mile radius)	33.91	23.89	0.00	87.89
Housing density (per residential acre in census tract)	21.88	54.86	0.00	252.27
% Multi-family residential land uses (within a one-mile radius)	5.72	7.33	0.00	41.08
Median value of owner-occupied housing (in census tract)	95,313	54,308	22,500	424,900
Ratio of housing to jobs (within four-mile radius)	0.67	0.50	0.17	3.60
Regional accessibility index to houses	173.57	49.16	51.64	275.71
Transportation provisions around workplaces				
% Workplaces within a quarter-mile radius from bus transit routes	68.52	-	-	-
Distance to the nearest controlled-access highway (in miles)	0.62	0.62	0.10	3.75

First, greater variations are shown in both employment and housing density. Particularly, the standard deviation of employment density is more than three times the mean value. Distributions of density are highly skewed, indicating a few high-density locations, with the remainder being mostly low-density locations.

Second, the mean ratio of housing to jobs is 0.67, indicating more jobs than houses around the sampled workplace locations. In general, both the ratio of housing to jobs at workplace locations and the ratio of jobs to housing at residential locations tend to be less than one, while both the ratio of jobs to housing at workplace locations and the ratio of housing to jobs at residential locations tend to be more than one. The housing-jobs ratio of the Dallas-Fort Worth region as a whole is 1.03, indicating that jobs and housing are almost balanced regionally.

Third, office and industrial land uses have greater variations across different workplace locations than retail land uses, indicating that office and industrial activities tend to cluster more than retail activities.

Fourth, more than a half of the sampled workplaces are within a quarter-mile radius from any bus transit route. Yet, the simple measure of distance does not reflect the quality of public transit service such as fare, operation interval, and access to transit stops. Further, workplaces (destinations) tend to have higher accessibility to public transit than residences (origins) since public transit routes go through the major activity corridors. Workplaces generally show a high degree of accessibility to highways, implying that highways are an important factor in business location (Shukla and Waddell 1991).

Factor Analysis

It has been suggested that spatial characteristics of a place can be described more effectively with composite dimensions that are made up through the synergy of various individual spatial elements (Cervero 1989a; Cambridge Systematics, Inc. 1994; Cervero and Kockelman 1997). A single element of urban form may display complementary or conflicting relationships to other spatial elements. For example, the share of retail land uses is likely to be positively correlated with the share of residential land uses because of the strong tendency towards customer orientation in retail activities. The degree of decentralization is likely to be negatively correlated with employment density and public transit availability. Using exploratory factor analysis, this section identifies a small number of composite variables (or "factors") that are helpful in summarizing the characteristics of workplace environs. Factor analysis is a generic term for multivariate statistical techniques that are concerned with data reduction and summarization (Hutcheson and Sofroniou 1999; SAS Institute Inc. 2000). It helps capture "latent" spatial dimensions that are explained by sets of "observable" elements.

The 16 original variables, which represent the spatial characteristics surrounding each of the 270 workplaces, were entered into the model of common factor analysis to obtain a smaller number of composite variables or underlying spatial factors for the workplace locations. A natural log transformation was applied to both employment and housing density variables to make them normally distributed.

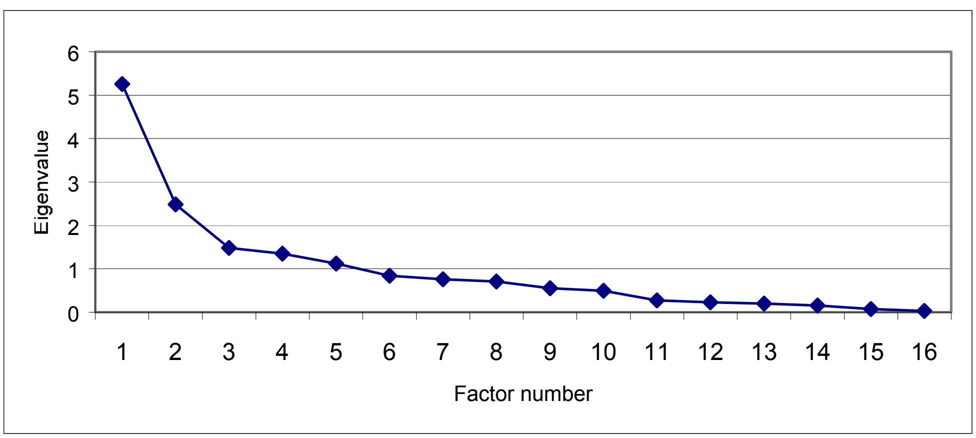

Figure 5.3 Scree plot of eigenvalues with the number of factors

There are no absolute criteria to determine the optimal number of factors. One of the most commonly used rules is to decide the number of factors where the eigenvalue (the variance in a set of original variables explained by a factor) is greater than one. The rationale is that each factor should have a variance at least as large as the variance of a single original variable. According to Figure 5.3, the proper number of factors appears to be five because it is the lowest number at which the eigenvalue is above 1.

Once the number of factors is decided, the next step is to determine the method of rotation to obtain a simpler and more meaningful factor structure. This study conducted the "promax" rotation, one of oblique rotation methods allowing factors to be correlated with one another. The reason for using this method is due to the possibility of correlation between spatial factors (Cervero and Kockelman 1997).

Table 5.6 shows the contribution ("factor loadings") of the original variables to each of the factors. To reduce complexity and ease of interpretation, only factor loadings higher than 0.4 are shown in the table. The 5 factors, which represent the underlying spatial dimensions of workplace environs, account for about 73% of the total variation in the 16 original variables. In other words, there is 27% loss in information by reducing the 16 original variables to the 5 composite variables.

Table 5.6 Factor loadings from common factor analysis

Original variables	Composite variables (Factors)				
	1	2	3	4	5
% Office land uses	0.923				
Employment density	0.834				
Housing density	0.781		-0.415		
Entropy index of land use mix	0.537				
Ratio of housing to jobs	-0.564		0.493		
Regional accessibility index to houses		0.902	-0.498		
Regional accessibility index to workplaces	0.426	0.897	-0.507		
Median value of owner-occupied housing		0.638			
% Multi-family residential land uses		0.553			0.409
Distance to the nearest bus transit route			0.875		
Distance to CBD	-0.489		0.814		
% Industrial land uses				0.847	
% Employment land uses	0.620			0.783	
% Residential land uses	-0.538			-0.694	
% Retail land uses					0.878
Distance to the nearest controlled-access highway	-0.436				-0.493
Summary statistics:					
Eigenvalue	5.257	2.485	1.483	1.346	1.119
Proportion of variation explained	0.329	0.155	0.093	0.084	0.070
Cumulative proportion of variation	0.329	0.484	0.577	0.661	0.731

Using the size and sign of factor loadings, each factor needs to be interpreted and named to help understand what aspect of workplace environs it captures. Figure 5.4 illustrates the process of naming each spatial factor. Note that the illustration only shows a few original variables having significant factor loadings for each factor. Since the illustration is simply for the purpose of ease in understanding, it should not be interpreted as if each factor is constructed only by those variables listed.

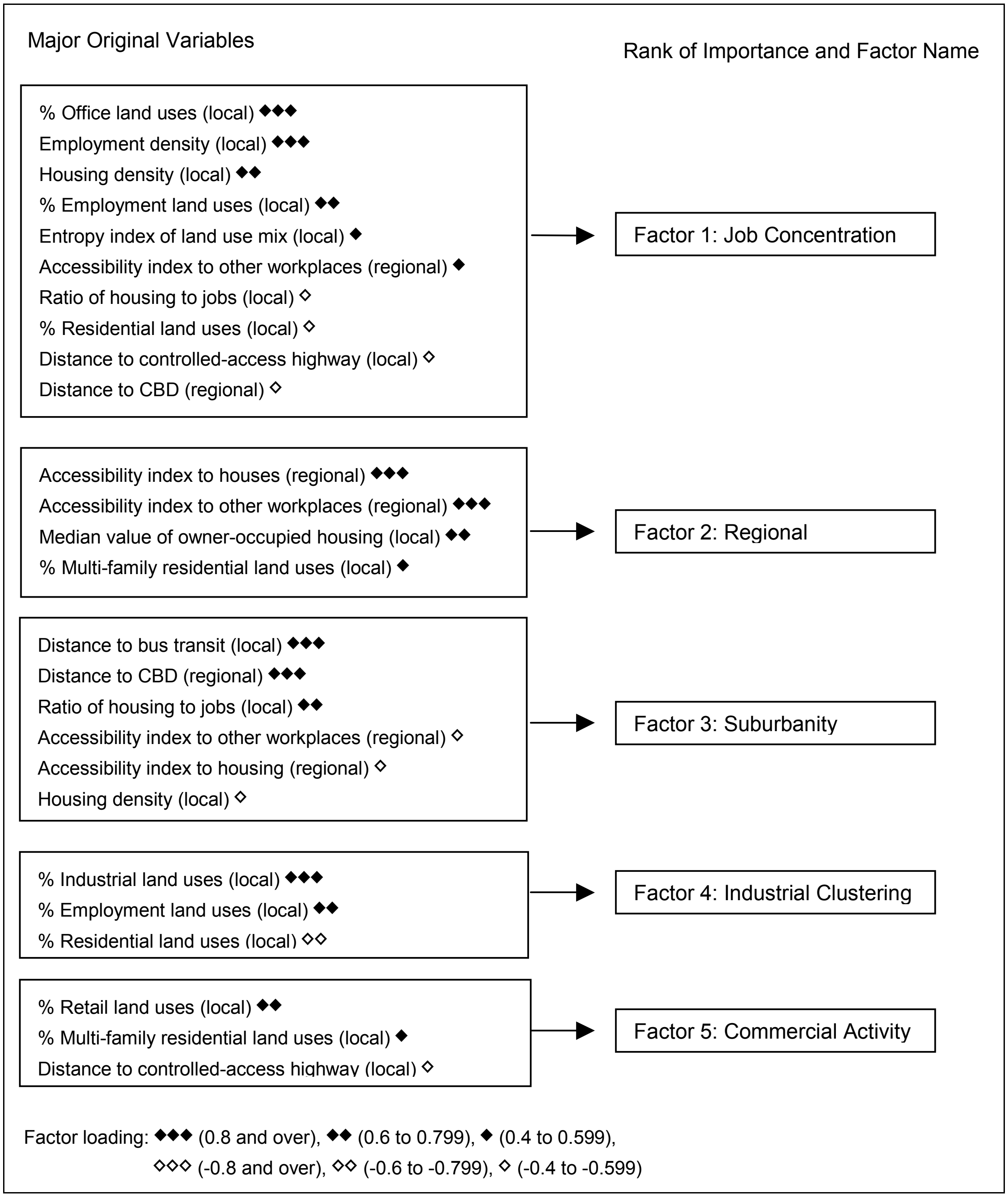

Figure 5.4 Original variables and labeling spatial factors

Factor 1, which accounts for the largest portion (32.9%) of the variance, appears to capture the degree of "job concentration" or simply "land use intensity" around a workplace. This factor is positively associated with office land use, housing and employment density, employment land use, land use mix, and many other urban compactness indicators. Some residential indicators such as the housing-jobs ratio and residential land use are negatively associated with this factor. The combination is consistent with intuitive expectations, as high-density employment areas tend to have high shares of office activities and high-density residential areas in the vicinity. Note again that this factor is the strongest factor to characterize workplace locations. This appears consistent with general notions that relate low-density dispersed development to sprawl (Burchell, et. al. 1998).

Factor 2, accounting for 15.5% of the variance, appears to mainly represent the "regional accessibility to housing and jobs" of a workplace. This factor helps identify whether a workplace is located in regional growth axes. The greater accessibility of a workplace to jobs and housing is also positively associated with high levels of housing prices and housing diversity (represented by the share of multi-family residential land uses). The negative relationship between accessibility and housing prices is consistent with economic theories in the sense that housing prices are a function of accessibility. Also, the combination appears related to the argument that compact development drives up housing prices.

Factor 3, accounting for 9.3% of the variance, appears to capture "suburbanity" or the degree of "decentralization" of a workplace. Among others, this factor is most strongly associated with the distance to CBD, distance to public transit, and ratio of housing to jobs. Levels of regional accessibility to housing and jobs and housing density around a workplace are negatively associated with this factor. The combination of variables for the "suburbanity" factor seems consistent with the image of suburbs in the sense that suburban workplaces in general should be farther from the primary regional center, less accessible by public transit, and surrounded by low-density residences.

Factor 4, accounting for 8.4% of the variance, appears to represent the degree of "industrial clustering" around a workplace. This factor is positively associated with industrial and employment land uses and negatively associated with residential land use. The apparent incompatibility between industrial and residential land uses is identified by this factor.

Finally, Factor 5, accounting for 7% of the variance, appears to represent the dimension of "commercial or retail activity" around a workplace. This factor is positively associated with retail and multi-family residential land uses and highway accessibility. The association of retail land use with highway accessibility implies that retail centers have often been developed as strip centers along major highways and arterials.

The labels for the five factors (job concentration, regional accessibility, suburbanity, industrial clustering, and commercial activity) may not fully capture the nature of the factors since the factors are not observable and combined by various observable individual variables. Nevertheless, the composite variables or spatial factors should help extract important dimensions of workplace environs. The five spatial factors are also helpful in identifying "affinity" and "exclusion" among various individual spatial elements.

Spatial Characteristics by Workplace Location

Individual Variables for Workplace Environs

Table 5.7 presents average statistics on the original 16 variables representing spatial characteristics around the 270 workplaces from the combination of two locational dichotomies: central versus suburban and inside versus outside major employment centers. The distinction between "central" and "suburban" is based on the straight-line distance points of 9 miles away from downtown Dallas and 6 miles away from downtown Fort Worth. The "major employment centers" are those 17 centers identified in the prior section.

Table 5.7 Mean statistics on spatial characteristics of 270 workplaces by location type

	Central		Suburban		F-statistic
	Inside center	Outside center	Inside center	Outside center	
Jobs distribution around workplaces					
% Employment land uses (within a half-mile radius)	56.17	24.50	55.54	23.12	91.95**
Employment density (per non-residential developed acre in TSZ)	249.92	20.31	28.65	10.11	13.19**
Entropy index of land use mix (within a half-mile radius)	0.70	0.54	0.64	0.50	21.91**
% Retail land uses (within a half-mile radius)	13.88	12.79	18.50	15.38	2.62*
% Office land uses (within a half-mile radius)	26.51	2.07	14.39	2.47	84.57**
% Industrial land uses (within a half-mile radius)	14.23	9.69	30.51	10.59	13.68**
Regional accessibility index to workplaces	374.74	308.66	337.81	199.09	49.13**
Distance to CBD (in miles)	1.55	5.29	12.16	15.01	141.12**
Housing distribution around workplaces					
% Residential land uses (within one-mile radius)	17.51	57.98	27.83	39.15	50.40**
Housing density (per residential acre in census tract)	56.51	7.46	9.40	5.20	18.54**
% Multi-family residential land uses (within one-mile radius)	4.80	7.90	7.24	4.29	3.89**
Median value of owner-occupied housing (in census tract)	91,272	86,761	113,336	92,569	2.71**
Ratio of housing to jobs (within four-mile radius)	0.31	0.73	0.53	1.09	57.98**
Regional accessibility index to houses	185.46	189.19	187.54	143.11	18.38**
Transportation provisions around workplaces					
% Workplaces within a quarter-mile radius from bus transit route	95.06	84.31	80.64	25.27	17.51**†
Distance to the nearest controlled-access highway (in miles)	0.34	0.67	0.48	0.95	96.02**
No. of cases	81	51	55	83	

* Indicates significance at the 0.1 level and ** indicates significance at the 0.05 level
† Based on chi-square

While the statistics on spatial characteristics are mostly consistent with the common image of the metropolitan landscape, there are also several interesting findings to be noted. Workplaces inside of employment centers in central areas show generally higher levels in urban compactness indicators such as density, land use mix, and regional accessibility. Both employment and housing density are particularly higher in this location type. For housing-related indicators, workplaces inside of centers in central areas exhibit higher levels in regional indicators (e.g., regional accessibility to housing) but lower levels in local indicators (e.g., ratio of housing to jobs). However, except for density indicators, spatial characteristics of workplaces in centers in central areas are not so distinct from other location types, particularly from workplaces inside of suburban centers.

Workplaces in suburban centers appear to attain some level of compact development. For example, the entropy index of land use mix and regional indices of housing and job accessibility are considerably high in this location type. The accessibility to public transit is also high. Yet, both employment and housing density are much lower than in workplaces in centers in central areas.

Some housing-related indicators (e.g., ratio of housing to jobs, percent of multi-family residences, and regional accessibility to housing) are higher around workplaces in suburban centers than those in centers in central areas, implying that an important factor for new business locations is quality housing and labor force in the suburbs. It is interesting to note that the share of multi-family residences is relatively higher around workplaces in suburban centers. This indicates that some multi-family houses have been constructed in the vicinity of major suburban centers.

While the share of office land uses is higher around workplaces in centers in central areas, both shares of retail and industrial land uses are higher around workplaces in suburban centers. The share of industrial land uses is particularly higher around workplaces in suburban centers. The patterns are consistent with general trends of business development, as retailing moved out to the suburbs to capture suburban customers, and manufacturing and distribution industries moved to new suburban industrial parks to secure cheaper sites for plants and warehouses.

Workplaces outside of major employment centers exhibit high levels in housing indicators, while workplaces inside of the centers exhibit high levels in job indicators. For those workplaces outside of centers, workplaces in central areas are not so different from suburban workplaces in local spatial indicators, particularly job indicators (e.g., land use mix, share of employment land uses). Yet, suburban workplaces show higher levels in housing-jobs ratio but lower levels in housing density and diversity, indicating low-density single-family oriented suburbs. Not surprisingly, suburban workplaces exhibit the lowest levels in public transit accessibility and in regional accessibility to jobs and housing.

Overall, differences in spatial characteristics are more distinct between workplaces inside and outside of major employment centers than between workplaces in central and suburban areas. It appears that density is the single most important factor that clearly distinguishes spatial characteristics of workplaces in central areas from those in suburbs. Workplaces in suburban centers attain some level of compact development in terms of jobs, housing, and transportation.

Spatial Factors

While the previous part presented the spatial characteristics around workplaces in terms of individual and observed spatial indicators, this part characterizes workplaces in terms of underlying spatial dimensions by using the 5 spatial factors (job concentration, regional accessibility, suburbanity, industrial clustering, and commercial activity) drawn by factor analysis. Factor scores, standardized scores of cases (i.e., workplaces) on each factor as drawn by factor analysis, are compared by workplace location to identify differences in spatial characteristics.

Figure 5.5 shows average scores of workplace locations in the five spatial factors.

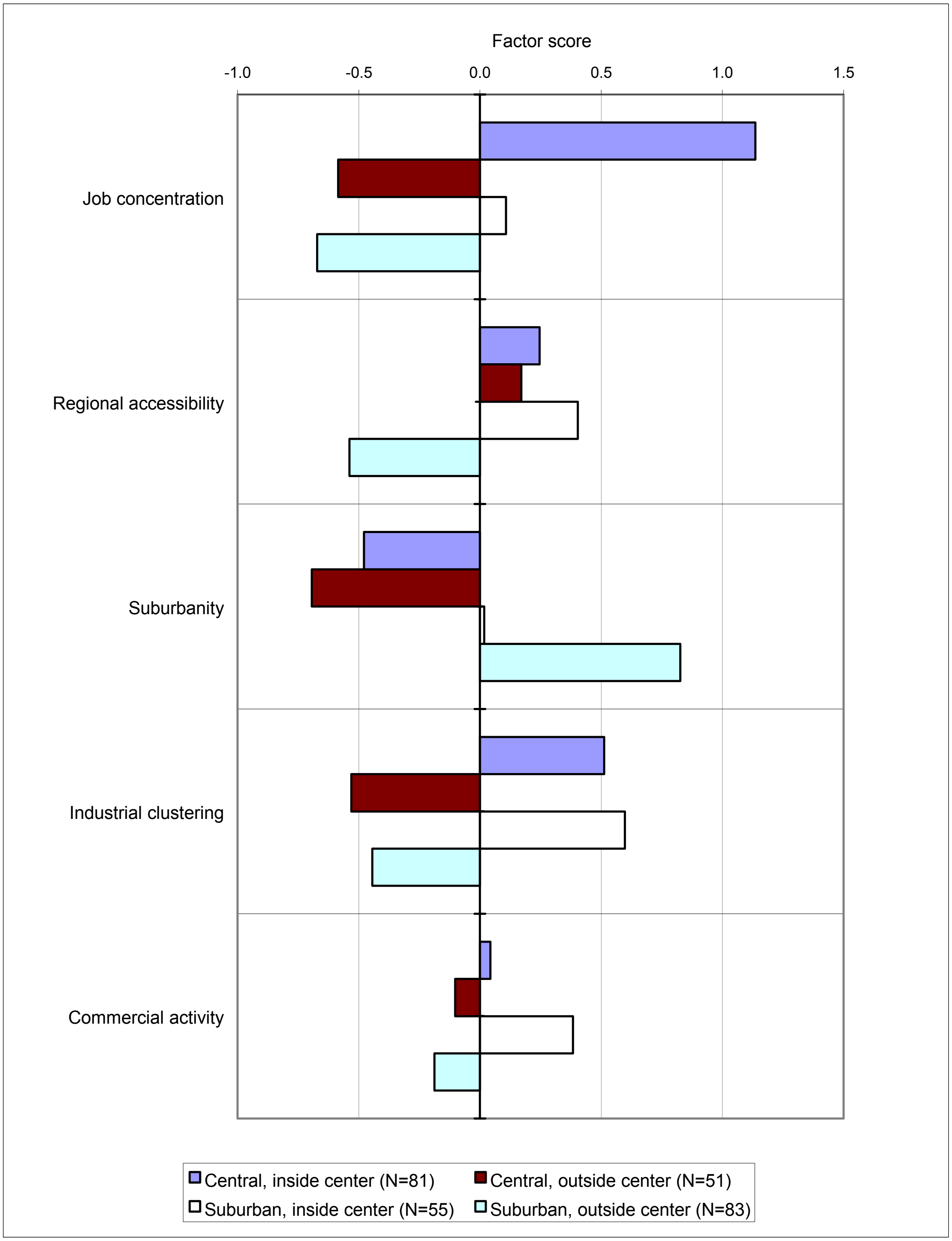

Figure 5.5 Mean scores on spatial factors by workplace location

Table 5.8 F-statistics for the comparisons of workplace locations in spatial factors

	Job concentration	Regional accessibility	Suburbanity	Industrial clustering	Commercial activity
F-statistic (p-value)	117.78 (0.0001)	16.60 (0.0001)	60.41 (0.0001)	38.37 (0.0001)	2.84 (0.0382)

The "job concentration" factor, which includes the share of employment, particularly office land use, employment density, housing density, and land use mix as major components, is highest in workplaces in centers in central areas. This factor is among the strongest factors that distinguish workplaces in different locations. Healthy economies of older downtowns appear to be reflected in this factor: office and density. The lowest scores in this factor are shown in workplaces outside of centers in both central and suburban areas. Although workplaces in suburban centers attain some levels in the average score, the score is much lower than those of their counterparts in central areas. The distribution of scores indicates that density and office spaces mainly concern inside versus outside of major activity centers, rather than the central city versus suburbs.

The "regional accessibility" factor includes the regional accessibility of housing and jobs, housing prices, and the share of multi-family residences as major components. In general, workplaces inside of employment centers show higher scores than workplaces outside of centers, indicating that employment centers constitute regional axes of urban activities. Workplaces in suburban centers exhibit higher scores on average than their counterparts in central parts of the region, indicating that suburban centers have some competitive power in regional accessibility to older primary centers. Yet, the higher score of workplaces in suburban centers is partly due to higher housing prices and variety in housing types in the vicinity of centers (see the linear combination of individual variables in Figure 5.4, page 91). Suburban workplaces outside of centers exhibit particularly lower scores in this factor.

The "suburbanity" factor, which includes the distance to CBD, distance to public transit, and ratio of jobs to housing as major components, is highest in suburban workplaces outside of major centers. Not surprisingly, workplaces in central areas show on average the lowest score. The average score of workplaces in suburban centers is not high, indicating that the workplaces are not really so "suburban." Part of the reason is that most suburban centers in the Dallas-Fort Worth area are located in the inner part of the suburbs with the good accessibility to housing and other firms.

The "industrial clustering" factor is mainly related to high shares of industrial and employment land uses and low shares of residential land uses as major components. In this factor, there is a clear contrast between those workplaces inside of centers and those outside of centers, indicating that industrial development, including manufacturing and warehousing, tends to cluster in a few districts. Suburban workplaces in general show slightly higher scores than their counterparts in central parts of the region, indicating that manufacturing and distribution industries have been decentralized to suburban industrial and business parks.

The "commercial activity" factor includes the share of retail land use and proximity to major highways as major components. Workplaces in suburban centers are highest on average. Compared to workplaces outside of centers, those inside of centers show higher average scores. Note that workplaces outside of centers in central areas get slightly lower scores than suburban workplaces outside of employment centers.

Overall, the differences in spatial characteristics are more distinct between those workplaces inside and outside of major employment centers than between those workplaces in central and suburban areas. Local spatial factors (job concentration, industrial clustering, and commercial activity) are particularly distinct in the dichotomy of "inside versus outside center" than in the dichotomy of "central versus suburban." Workplaces in suburban centers share many spatial characteristics with their counterparts in central areas, rather than with other scattered employment sites in suburbs. However, the degree of "job concentration," the most influential spatial factor, is far lower than their counterparts in the central city.

Suburban Downtown, Master Planned Community, and High-Tech Corridor

An interesting question is how suburban employment centers differ in spatial characteristics from one another. Since suburban centers play an important role in shaping urban development and transportation, it would be meaningful to look at their spatial characteristics. This section examines spatial characteristics of workplaces in three types of suburban centers: suburban downtown, master planned community, and high-tech corridor. These three types are perhaps among the leading suburban location types that have accommodated producer services and high-tech industries over recent decades. As a representation of each type, this study selects three locations: Galleria (Dallas), Las Colinas (Irving), and Telecom Corridor (Richardson). All the three centers are located in the northern part of Dallas.

Land Use

Figure 5.6 shows a portion of the Galleria area. Located around the intersection of IH 635 (L. B. Johnson Freeway) and Dallas North Tollway, this area is a downtown-like mixed-use center in terms of physical and functional characteristics. As indicated by the name, it is centered on a large mixed-use shopping complex. The type of center has various names, including edge city (Garreau 1989), suburban downtown (Hartshorn and Muller 1989), and sub-city (Cervero 1989a).

Freeways and the interchange appear to be a major locational factor. While retail activities constitute an anchor, this area also contains a variety of business activities such as office and industrial. As clearly shown in the figure, retail buildings are surrounded by vast horizontal parking lots. It is notable that this includes some portion of multi-family housing as well as single family housing in close proximity to the center. There is also some portion of vacant lands, indicating that the suburban center has the potential for further growth.

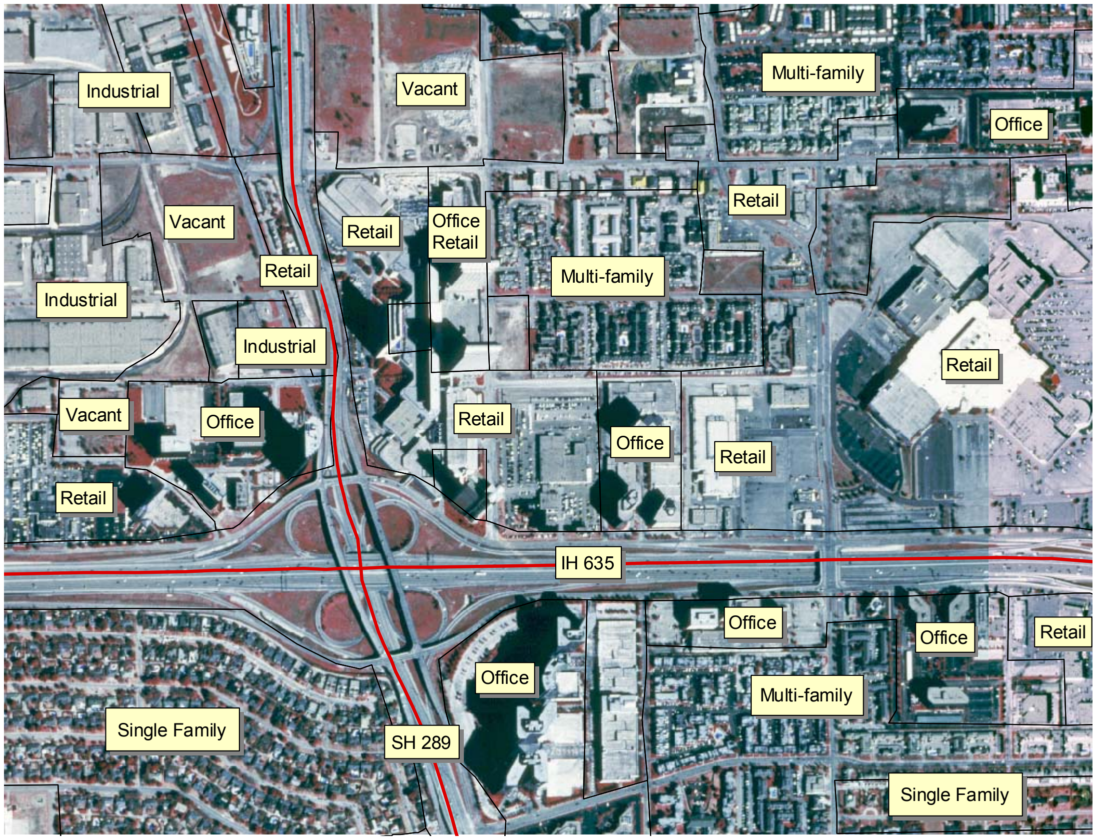

Figure 5.6 Aerial photograph of Dallas Galleria (part)

Figure 5.7 shows a portion of Las Colinas. Located along SH 114 (J. W. Carpenter Freeway) near the Dallas-Fort Worth Airport, this area is a large-scale master planned business and residential community, containing commercial, residential, and recreational activities. This is a classic example of "greenfield" development (Leinberger 1988; Garreau 1989).

Superblocks bounded by curvilinear roadway networks are clearly shown in the figure. This area appears to be more specialized in office activities. Vast horizontal parking lots buffer commercial buildings. Recreation facilities and water bodies reflect the quality of this area. This area also contains a portion of multi-family housing as well as vacant lands.

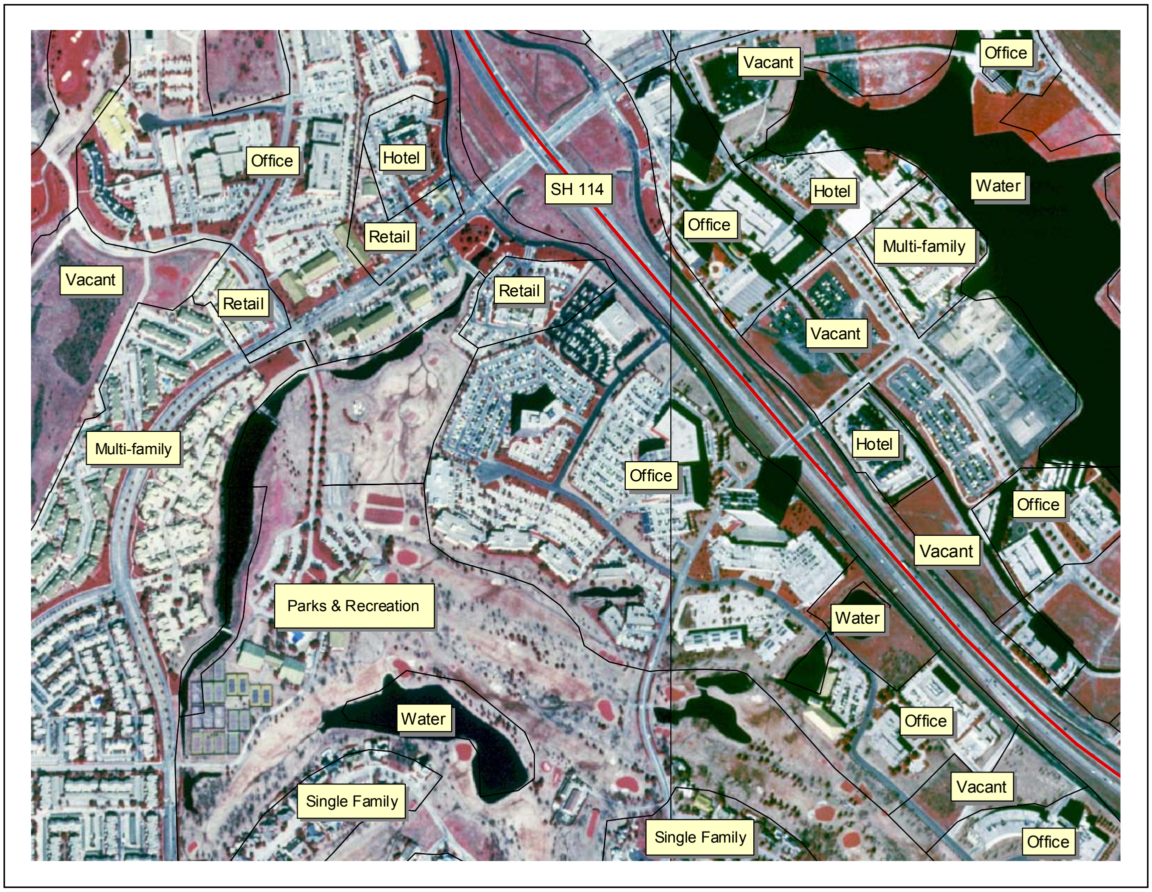

Figure 5.7 Aerial photograph of Las Colinas (part)

Figure 5.8 shows a portion of the Telecom Corridor. Located along US 75 (North Central Expressway) and SH 190 (George Bush Freeway), this area has a large concentration of cutting-edge telecommunications and technology-based enterprises.

Like Las Colinas, this area is structured by superblocks and curvilinear roadway networks. While industrial districts are a driving force of growth, this area also includes a large portion of office and institutional activities. Vacant lands indicate that this area is still in the process of development.

Figure 5.8   Aerial photograph of Telecom Corridor (part)

Overall, the three figures demonstrate that suburban centers take advantage of major freeways and interchanges. Like many typical centers, Las Colinas and Telecom Corridor clearly show superblocks bound by curvilinear roadway networks. Each office or commercial building is buffered by extensive horizontal parking lots, indicating that suburban employment is a product of automobile age.

Compared to Las Colinas and Telecom Corridor, the Galleria appears to attain some level of high-intensity and mixed-use land development. Las Colinas and Telecom Corridor exhibit more park-like settings. These two areas are more specialized in office and industrial activities respectively. A portion of vacant lands is shown in all the three areas, indicating that the centers are still in the evolving process of development. Some portions of high-density multi-family houses are also shown in the three areas, particularly in the Galleria. This shows that high-density housing development would have suburban markets as suburban centers become mature.

Spatial Factors

Figure 5.9 summarizes the average scores on the five spatial factors of workplace environs for sampled workplaces in the three centers. For the purpose of comparison, factor scores for workplaces in downtown Dallas are also included.

In the "job concentration" factor, downtown Dallas shows a much higher average score than the suburban centers. Galleria shows a slightly higher score of the three suburban centers. Yet, the differences among the suburban centers appear to be moderate. Telecom Corridor exhibits the lowest score, possibly because of the single-floor operations in hi-tech companies.

In the "regional accessibility to housing and jobs" factor, downtown Dallas, Galleria, and Las Colinas show similar scores. Telecom Corridor exhibits the lowest score. Compared to other centers, Telecom Corridor is geographically located in the less central part of the Dallas-Fort Worth region. Galleria shows slightly higher scores than downtown Dallas. Part of the reason may be for higher housing prices and more housing diversity (see the linear combination of individual variables in Figure 5.4, page 91) within the Galleria.

In the "suburbanity" factor, Las Colinas exhibits the highest score because of its farther distance from CBD and lower accessibility of public transit. Not surprisingly, downtown Dallas shows the lowest score.

In the "industrial clustering" factor, Telecom Corridor shows the higher score on average than other centers. Las Colinas shows the lowest score because of office specialization.

In the "commercial activity" factor, the Galleria area exhibits the highest score, indicating that this area is literally an "edge city" anchored by large-scale shopping malls.

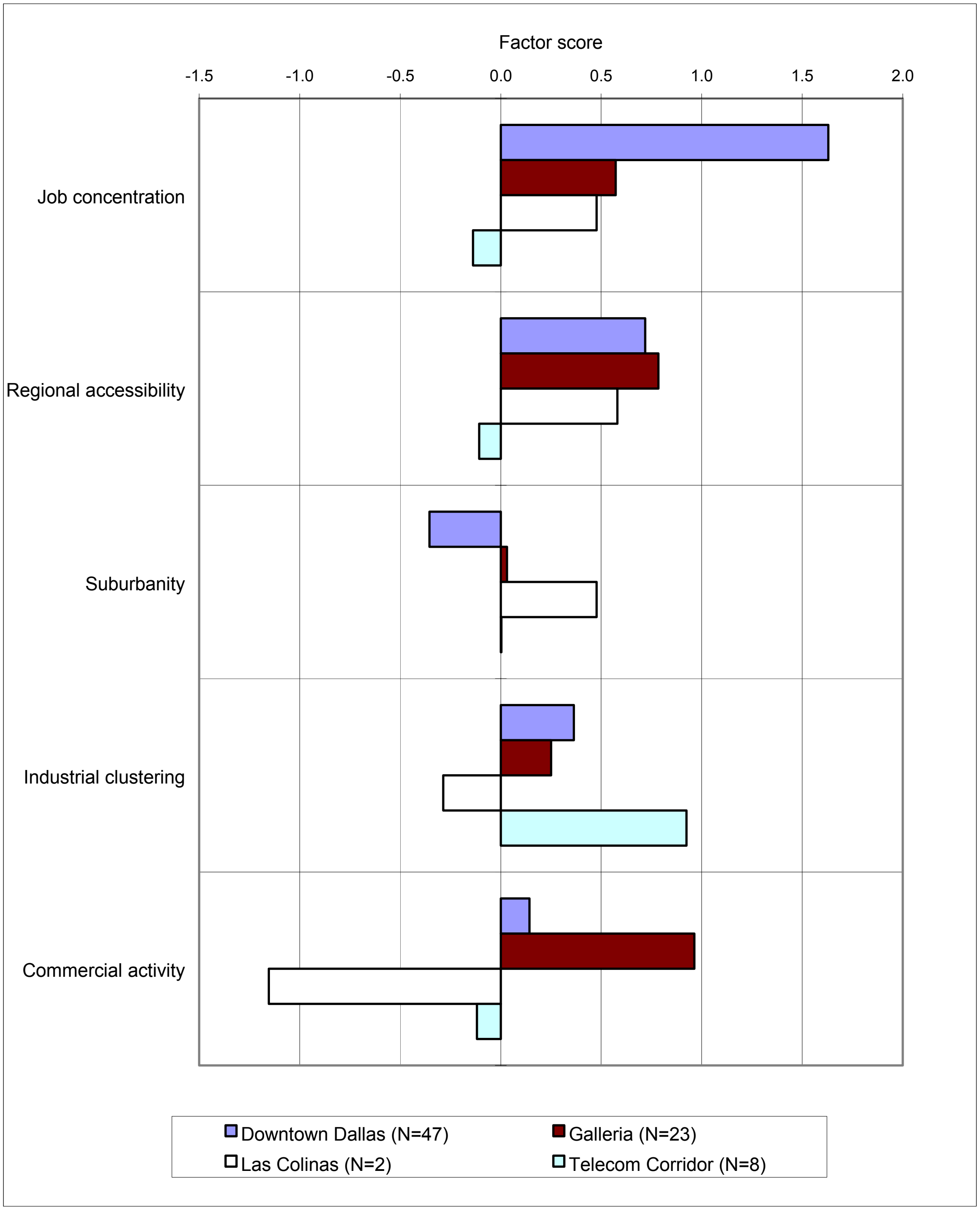

Figure 5.9 Mean scores on spatial factors of four major employment centers: Downtown Dallas, Galleria, Las Colinas, and Telecom Corridor

Table 5.9 F-statistics for the comparisons of four employment centers in spatial factors

	Job concentration	Regional accessibility	Suburbanity	Industrial clustering	Commercial activity
F-statistic (p-value)	17.31 (0.0001)	6.72 (0.0004)	12.59 (0.0001)	2.65 (0.0546)	2.97 (0.0372)

Overall, the differences in spatial factors among the three suburban centers tend to be larger in the factors of "job concentration" and "suburbanity." Differences are moderate in the factors of "industrial clustering" and "commercial activity." In relation to downtown Dallas, the three suburban centers show far lower scores in the "job concentration" factor. The results indicate that, while major suburban centers attain some level of compact development in terms of activity mix and regional accessibility, the intensity is far lower than their counterparts in the center city. The three suburban centers are not so different in spatial characteristics.

Classifying Suburban Workplaces

Cluster Analysis

Policy concerns using land use strategies to address transportation issues such as automobile dependence and air quality are in many cases related to how to make suburban development better. Since suburbs are in the evolving process, there is room for applying new planning strategies for infill and new development. Thus, it would be meaningful to identify different types of suburban workplace locations and their spatial characteristics.

This study uses cluster analysis to classify suburban workplaces by their surrounding spatial characteristics. Cluster analysis is a statistical technique used to combine a large number of cases into a few groups while the cases in each group are homogeneous with respect to certain characteristics (Kaufman and Rousseeuw 1990; SAS Institute Inc. 2000). Ward's minimum variance method was used as a clustering method. Five factors from the prior factor analysis (job concentration, regional accessibility, suburbanity, industrial clustering, and commercial activity) of workplace environs were used as reference variables to hierarchically cluster 138 suburban workplaces.

There are no absolute criteria to determine the number of groups. The larger number of groups indicates more emphasis on uniqueness of individual workplaces, while the smaller number does so on generality of workplaces. One of practical solutions is to use statistical tests to look for where the dissimilarity measures make a big change as the number of groups decreases. This study used the semi-partial R-square indicator, perhaps the most widely used statistic, to determine the number of groups. This statistic measures the loss of homogeneity resulting when two groups are merged.

Figure 5.10 indicates that the statistically optimum number of groups is two because the semi-partial R-square makes the largest jump when the 138 workplaces are grouped from two to one. Yet, this study needs more variations in workplace types to identify possibly wide variations in travel outcomes. Thus, this study sets the number of suburban workplace groups at five at which the curve makes an "elbow".

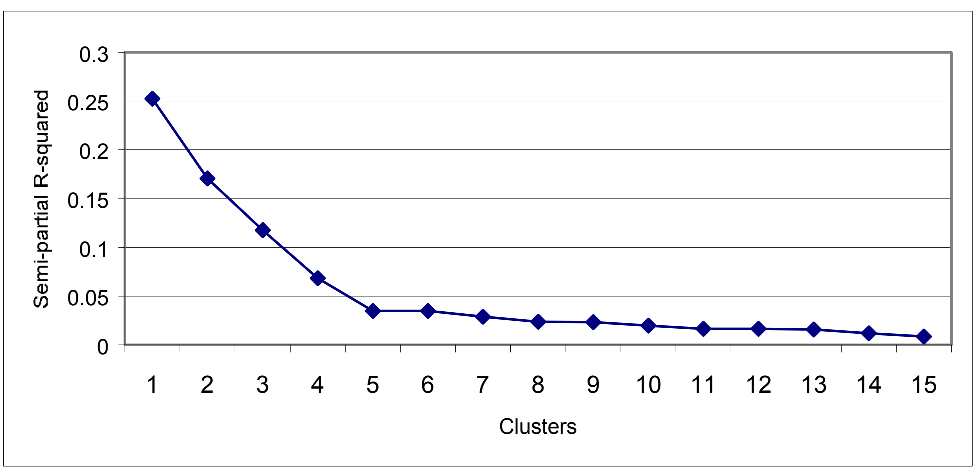

Figure 5.10 Changes in semi-partial R-square with the number of clusters

Suburban Workplace Types

Once the number of workplace groups is determined, the next step is to compare spatial characteristics among the suburban workplace groups and assign meaningful names. Due to the inductive nature of cluster analysis, one may give the proper name for each workplace group after the examination of spatial characteristics. However, for ease of discussion, this study first gives the workplace groups the names and then compares their characteristics. Names for the five suburban workplace groups are "core," "industrial," "intermediate," "residential," and "peripheral." Note that the naming is based on typical characteristics of workplaces in each group. Some workplaces may not neatly correspond to general characteristics of the type to which workplaces belong.

Table 5.10 shows the frequency of suburban workplaces by industry and workplace type. The "core" includes the larger number of workplaces in service businesses (e.g., finance, insurance, real estate, etc.). As the group name suggests, the "industrial" includes the larger number of workplaces in basic industries. Workplaces in retail businesses are particularly lower in this type, implying that the industrial activities are less oriented to customers. Both "intermediate" and "residential" include the larger number of retail businesses, indicating that these types are more oriented to customers. The "peripheral" includes a wider range of business types.

Table 5.10 Number and percent of suburban workplaces by industry and workplace type

	Core	Industrial	Intermediate	Residential	Peripheral	Total
Retail	15 (36.6)	2 (8.7)	15 (55.6)	16 (59.3)	8 (40.0)	56 (40.6)
Service	21 (51.2)	8 (34.8)	11 (40.7)	11 (40.7)	8 (40.0)	59 (42.7)
Basic	5 (12.2)	13 (56.5)	1 (3.7)	0 (0.0)	4 (20.0)	23 (16.7)
Total	41 (100.0)	23 (100.0)	27 (100.0)	27 (100.0)	20 (100.0)	138 (100.0)

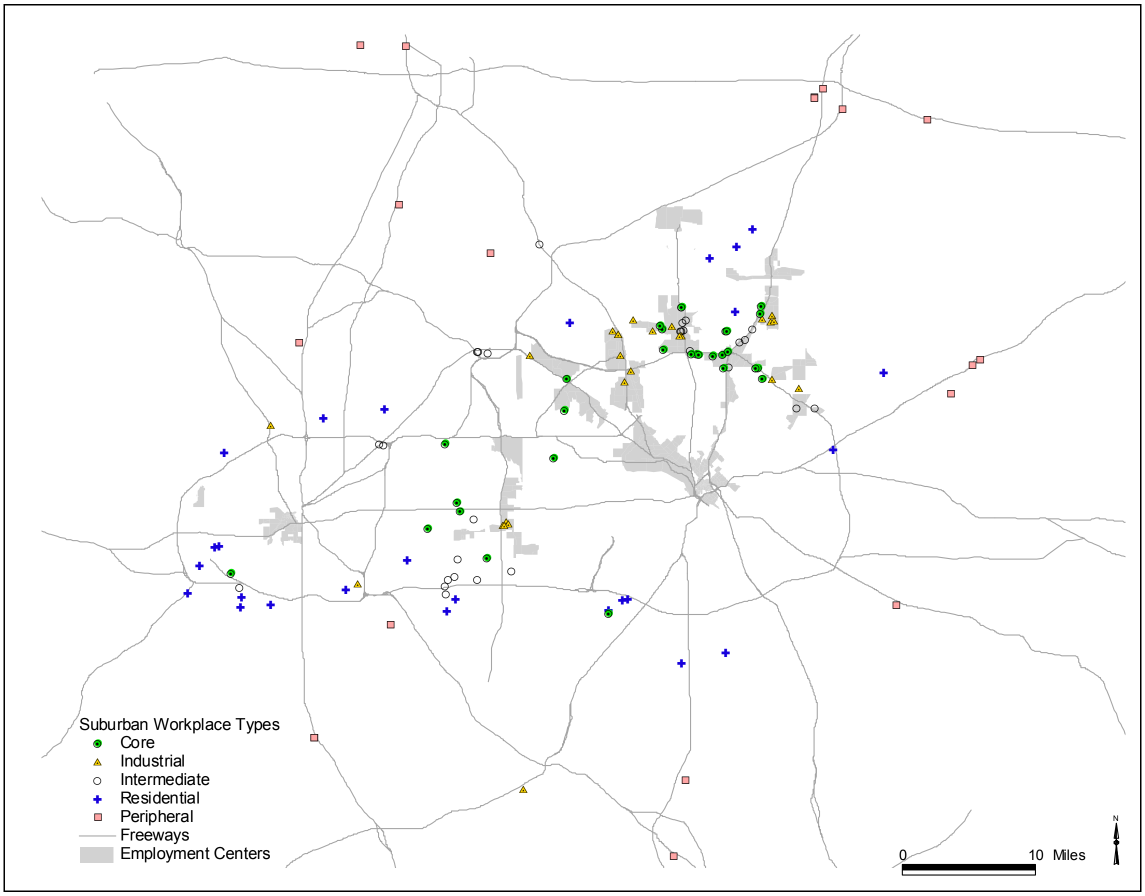

Figure 5.11 Location of suburban workplace types

Figure 5.11 shows the location of the five suburban workplace types. Notice that workplaces in each workplace type display a general tendency of location in relationship to major employment centers, freeways, and other workplaces of the same type.

Workplaces in the "core" type are often found in major suburban centers that constitute metropolitan growth cores and corridors. Workplaces are characterized by good regional accessibility to both housing and jobs. Closer proximity to major highways and the interchanges (thus busy) are another important location factor for this type. Compared to other suburban types, workplaces are surrounded by denser but diverse land uses. Office and large-scale shopping malls are focal activities. In the Dallas-Fort Worth area, many workplaces of this type are located along IH 635 (L. B.

Johnson Freeway) and US 75 (North Central Expressway) that weave Galleria and Telecom Corridor together. And, some workplaces are shown in Las Colinas and Arlington (Six Flags area).

Workplaces in the "industrial" type are often found in specialized industrial districts and portions of major suburban centers. Workplaces are surrounded by other firms in similar industries such as manufacturing and warehousing. Good accessibility to regional highways is important to this workplace type because of their heavy reliance on trucking. In the Dallas-Fort Worth area, many workplaces of this type are found in Telecom Corridor, Garland, Carrollton, and Farmers Branch.

The "intermediate" is in between the "core" and "residential" types. Workplaces in this type are often found in medium-sized community centers and strip centers along highways or arterial roads. Typically, centers are anchored by supermarket and discount stores. Other commercial activities (e.g., insurance, car rental, hotel/motel) may also be located in the centers. As the name indicates, however, this type contains a broader range of workplace locations.

Workplaces in the "residential" type constitute relatively small-sized neighborhood centers amidst residential areas. Many workplaces may provide goods and services for day-to-day living, serving small residential areas. Sometimes, this type shares certain characteristics with the "intermediate," as workplaces are located in strip centers along major arterial roads.

The "peripheral" is comprised of workplaces on the fringe of suburbs. This type is characterized by poor regional accessibility. Since this type of workplace is farther from major activity centers, the workplaces appear to be isolated and scattered. Yet, some workplaces are also found in small towns, serving the communities on the peripheries of the metropolitan region. In some cases, the location might be better described by "exurbs," meaning in between suburbs and rural areas (Davis, Nelson, and Dueker 1994).

Spatial Factors

Figure 5.12 shows factor scores of five suburban workplace types in the five spatial factors.

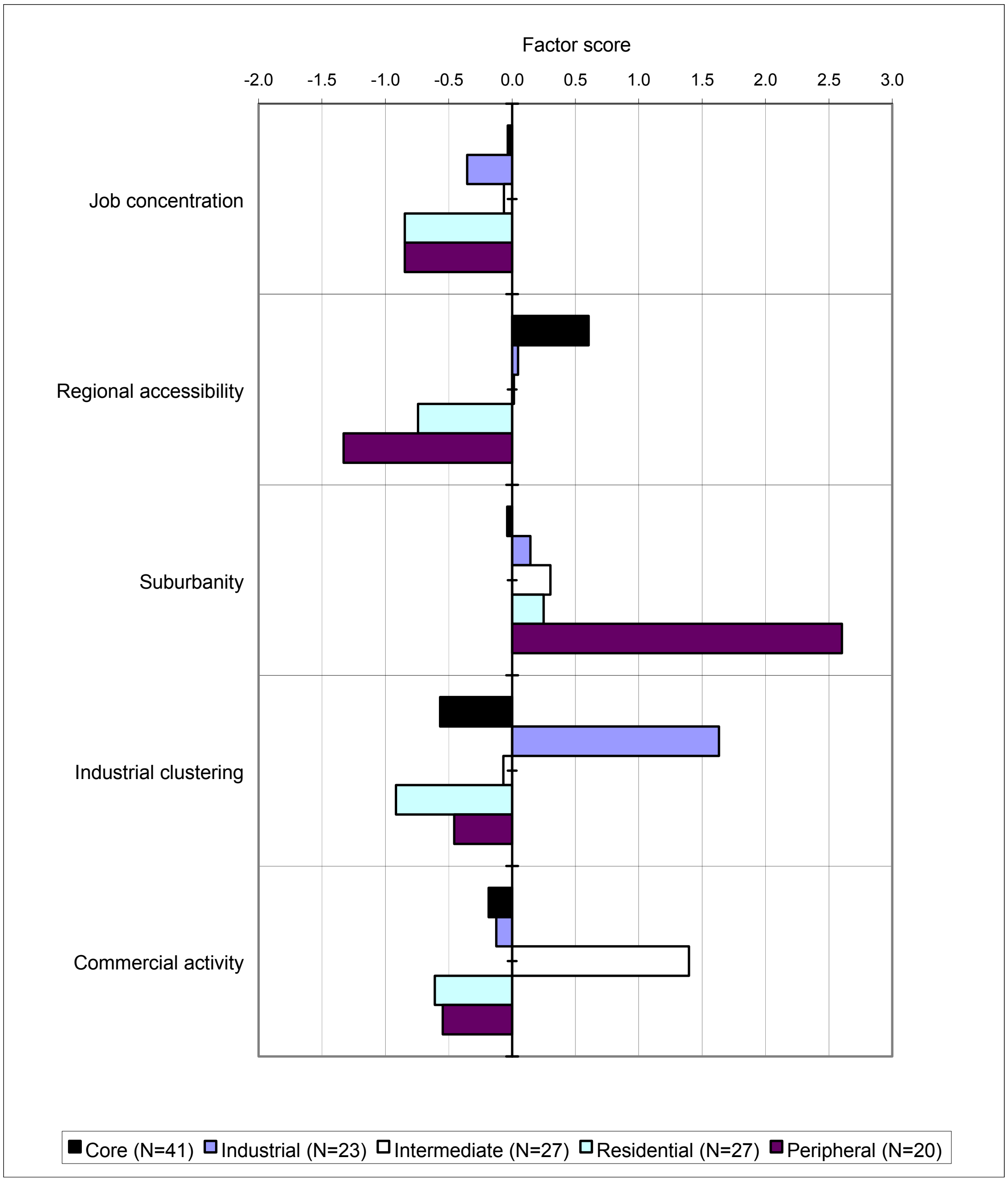

Figure 5.12 Mean scores on spatial factors by suburban workplace type

Table 5.11 F-statistics for the comparisons of the five suburban workplace types in spatial factors

	Job concentration	Regional accessibility	Suburbanity	Industrial clustering	Commercial activity
F-statistic (p-value)	18.45 (0.0001)	46.87 (0.0001)	62.18 (0.0001)	75.82 (0.0001)	25.64 (0.0001)

In the "employment concentration" factor, all the workplace types exhibit minus scores. This is because, compared to workplaces in the central city, suburban workplaces in general are characterized by low-density scattered land use patterns. Of the suburban workplace types, the "core" and "intermediate" get higher scores on average than other types.

In the "regional accessibility" factor, the "core" shows the highest score, indicating that workplaces in this type are located in regional growth centers and corridors. The "peripheral" is the lowest because the workplaces are located on the outer edge of suburbs, farther from regional centers.

In the "suburbanity" factor, the "peripheral" exhibits the highest score because workplaces in this type are farthest from the regional center. The "core" shows the lowest score, indicating that many of the major suburban centers are located in the inner-ring of the suburbs. The "industrial" also shows a lower score. Decreasing attractiveness of older suburbs as a place to live may be related to the concentration of "core" and "industrial" type-workplaces.

In the "industrial clustering" factor, the "industrial" gets the highest score while the "residential" shows the lowest score. Not surprisingly, industrial activities are less compatible with residential land uses.

In the "commercial activity" factor, the "intermediate" shows the highest score on average. This is because the "intermediate" constitutes medium-sized retail-oriented strip centers along major arterials and highways.

Overall, the spatial characteristics of suburban workplace types appear considerably consistent with the general image of suburban workplaces. It is interesting that workplaces with higher scores in regional spatial factors (e.g., regional accessibility of housing and jobs) tend to get higher scores in local land use factors (e.g., job concentration), and vice versa. Compared to other suburban workplaces, workplaces in the "core" type exhibit more compact land use patterns. But, the intensity is far lower than that of their counterparts in the central city.

Summary

Compared to other US metropolitan regions, the Dallas-Fort Worth area has two relatively vital central cities. Yet, this area has also experienced rapid suburbanization in both population and employment over the recent decades. Suburbs have gained more shares of new jobs than central cities. Employment growth concentrates on a few affluent suburbs in the northern Dallas area. Suburban centers are increasingly competing with the prestigious role of older primary centers in the central city by utilizing the advantage of improved mobility through highways and automobiles. Yet, the morphology of suburban jobs is much more complex, as a larger share of suburban jobs is located in low-density scattered sites throughout suburbs and exurbs. Scattered workplaces include a wide range of locations, from small- to medium-sized neighborhood centers to isolated sites.

The analysis of 270 workplaces reveals five important spatial factors of workplace environs: job concentration, regional accessibility to housing and jobs, suburbanity, industrial clustering, and commercial activity. Of the five factors, "job concentration" is the strongest factor in characterizing workplace environs. Spatial characteristics of individual workplaces can be evaluated by five spatial factors.

Table 5.12 Summary of spatial factors for workplace environs and the major elements

Spatial factor	Spatial elements in positive association	Spatial elements in negative association
Job concentration	% Office land uses (local) Employment density (local) Housing density (local) % Employment land uses (local) Entropy index of land use mix (local) Accessibility index to other workplaces (regional)	Ratio of housing to jobs (local) % Residential land uses (local) Distance to controlled-access highway (local) Distance to CBD (regional)
Regional accessibility	Accessibility index to houses (regional) Accessibility index to other workplaces (regional) Median value of owner-occupied housing (local) % Multi-family residential land uses (local)	
Suburbanity	Distance to bus transit (local) Distance to CBD (regional) Ratio of housing to jobs (local)	Accessibility index to other workplaces (regional) Accessibility index to housing (regional) Housing density (local)
Industrial clustering	% Industrial land uses (local) % Employment land uses (local)	% Residential land uses (local)
Commercial activity	% Retail land uses (local) % Multi-family residential land uses (local)	Distance to controlled-access highway (local)

The analysis of workplace environs by location type indicates that the differences in spatial characteristics tend to be more distinct between those workplaces inside and outside of major employment centers than between those workplaces in central and suburban areas. Local spatial factors (job concentration, industrial clustering, and commercial activity) are particularly distinct between inside and outside the employment centers.

A few mature suburban centers attain some level of compact development in terms of local land use diversity and regional accessibility. However, the degree of job concentration of workplaces in suburban centers is far lower than that of their counterparts in older primary centers in central parts of the metropolitan area. Scattered workplaces outside of major centers in both central and suburban areas are not so different in their surrounding spatial characteristics.

The analysis of 138 suburban workplaces identifies five workplace types in terms of their environs: core, industrial, intermediate, residential, and peripheral. Again, workplaces in the "core" type exhibit more compact spatial patterns than workplaces in other suburban types, although the compactness is much lower than that of their counterparts in the older primary center. Mature suburban centers appear to increasingly resemble older and larger centers in the central city, apart from their colleague workplaces in suburbs. The spatial patterns of suburban workplaces have a lot of implications for transportation. The next chapter examines how such spatial characteristics of workplaces are related to travel patterns made by workers there.

Table 5.13 Summary of characteristics of workplace environs by workplace type

		Job concentration	Regional accessibility	Suburbanity	Industrial clustering	Commercial activity
Workplace locations	Central, inside center	Higher	Medium to higher	Lower	Higher	Medium
	Central, outside center	Lower	Medium to higher	Lower	Lower	Medium to lower
	Suburban, inside center	Medium to higher	Higher	Medium	Higher	Higher
	Suburban, outside center	Lower	Lower	Higher	Lower	Medium to lower
Selected employment centers	Downtown Dallas (CBD)	Higher	Higher	Lower	Medium to higher	Medium to higher
	Galleria (Suburban downtown)	Medium to higher	Higher	Medium	Medium to higher	Higher
	Las Colinas (Master planned community)	Medium to higher	Higher	Higher	Medium to lower	Lower
	Telecom Corridor (High-tech corridor)	Medium	Medium	Medium	Higher	Medium to lower
Suburban workplace types	Core	Medium	Higher	Medium	Medium to lower	Medium
	Industrial	Medium to lower	Medium	Medium to higher	Higher	Medium
	Intermediate	Medium	Medium	Medium to higher	Medium	Higher
	Residential	Lower	Lower	Medium to higher	Lower	Medium to lower
	Peripheral	Lower	Lower	Higher	Medium to lower	Medium to lower

CHAPTER VI
WORKPLACE ENVIRONS AND COMMUTING

Using work trip data from the 1994 NCTCOG Workplace Survey, this chapter analyzes commuting characteristics of employees in sampled workplaces in the Dallas-Fort Worth region. The travel measures are travel time, travel mode, and trip chaining. The role of workplace environs in affecting commuting is explored in two ways. First, simple group comparisons are conducted by using several spatial references: two locational dichotomies (central versus suburban, and inside versus outside of major employment centers), three types of suburban employment centers (suburban downtown, master planned community, and high-tech corridor), and five suburban workplace types (core, industrial, intermediate, residential, and peripheral). Second, statistical models, including standard regression and logit models, are used to identify factors affecting commuting behavior exhibited by individual employees. The models include spatial factors around workplaces as well as socioeconomic characteristics of employees and employer characteristics.

Basic Characteristics of Commuting

Time Traveled

The measure of commuting duration is vehicle minutes traveled to work by workers who use private vehicles (car, pickup, truck, or van). This measure is based on the expected vehicle travel times when each worker is assumed to make non-stop travel through the shortest route between home and work. Thus, non-automobile (e.g., public transit, walking, bicycling) commuters are excluded from the travel time analysis.

Table 6.1 presents the basic statistics of travel times made by 4,880 workers who use automobiles to go to work. The mean travel time is 15.8 minutes. The mean peak travel time is 17.0 minutes, and the mean off-peak travel time is 13.7 minutes. Travel times based on shortest paths look much shorter than self-reported travel times. For example, the 1990 census shows that, nationwide, the mean drive-alone commute travel time is 21.1 minutes (Pisarski 1996). Similarly, the 1995 NPTS shows that the mean commuting time by privately-owned vehicles is 20.1 minutes (Hu and Young 1999).

Table 6.1 Basic characteristics of vehicle travel times to work made by automobile commuters

	Mean	Standard deviation	No. of cases*
Mean travel time in minutes**			
Overall	15.8	9.2	4,880
Peak hours	17.0	8.8	2,870
Off-peak hours	13.7	8.6	2,010
Mean travel distance in miles**	14.8	8.6	4,880

* Excludes workers using non-personal vehicle modes (bus, walk, bike, etc.)
** Based on the shortest path

The mean travel distance between home and work through the shortest roadway path is 14.8 miles, which is longer than the national average. The 1995 NPTS reports that the average vehicle trip length to or from work is 11.8 miles. Thus, shorter commuting time but longer distance indicates that average commuting speeds made by drivers in Dallas-Fort Worth are faster than the national average.

It should be noted that travel time and distance based on the shortest route are likely shorter than the actual time and distance traveled made by an average individual worker. Part of the reason may include: (a) individuals do not have perfect knowledge about traffic conditions of alternative routes; (b) in addition to travel time, tripmakers consider various factors such as security and the general ambiance of roadways in choosing travel routes; (c) there may be habitually used routes, regardless of traffic conditions; and (d) the shortest vehicle travel times do not contain any stops during work trips and out-of-vehicle times such as times to access from parking to office. Thus, the travel times based on the shortest path should be used as a relative indicator for comparison.

It would be useful to touch upon commute travel times in relation to a few confounding factors (i.e., variables related to socioeconomic characteristics of workers and to employer characteristics). Table 6.2 shows some of comparative statistics of travel times.

Many studies indicate that women make shorter travel due to household responsibility (Hanson and Hanson 1980; Madden 1981; Turner and Niemeier 1997). While our work trip data show that women travel (15.4 minutes) slightly shorter times than men do (16.1 minutes), the difference appears to be modest.

Table 6.2 Vehicle travel times to work in relation to selected confounding variables

		Mean travel time in minutes	F-statistic (p-value)
Gender (N=4,880)	Male	16.1	3.56 (0.0593)
	Female	15.4	
Income (N=4,880)	Under $15,000	11.8	28.73 (0.0001)
	$15,000 to $24,999	13.7	
	$25,000 to $34,999	15.5	
	$35,000 to $49,999	16.5	
	$50,000 to $74,999	17.7	
	$75,000 and higher	16.8	
Industry type of workplace (N=4,880)	Retail	11.3	169.48 (0.0001)
	Service	16.4	
	Basic	17.9	

It has been suggested that higher-income workers are likely to make longer travel because the income elasticity of demand for housing is stronger than that for reduction of trip costs (Mills 1980; Giuliano 1995). Consistent with this theory, higher income workers consume more transportation resources as they travel longer in minutes.

Given that this study is workplace-based, the type of industry may affect travel times made by the employees there. Our data show that workers in retail businesses make much shorter travel than those in service and industrial businesses. The market orientation of retail activities and thus closer proximity to residences may help the employees shorten travel times. Office and industrial activities tend to give a priority to the closer proximity to other firms for the economies of agglomeration. Further, the negative features of some industrial activities (e.g. manufacturing) may dictate that those activities be farther from residential areas.

Figure 6.1 shows mean travel times and distances in relation to the distances from CBD to homes of workers (i.e., as an indicator of housing suburbanization). Both travel times and distances become longer as the residences of workers are farther from CBD, indicating that suburbanites consume more transportation resources.

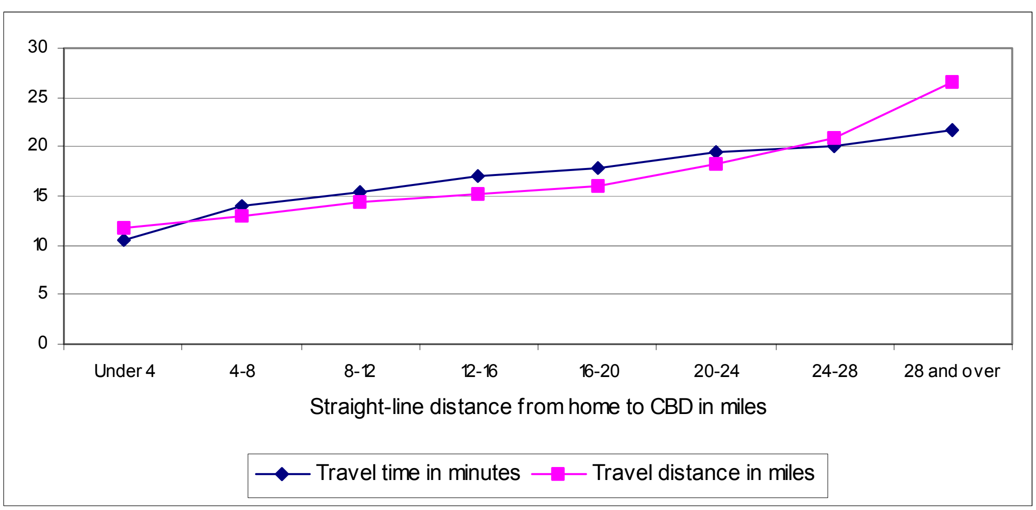

Figure 6.1 Mean commute travel times with distance from home to CBD

Travel Mode

Figure 6.2 shows the share of trip mode to work. Workers overwhelmingly use private automobiles as their usual trip mode. The share of drive-alone commuting, the most resource intensive mode, is 75.1%. This number is higher than the 64.4% of the 1990 census but lower than the 79.6% of the 1995 NPTS concerning the national averages of drive-alone commuting (Pisarski 1996; Hu and Young 1999).

Carpooling, which accounts for 19.2% of total commuting trips, appears much higher than the national average. The 1990 Census and 1995 NPTS show 13.4% and 11.1% respectively concerning the national averages of carpooling. While the share of automobile commuting (drive-alone plus carpool) is 94.3% in our data, the 1990 Census and 1995 NPTS show 86.5% and 90.7% respectively.

Bus transit, which accounts for 4.3% of total commuting trips, is slightly lower than the national average. Both 1990 Census and 1995 NPTS show 5.1% concerning the average share of public transit commuting.

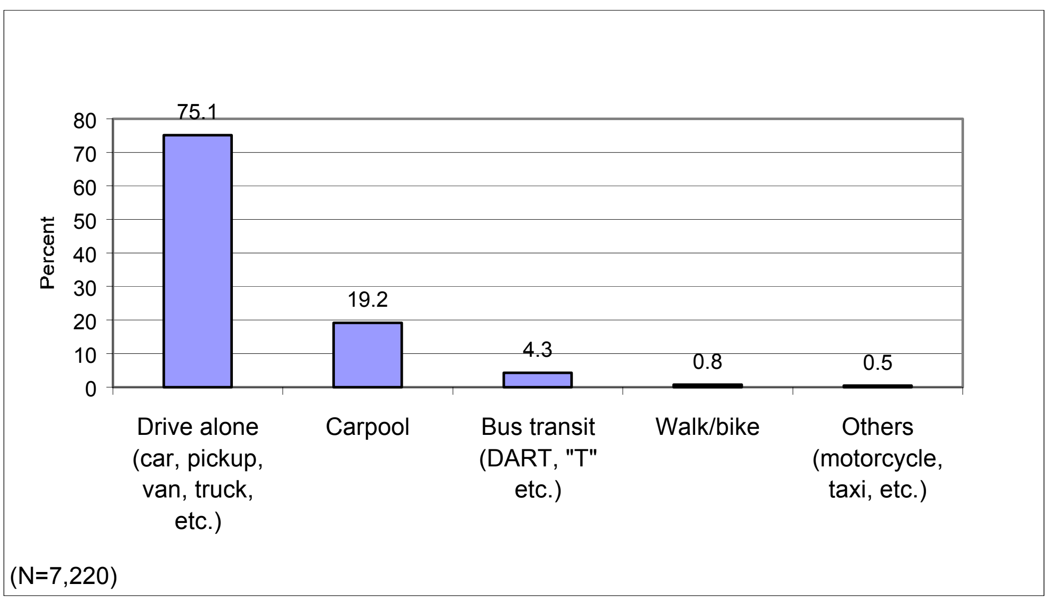

Figure 6.2   Modal split of commuting trips

The share of walk/bike mode, among the least resource intensive modes, is as low as 0.8%. For commuting trips, the share of non-motorized modes is likely lower than non-work trips because work trips tend to be the longest among daily trip purposes (Hu and Young 1999).

Table 6.3 presents the characteristics of trip mode to work in relation to a few confounding factors. Women tend to make less energy intensive trips, as they drive less alone and use more carpool and public transit than men do. A positive relationship exists between household income and energy intensive modes such as drive-alone trips. Peak-hour traffic tends to discourage drive-alone trips but encourage carpooling and public transit commuting. As traffic congestion during peak hours takes off the advantage of automobile travel, so workers adjust their travel through carpooling and transit.

Table 6.3 Modal split in relation to selected confounding variables

	Percent of making any stops					Chi-square (p-value)
	Drive alone	Carpool	Bus transit	Walk/bike	Others	
Gender (N=7,164)						153.91
Male	81.7	13.0	3.9	0.8	0.6	(0.0001)
Female	70.3	24.0	4.7	0.9	0.1	
Annual household income (N=7,220)						213.72
Under $15,000	60.0	26.0	9.4	3.9	0.8	(0.0001)
$15,000 to $24,999	71.6	19.6	6.5	1.7	0.7	
$25,000 to $34,999	75.3	19.9	4.1	0.5	0.2	
$35,000 to $49,999	75.9	19.6	3.5	0.7	0.4	
$50,000 to $74,999	80.7	15.8	3.3	0.1	0.1	
$75,000 and higher	82.83	14.2	2.2	0.3	0.5	
Time period of commuting (N=7,220)						57.24
Peak hours	74.6	19.8	5.1	0.4	0.1	(0.0001)
Off-peak hours	77.7	17.1	3.1	1.5	0.7	

Trip distances are supposedly related to travel mode because different trip modes provide different levels of individual mobility, which is the ability to move between different activity sites. In residential choice, the decision on how far to live from work is closely related to trip mode to be used, as people schedule their daily lifestyle as a set (Lerman 1976; Ben-Akiva and John Bowman 1998). Figure 6.3 shows modal split in relation to work trip distance made by individual workers. Drive-alone trips tend to increase slightly with work trip distances, while bus transit and walk/bike trips tend to decline. Walking and bicycling occur only over shorter distances. Carpooling appears relatively constant over trip distances. However, modal split patterns in relation to trip distance are not quite distinct, implying that, overwhelmingly, people use private automobiles regardless of distances traveled.

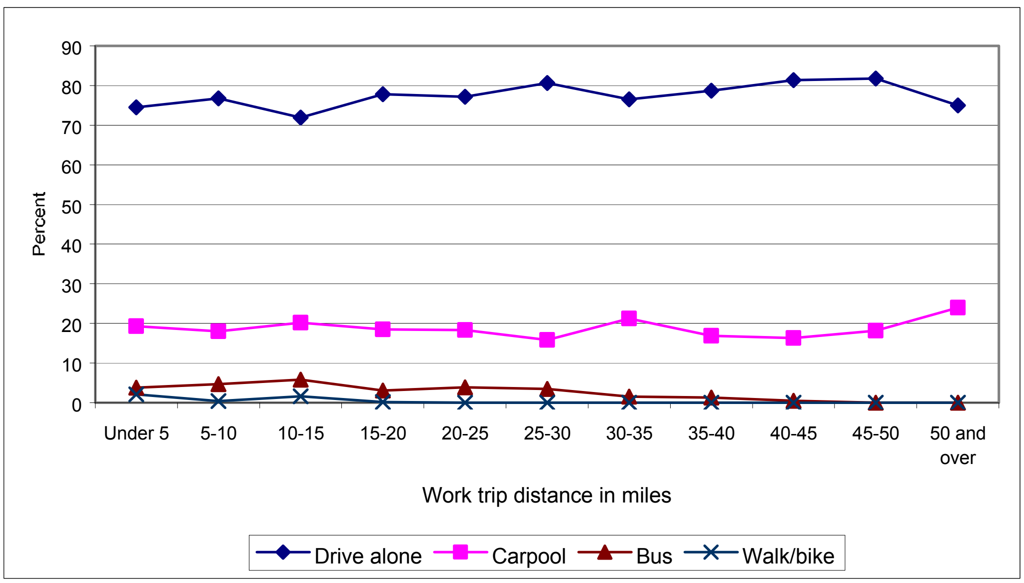

Figure 6.3 Modal split with work trip distance

Figure 6.4 shows modal split in relation to the distance between home and CBD. Workers who live in the suburbs appear more automobile dependent since the share of drive-alone trips increases with the distance of residences from CBD. In the previous section, we saw that workers who live in the suburbs travel longer to work. Again, population suburbanization is related to more resource consumption due to more work trips being made with private automobiles.

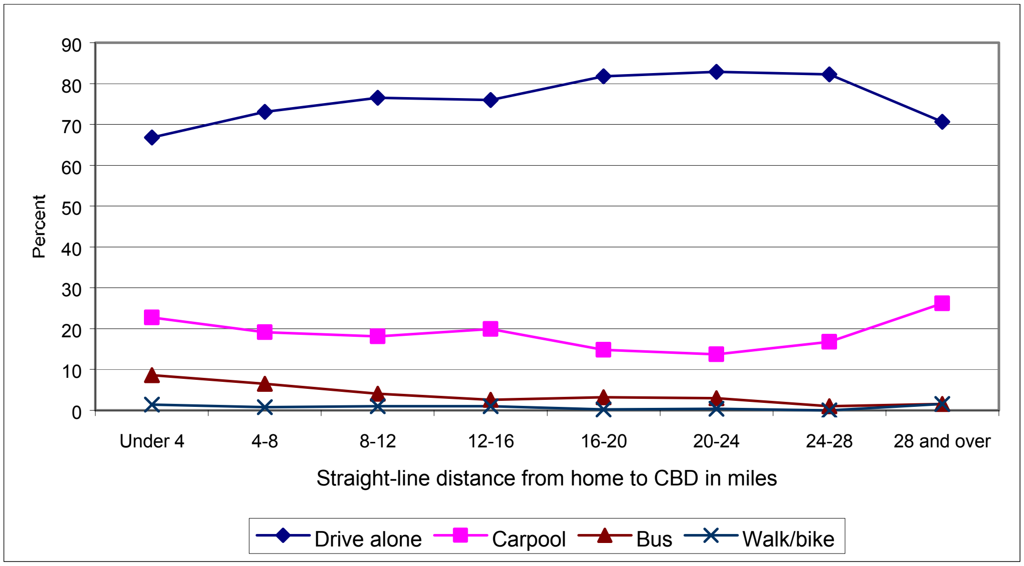

Figure 6.4 Modal split with distance from home to CBD

Trip Chaining

Table 6.4 shows activity stops made during commuting trips. Activity stops are made more on the way home after work. While 28.8% of the workers make at least one stop on the way to work, nearly half of the workers, 46.4%, do on the way home after work. The frequency of activity stops is also higher for the stops after work. The statistics are quite consistent with intuitive expectations in the sense that most people do personal business and household preparation on the way home after work.

Table 6.4 Basic statistics of activity stops during commuting trips

Whether making at least one stop	Home-to-work	28.8%
	Work-to-home	46.4%
Mean number of stops if making any stops	Home-to-work	1.16
	Work-to-home	1.29
No. of cases		7,220

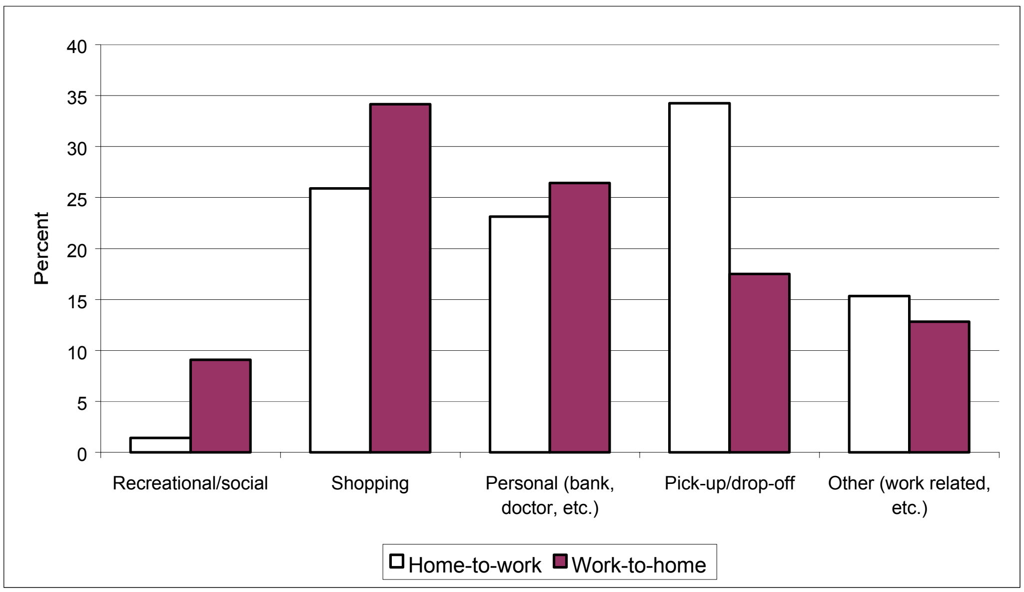

Figure 6.5 Activity stops during commuting trips by purpose

Figure 6.5 shows the distribution of activity stops during commuting by purpose. Overall, major activity purposes are shopping, personal businesses (e.g., bank, doctor), and pick-up/drop-off (e.g., family members). While the share of pick-up/drop-off is highest for the stops before work, the shares of shopping and personal business are highest for the stops after work. It appears that activity stops on the way home after work are somehow related to "discretionary" activities (e.g., shopping, personal business, and recreational and social activities), implying that they may have more implications for land use planning such as mixed land use in and around business districts.

Table 6.5 Activity stops during commuting trips in relationship to selected confounding variables

	Home-to-work		Work-to-home	
	Percent	Chi-square (p-value)	Percent	Chi-square (p-value)
Gender (N=7,164)		53.02 (0.0001)		147.21 (0.0001)
Male	24.9		39.3	
Female	32.7		53.6	
Annual household income (N=7,220)		7.95 (0.1591)		45.01 (0.0001)
Under $15,000	26.8		34.0	
$15,000 to $24,999	27.2		47.1	
$25,000 to $34,999	27.9		45.8	
$35,000 to $49,999	31.6		46.6	
$50,000 to $74,999	30.0		50.4	
$75,000 and higher	28.2		49.0	
Time period of commuting (N=7,220)		6.45 (0.0111)		8.88 (0.0029)
Peak hours	27.7		49.3	
Off-peak hours	30.4		45.7	
Number of midday trips (N=7,220)		42.32 (0.0001)		103.71 (0.0001)
0	25.5		41.0	
1	32.2		50.9	
2 and more	32.8		55.9	

Table 6.5 shows some statistics on activity stops in relation to selected confounding variables. First, women make far more activity stops than men do during both home-to-work and work-to-home trips. This is consistent with general explanations that women make more activity stops to perform household-sustaining activities such as shopping and child-care (Hanson and Hanson 1980; McGuckin and Murakami 1999).

Most activity stops require economic resources (i.e., money) for participation. Also, trip chaining is related to substituting money for time (Levinson and Kumar 1995). The statistic is consistent with these expectations as workers with higher household incomes make more activity stops.

Workers who travel to work during morning peak hours (6:30 a.m to 8:29 a.m) make fewer stops than workers who travel during off-peak hours. On the other hand, workers who travel home during evening peak hours (5:01 p.m to 7:00 p.m) make more stops than workers who travel during off-peak hours. For home-to-work trips, time constraints on getting to work during morning peak hours may deter workers from making any stops during commuting trips. For work-to-home trips, workers may have to prepare for housing services before getting home. Traffic congestion during evening peak hours may be partly attributable to more non-work activity stops on the way home after work.

An interesting point is the relationship between activity stops during commuting trips and activity stops during work (i.e., midday trips). Midday trips are a part of trip chaining made during work. The substitutive or complementary relationship can provide implications for land use planning such as putting activity sites in and around employment concentrations. Workers who make more midday trips during work tend to make more activity stops during commuting trips than otherwise. The relationship indicates that major trip purposes are different between those activity stops made during work and after work. Workers do not substitute their stops during commuting trips with midday trips. It implies that lifestyle persistent to the daily activity schedules of individual workers would be an important factor. If trip chains burden peak-hour traffic, particularly evening peak congestion, some activity sites such as shopping, should be put in closer proximity to residences because shopping trips account for the majority of activity stops on the way home after work.

Figure 6.6 shows activity stops in relation to trip distance between home and work. Although the relationship is not clear, workers who travel longer to work tend to make more activity stops while commuting. Workers appear to compensate for longer trip distances by linking their work trips to multipurpose trips (Ewing, Haliyur, and Page 1994; Levinson and Kumar 1995).

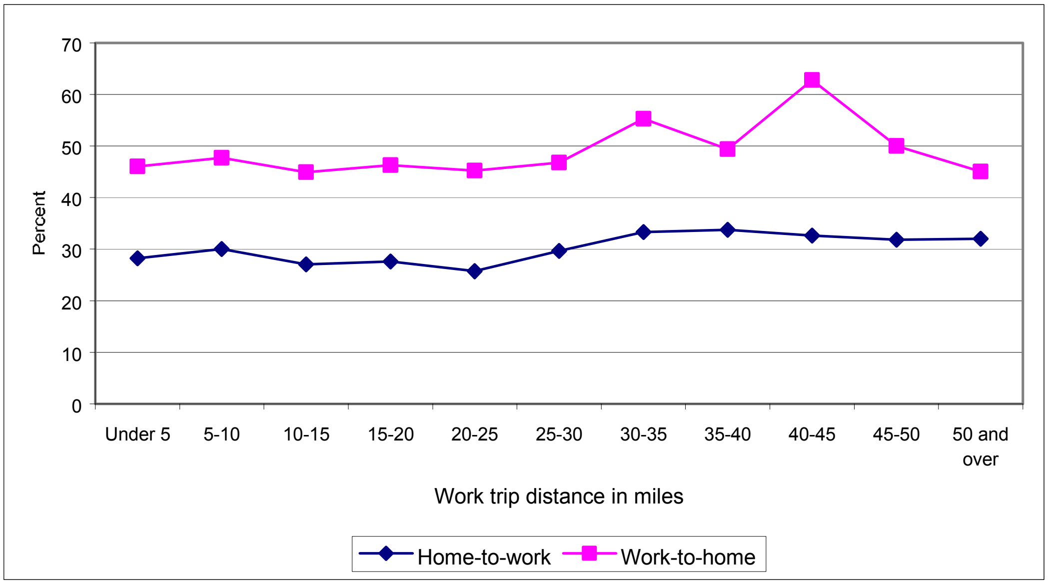

Figure 6.6 Activity stops with work trip distance

Comparing Commuting by Workplace Type

Workplace Locations and Commuting

This section compares commuting characteristics of workers by means of the combination of two locational dichotomies: central versus suburban, and inside versus outside major employment centers. As used in the previous chapter, the distinction between "central" and "suburban" is based on the straight-line distance points of 9 miles away from downtown Dallas and 6 miles away from downtown Fort Worth. Also, the "major employment centers" are those 17 centers identified in the previous chapter.

Time Traveled

Table 6.6 shows average vehicle travel times to work by workplace location. Employees of workplaces in central, employment-center areas make the longest travel times, while employees outside of suburban, employment-centers make the shortest travel times. Travel made by employees of suburban workplaces is shorter in duration than that by employees of workplaces in central areas. Travel made by employees of workplaces outside of employment centers is shorter in duration than that by employees of workplaces inside of centers. Greater differences are shown between those workplaces inside of centers and those outside of centers than between those workplaces in central areas and those in suburban areas.

Differences in travel times by workplace location are consistent with theoretical expectations since larger and denser centers require correspondingly larger market ranges and thus longer overall travel times. Previous studies have also found that larger and denser centers are associated with longer commute travel times (Giuliano and Small 1991; Cervero and Wu 1997). Shorter commuting times in lower-density suburban workplaces appear to lend some credibility to the hypothesis of "co-location", which denotes that job decentralization reduces commuting times as firms and workers mutually co-locate to each other at the suburbs (Gordon, Kumar, and Richardson 1989; Giuliano 1991; Gordon, Richardson, and Jun 1991; Levinson and Kumar 1994).

Table 6.6 Commute travel times by workplace location

	Central		Suburban		F-statistics (p-value)
	Inside center	Outside center	Inside center	Outside center	
Mean vehicle travel time in minutes	18.3	13.6	15.8	12.5	157.75 (0.0001)
No. of cases	2,111	572	1,139	1,058	

It is widely acknowledged that low-density suburban workplaces are a product of widespread automobile use and ubiquitous highway systems. Thus, it is expected that low-density suburban development may be more related to shorter travel times than to travel distances, since automobiles enhance travel speeds, while low-density development increases physical distances between activity sites. Figure 6.7 shows the changes of both commute travel times and distances made by employees with respect to the degree to which their workplaces are decentralized.

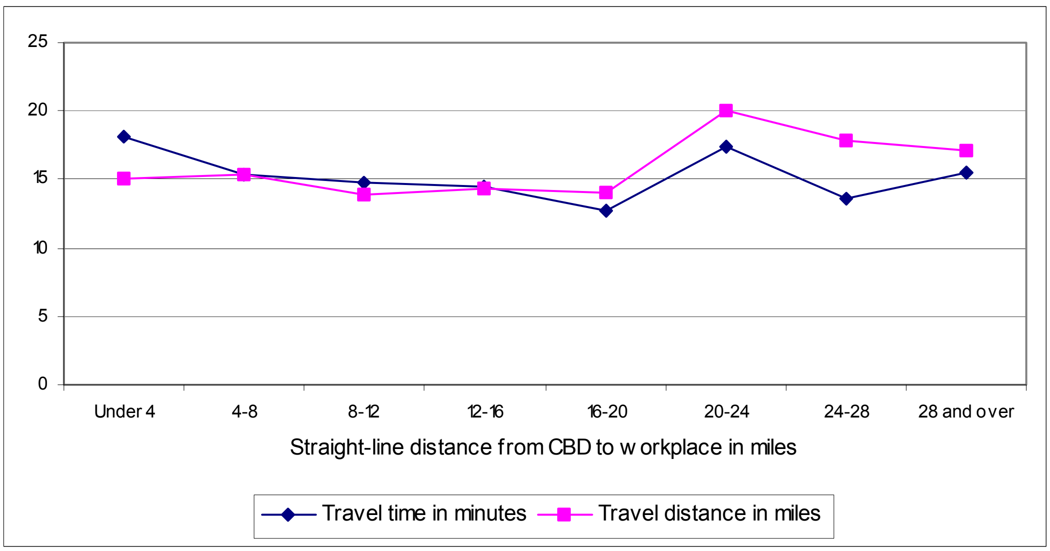

Figure 6.7 Mean commute travel times and distances with distance from CBD to workplace

In general, travel times tend to decline up to approximately 16-20 miles from the regional center (CBDs of Dallas and Fort Worth respectively), but then increase thereafter. Travel distances are relatively flat within the 16-20 mile point from the regional center, but then increase more than travel times thereafter. The relationship indicates that suburban jobs are related more to shortening travel times by increasing travel speeds than to shortening travel distances. It also indicates that shorter commute travel due to job decentralization, as suggested by the "co-location" hypothesis, may be effective only up to a certain degree of decentralization. In the previous section, we saw that both commute travel times and drive-alone trips increased with the degree of residential suburbanization. A metropolitan-wide policy to contain outward expansion of urban development may be helpful in relieving transportation and air quality problems.

Travel Mode

Table 6.7 shows shares of travel mode to work by workplace location. Employees of workplaces inside of employment centers in central areas make the least drive-alone commuting but the most carpool and bus transit commuting. Drive-alone trips are particularly lower for those of workplaces in centers in the central city.

In the previous chapter, we observed that workplaces inside of suburban centers attained some level of activity diversity and transit accessibility. But, employees of workplaces inside of suburban centers are far more frequent drive-alone commuters than their counterparts in central areas. This implies that the compactness of suburban centers may not be enough for non-automobile travel to be an effective mode of commuting. Also, the connectivity of public transit to suburban residences might be very poor.

Table 6.7 Modal split by workplace location

	Central		Suburban		Chi-square (p-value)
	Inside center	Outside center	Inside center	Outside center	
Drive alone	70.0	78.9	79.5	78.1	289.44
Carpool	20.8	15.9	17.7	19.5	(0.0001)
Bus transit	8.6	2.5	1.3	0.5	
Walk/bike	0.2	1.8	1.0	1.4	
Others	0.4	0.9	0.5	0.5	
No. of cases	3,037	853	1,611	1,719	

The least resource intensive means of commuting such as walking and cycling are relatively homogeneous across workplace locations because automobile trips are overwhelming. Yet, employees of workplaces outside of employment centers make slightly more walking and cycling trips. This implies that long trip distances and busy vehicle traffic on streets discourage non-motorized trips for employees in major employment centers.

Trip Chaining

Table 6.8 shows activity stops made by employees during commuting trips by workplace location. The frequency of activity stops made during home-to-work trips is relatively homogeneous across the workplace locations, although employees of workplaces in suburban centers make slightly more stops than those in other location types. Note that activity stops before work are related to "regular" activities such as dropping off family members.

Table 6.8 Activity stops during commuting trips by workplace location

	Central		Suburban		Chi-square (p-value)
	Inside center	Outside center	Inside center	Outside center	
Percent of activity stops during home-to-work trips	27.9	29.1	31.0	28.1	5.60 (0.1326)
Percent of activity stops during work-to-home trips	51.3	41.5	44.2	42.3	52.76 (0.0001)
No. of cases	3,037	853	1,611	1,719	

For work-to-home trips, employees of workplaces in larger and denser centers make more stops after work. Particularly, employees of workplaces in employment centers in central areas make much more stops than employees of other locations. Employees of workplaces in suburban centers make slightly more stops than those of workplaces outside of centers. Given that activity stops after work are related to more "discretionary" activities (e.g., shopping), longer commute travel may encourage employees to link their work trips with other non-work trips. Also, workers tend to take advantage of the greater variety of potential destinations during commuting trips. The findings have a connection with the theory of more trips with the greater range of choice (Crane 1996; Handy 1996b).

In summary, employees of workplaces in larger and denser centers travel longer to work. Up to a certain degree of decentralization, suburban workplaces tend to shorten auto travel times, giving some credibility to the "co-location" hypothesis. However, except for workplaces in central areas, workplaces exhibit an overwhelming automobile dependence, particularly in drive-alone commuting, by their employees. Employees of workplaces in employment centers in central areas drive alone to work less but use more carpooling and public transit than employees of other workplace locations. The least resource intensive trip modes such as walking and cycling are quite homogeneous across the different workplace types due to the overwhelming auto dependence.

Employees of workplaces in larger and denser centers tend to make more activity stops after work. Activity-trip patterns are complex, as workers link commuting trips to various non-work activities in order to economize the allocation of daily hours. Given that trip chaining is overwhelmingly automobile-based, careful planning strategies are required to relieve traffic congestion in and around major activity centers.

Commuting in Suburban Downtown, Master Planned Community, and High-Tech Corridor

Commuting patterns are compared for employees of workplaces in three types of suburban employment centers: suburban downtown, master planned community, and high-tech corridor. Like the previous chapter, three suburban centers are chosen to represent the three center types: Galleria (suburban downtown), Las Colinas (master planned community), and Telecom Corridor (high-tech corridor). Employees of workplaces in downtown Dallas are also included for comparison.

Time Traveled

Table 6.9 shows average auto travel times and distances to work made by employees of workplaces in the four major employment centers. Employees of workplaces in downtown Dallas make the longest commuting in both duration and distance, while employees of workplaces in Telecom Corridor do the shortest commuting. Compared to travel times, travel distances are not much different from one another. Travel speed indicators (means of auto travel distances in miles divided by times in minutes) show that mature suburban downtowns, like Galleria, are increasingly burdened by traffic congestion.

Table 6.9 Mean commute travel times in four major employment centers

	Downtown Dallas	Galleria	Las Colinas	Telecom Corridor	
Center type	CBD	Suburban downtown	Master planned community	High-tech corridor	F-statistic (p-value)
Mean auto travel time to work in minutes	18.0	16.5	16.3	13.8	14.02 (0.0001)
Mean auto travel distance in miles	15.2	14.8	16.0	12.2	7.17 (0.0001)
Mean auto travel distance divided by time	0.95	1.11	1.21	1.27	6.42 (0.0003)
No. of cases	1,225	477	67	188	

The reason for shorter commute travel times and distances made by employees in Telecom Corridor is not clear, since the area is characterized by higher levels of industrial concentration and lower levels of regional accessibility in terms of jobs and housing. One reason might be that the "corridor" form of development, in which activities string out along an axial freeway, contribute to the connectivity and traffic flow (Baerwald 1982). Another reason might be the lower levels of land use intensity (e.g., lower employment density) that help enhance travel speeds.

Master planned communities are by definition "balanced" since they are planned to contain a mix of jobs and housing, and are developed by a single master developer. The balance between jobs and housing is expected to help employees of workplaces in the self-contained communities make shorter commuting times and exhibit less automobile dependence (Cervero 1989b, 1996a). As shown in Las Colinas, there is no clear evidence for shorter commute travel times and distances made by employees in this master planned community. This implies that there are numerous non-spatial factors that affect residential choices made by households (Giuliano 1991).

Travel Mode

Figure 6.8 shows shares of commuting modes in the four employment centers. Employees of workplaces in downtown Dallas drive alone less but use more public transit. Employees of workplaces in Galleria exhibit the highest levels of drive-alone trips but the lowest levels of carpooling. In the previous chapter, we observed that workplaces in Galleria attained higher levels of compact development patterns both locally and regionally than other suburban workplaces. Yet, the commuting patterns made by employees in this downtown-like mixed-use center appear to be far from expected. Among other reasons, to be effective, land use intensity (e.g., density) may still be still lower for alternative commuting such as public transit, while increasing land use intensity within the area produces traffic congestion. Further, large-scale shopping malls anchoring the area may facilitate automobile dependence due to the need for transporting bulky purchases.

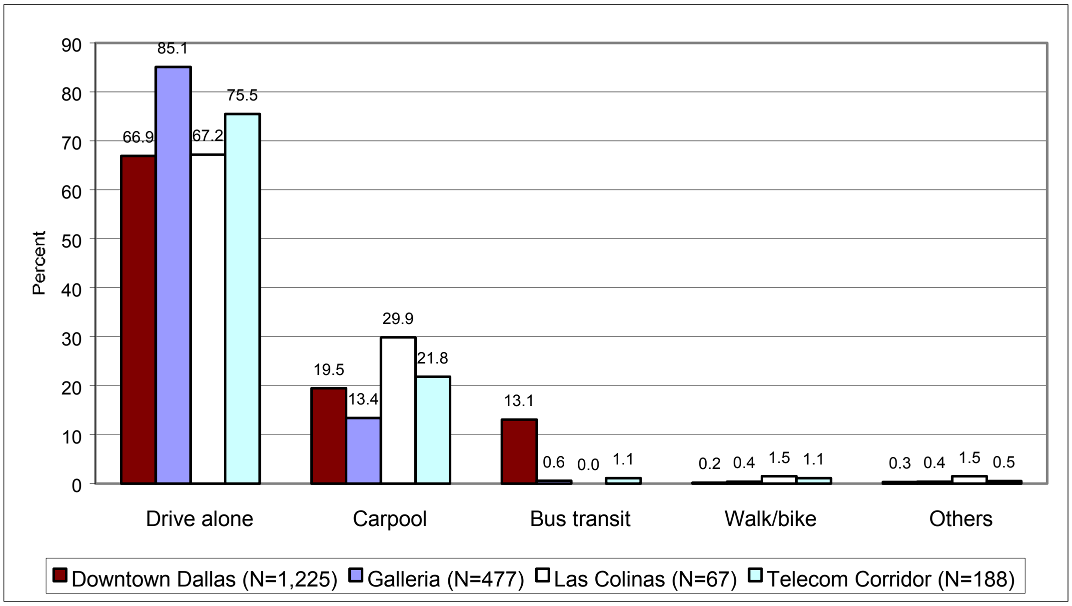

Figure 6.8 Modal split in four major employment centers

It is interesting that employees of workplaces in Las Colinas make less drive-alone commuting but more carpooling. Carpooling is particularly higher in this master planned community. Also, walking and cycling to work tend to be slightly higher in this area. Suburban planned communities might be an effective means to reduce automobile dependence, even though they do not make significant differences in travel duration.

Trip Chaining

Figure 6.9 shows activity stops made by employees in the four employment centers. Downtown Dallas, Galleria, and Telecom Corridor show relatively similar patterns of activity stops made by employees. Employees of workplaces in Las Colinas exhibit quite different trip-activity patterns from those in other centers, showing more activity stops before work but fewer stops after work. Note that activity stops before work are mainly related to pickup and drop-off, while stops after work are mainly related to shopping and personal business (e.g., bank, doctor, social and recreational). In the prior section, employees of workplaces in Las Colinas exhibited a higher share of carpool than those in the other suburban centers, indicating that carpooling and trip chaining are closely related to each other in the planned community.

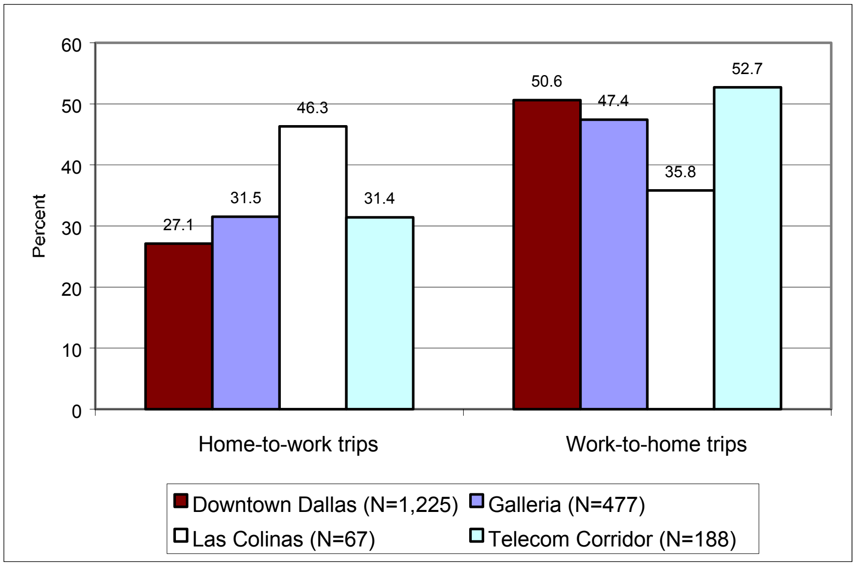

Figure 6.9 Activity stops during commuting trips in four major employment centers

In summary, major suburban employment centers show relatively similar characteristics in commute travel times to the primary older downtown, implying that suburban centers, particularly mature suburban centers, are increasingly burdened by traffic congestion like their counterparts in the central city. Employees of workplaces in suburban centers are more likely to drive alone than employees in the central city. Automobile dependence is highest in suburban mixed-use centers. While land use patterns were auto-oriented in the beginning of development, the increasing inward agglomeration of jobs in suburban centers tends to create disastrous consequences in traffic: congestion, with few choices but private automobile. The master planned community seems to do a good job in addressing automobile dependence, as employees in this location make less drives alone but more carpooling. Daily activity patterns of employees in the planned centers are also different.

Suburban Workplace Types and Commuting

This section compares commuting characteristics among five suburban workplace types: core, industrial, intermediate, residential, and peripheral. The five workplace types are those identified through cluster analysis for the 138 suburban workplaces in the previous chapter.

Time Traveled

Table 6.10 shows commute travel times made by employees in four suburban workplace types. Employees of workplaces in the "residential" type exhibit the shortest travel times. In most cases, workplaces in this type constitute small-sized neighborhood centers in close proximity to residences.

Except for the "residential" type, there are moderate differences in travel times among different suburban workplace types. Yet, employees of workplaces in the "industrial" type make longer travel than others. This is consistent with theoretical expectations since workplaces in the "industrial" type tend to be farther from residences due to the possibility of negative externalities (e.g., noise, pollution) and the requirements for large sites for operations.

On the other hand, employees of workplaces in the "peripheral" type tend to travel shorter. Part of the reason might be because many workplaces serve as small town centers in peripheries.

Table 6.10 Mean commute travel times by suburban workplace type

	Core	Industrial	Intermediate	Residential	Peripheral	F-statistic (p-value)
Mean vehicle travel time in minutes	14.5	16.3	14	9.2	13.6	25.17 (0.0001)
No. of cases	735	520	455	261	160	

Travel Mode

Figure 6.10 shows differences of modal use to work among the suburban workplace types. Overall, the "core," "industrial," and "intermediate" types exhibit higher levels of drive-alone commuting than the "residential" and "peripheral" types. The "core" type does not make any difference in modal use, although workplaces in this type are characterized by higher levels of compact development than other suburban workplaces.

Employees of workplaces in the "intermediate" type exhibit the highest level of drive-alone commuting and the lowest level of carpooling. Many workplaces in this type constitute medium-sized retail-based strip centers along major highways and arterials. Highway-based retail activities appear to be among the important factors in producing automobile dependence.

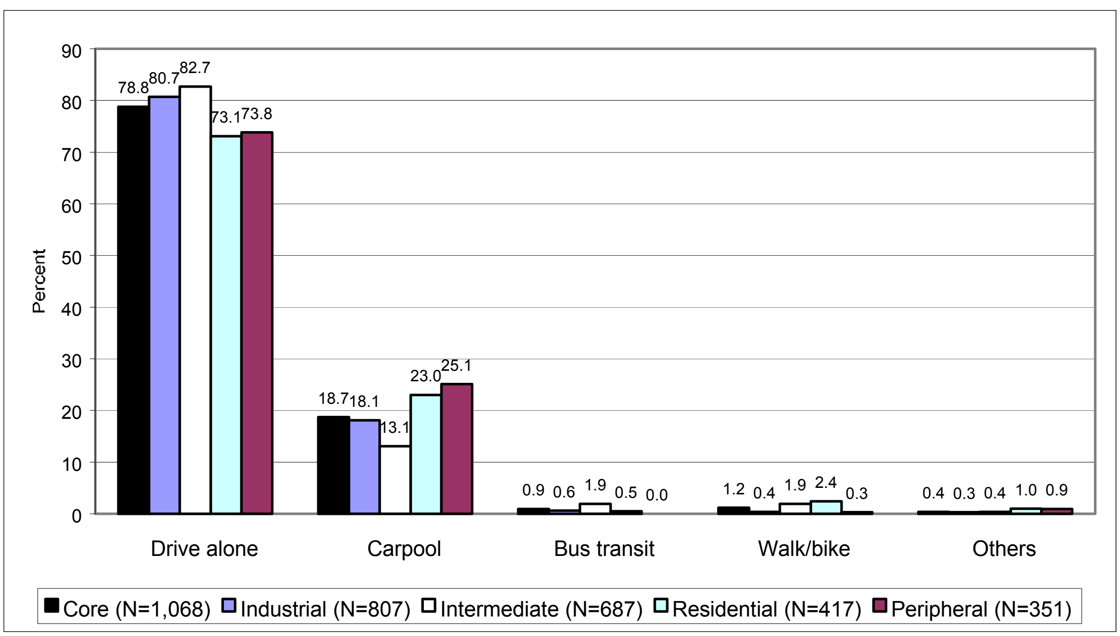

Figure 6.10 Modal split by suburban workplace type

Employees of workplaces in the "residential" type exhibit the lowest level of drive-alone commuting and the highest level of carpooling. Employees in this type also tend to make more walking and cycling to work than employees in other workplace types. For retail activities, residential-based small-sized centers appear to do a good job in attaining less resource intensive travel patterns made by the employees.

Trip Chaining

Figure 6.11 shows differences of activity stops during commuting trips among the suburban workplace types. Patterns of activity stops are relatively similar across the suburban workplace types. Employees of workplaces in the "intermediate" type make the highest levels of activity stops both before and after work. In the prior part, we observed that employees in this workplace type are more likely to drive alone. Trip chaining appears to be closely related to increasing automobile trips and commercial activity sites along the highway corridors.

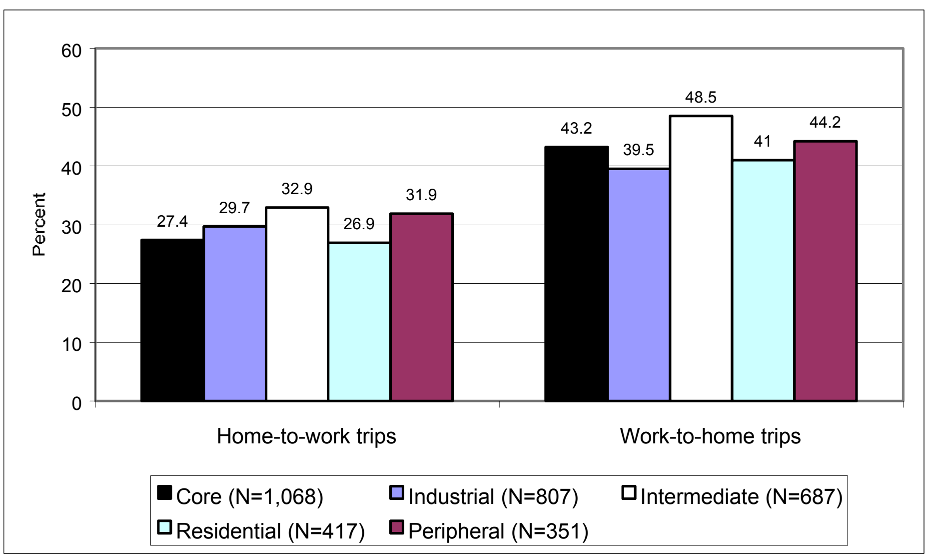

Figure 6.11 Activity stops during commuting trips by suburban workplace type

Workplaces in the "core" type in which activity sites are most concentrated among the suburban workplace types make little difference upon the trip chaining patterns. Yet, employees in this type make fewer stops before work but more stops after work. Longer trip distance and congestion may affect such trip-activity patterns.

Employees of workplaces in the "industrial" and "residential" types tend to make less trip chaining. Patterns of activity stops made by employees in each workplace type are closely related to each one's affinity to commercial activities.

In summary, the small-sized "residential" type is related to less resource intensive commuting, as employees in these workplace types make shorter travel in duration and less drive-alone commuting. Workplaces in the "intermediate" type, mostly retail-based strip centers along the major highway corridors, exhibit the highest levels of drive alone trips and activity stops, implying that automobile use and trip chaining are closely related.

Factors Affecting Commuting Behavior

The previous comparative analysis provides some insights into what types of workplaces are related to certain characteristics of commuting made by employees there. Yet, it does not provide the information for what spatial factors are associated with particular travel patterns, and if so, which ones do so. Using statistical models for commute travel times, travel mode, and trip chaining, this section explores the important factors affecting commuting behavior made by individual workers.

Time Traveled

An ordinary linear regression is used to estimate travel times. The dependent variable is the shortest vehicle minutes traveled to work by individual automobile commuters. Independent variables are the five spatial factors of workplace environs, which were identified by the factor analysis in the previous chapter. Confounding variables include the variables representing the socioeconomic characteristics of individual employees and the characteristics of employers. Before estimating parameters, stepwise regression is implemented to address a multicolinearity problem, where the independent variables are correlated themselves.

Table 6.11 Variables used for the travel time model

Type	Variables
Dependent	• Time traveled: vehicle minutes traveled through the shortest path to work in a private vehicle by each employee
Independent	• 5 spatial factors of workplace environs (5): factor scores of job concentration, regional accessibility to housing and jobs, suburbanity, industrial clustering, and commercial activity
Confounding	• Employee characteristics (10): age, gender (dummy), job attachment (dummy: full-time or part-time), number of persons in household, number of workers in household, number of vehicles per licensed driver in household, annual household income (dummy: 6 income groups), distance from home to CBD, MSA of residence (dummy: Dallas or Fort Worth), time of arrival at work (dummy: peak or off-peak) • Employer characteristics (3): industry type of workplace (dummy: retail, service, and basic), number of employees in workplace, MSA of workplace (dummy: Dallas or Fort Worth)

Regression Model without Spatial Factors

Table 6.12 presents the results of regression without the spatial factors variables. The model with confounding variables (i.e., socioeconomic characteristics of individual workers and workplace-specific characteristics) explains 22.9% of the variance in actual travel times. Some socioeconomic variables (e.g., gender, number of workers in household, and some income groups) were abandoned during stepwise regression because they contribute little to estimating travel times.

Table 6.12 Regression of vehicle time traveled to work: without spatial factors

	Coefficient	Beta	t-statistic
Age	0.028	0.035	2.52**
Dummy attachment to employer: full-time	3.782	0.117	8.18**
No. of persons in household	0.560	0.087	6.33**
No. of vehicles per licensed driver in household	0.629	0.023	1.73*
Dummy annual household income (reference category: under $15,000):			
$25,000 to <$35,000	0.516	0.027	1.74*
$35,000 to <$50,000	1.047	0.044	2.95**
$50,000 to <$75,000	1.251	0.054	3.60**
Distance from home to CBD	0.322	0.209	15.25**
Dummy MSA of residence: Dallas MSA	-7.258	-0.364	-17.85**
Dummy time of arrival at work: peak hours	1.325	0.073	5.02**
Dummy industry type of workplace (reference category: retail):			
Service	3.241	0.183	9.64**
Basic	3.029	0.155	7.67**
Number of employees in workplace	0.004	0.130	8.44**
Dummy MSA of workplace: Dallas MSA	6.542	0.298	14.37**
Constant	0.569		0.71
No. of cases		4,315	
R-square (Adjusted R-square)		0.229 (0.227)	
F-statistic		91.47**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

Most socioeconomic variables are positively associated with commute travel times. For example, workers with larger household size make longer trips. Workers with higher household incomes travel longer. Workers who reside in the suburbs travel longer. Workers in service and basic (e.g., manufacturing) industries travel longer than workers in retail businesses.

Some relationships are different from general theoretical expectations. For example, full-time workers travel longer than part-time workers, although long-term attachment to an employer is expected to contribute to shortening travel times by providing the opportunity for the employee to live closer to current work. Gender difference does not make any significant difference in travel times in our data, although theory holds that women make shorter commute travel.

It is interesting that workers who reside in the Dallas area travel shorter than workers who reside in the Fort Worth area, while workers who work in the Dallas area travel longer than workers who work in the Fort Worth area. The reason may be because a majority of workplaces (also the sampled workplaces for the 1994 NCTCOG Workplace Survey) are located in the Dallas area.

The standardized regression coefficients (labeled "beta") provide the information about which variables are more important in explaining travel times. First, the regression result indicates that where individual workers live and work in the Dallas-Fort Worth region are important factors. Second, the industry type of employer in which individual workers are employed is clearly an important factor. Third, of the socioeconomic variables, the term of attachment to employer (i.e., full-time or part-time) and household size are important among others. Lifecycle and the associated residential requirements appear to be important factors in shaping commuting characteristics. Positive relationships of most socioeconomic factors to travel times indicate that reducing auto travel times is a difficult job.

Regression Model with Spatial Factors

Table 6.13 presents the result of regression for travel times with both spatial and non-spatial factors. Model fitting (R-square) increases to 31.4% from the 22.9% in the prior model. All of the 5 spatial factors are found to be significant in explaining travel times at either 5% or 10% level. Among the spatial factors, 2 factors (suburbanity and regional accessibility to housing and jobs) are associated with shorter auto commute travel times, and 3 factors (job concentration, industrial clustering, and commercial activity) are associated with longer auto travel times.

Table 6.13 Regression of vehicle time traveled to work: with spatial factors

	Coefficient	Beta	t-statistic
Age	0.026	0.033	2.51**
Dummy attachment to employer: full-time	3.118	0.096	7.25*
No. of persons in household	0.607	0.094	7.26**
No. of vehicles per licensed driver in household	0.612	0.023	1.78*
Dummy annual household income (reference category: under $15,000):			
$25,000 to <$35,000	0.510	0.026	1.82*
$35,000 to <$50,000	0.941	0.039	2.80**
$50,000 to <$75,000	1.188	0.052	3.62**
Distance from home to CBD	0.474	0.308	22.32**
Dummy MSA of residence: Dallas MSA	-7.400	-0.371	-19.14**
Dummy time of arrival at work: peak hours	0.995	0.055	3.97**
Dummy industry type of workplace (reference category: retail):			
Service	1.810	0.102	5.38**
Basic	1.537	0.079	3.82**
Number of employees in workplace	0.001	0.036	2.38**
Dummy MSA of workplace: Dallas MSA	6.545	0.298	13.27**
Factor "job concentration"	1.340	0.173	11.91**
Factor "regional accessibility"	-0.608	-0.064	-3.50**
Factor "suburbanity"	-2.786	-0.225	-14.87**
Factor "industrial clustering"	0.796	0.087	6.19**
Factor "commercial activity"	0.239	0.026	1.90*
Constant	0.402		0.52
No. of cases		4,315	
R-square (Adjusted R-square)		0.314 (0.311)	
F-statistic		98.63**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

The "suburbanity" factor, which includes the distance to CBD, distance to public transit, and ratio of jobs to housing as major spatial components among others (see the linear combination of individual variables in Figure 5.4, page 91), implies that job decentralization helps shorten auto commute travel times. This finding lends support to the "co-location" hypothesis denoting that jobs-housing balance is part of natural evolutionary development process as firms and households maintain an equilibrium (Cervero 1989b; Gordon, Kumar, and Richardson 1989; Giuliano 1991; Gordon, Richardson, and Jun 1991; Levinson and Kumar 1994; Cervero 1996a). Suburban workplaces have the advantage of utilizing the suburban labor force, suburban housing stock, ubiquitous highways, and widespread automobile availability.

Some care is needed in interpreting shorter commuting in relation to the "suburbanity" factor. As Levinson (1998) points out, it is the suburbanization of jobs, not the suburbanization of housing, to balance jobs and housing and thus to shorten commute travel times. In the previous section (see Figure 6.1, page 120), this study saw that housing suburbanization was related to longer auto travel times. Furthermore, there was an indication that travel times increased beyond a certain level of decentralization (approximately 16-20 miles from the regional center, see Figure 6.7, page 130).

The "regional accessibility" factor, which includes the regional accessibility to housing and jobs, local housing prices, and share of multi-family housing in the vicinity of each workplace as major spatial components among others (see the linear combination of individual variables in Figure 5.4, page 91), indicates that putting jobs in relation to the distributions of jobs and housing in the metropolitan region contribute to shortening commute travel times. It also implies that metropolitan spatial structure is important in affecting commute travel times. Note that, while the "regional accessibility" factor includes both levels of accessibility to housing and jobs in the metropolitan region as the most influential elements, it is also positively associated with local housing prices.

Higher values on the spatial factors of "job concentration," "industrial clustering," and "commercial activity" are associated with longer auto commute travel times. These factors are related to certain aspects of employment agglomeration. The "job concentration" factor includes the share of employment, particularly office land use, employment density, housing density, and activity mix as major spatial components among others. The relationship to travel times is consistent with the findings of previous studies, suggesting that larger and denser centers are associated with longer commuting times (Giuliano and Small 1991; Cervero and Wu 1997). Note that, as identified in the prior factor analysis, this factor is the most influential one in characterizing workplace locations.

The "industrial clustering" factor combines the high shares of industrial and employment land uses and low shares of residential land uses as major components among others. This factor is related to the incompatibility with residential land use, particularly single-family, which results in longer travel times.

The "commercial activity" factor includes the share of retail land uses and proximity to major highways as major components among others. Strip retail centers along major highways provide the opportunity for automobile commuters to make more stops for non-work activities during commuting trips and thus increase the possibility of longer travel times and more traffic congestion.

The standardized regression coefficients indicate that, among the spatial factors, the "suburbanity" and "job concentration" factors are most important in explaining travel times. Further, the standardized coefficients indicate that, while socioeconomic variables are important in shaping commute travel times, spatial factors also important.

In chapter II, this study hypothesized that a workplace in a job-rich area is associated with longer commute travel times, and a workplace in a housing-rich area is associated with shorter commute travel times. While the research result generally supports the hypothetical expectations, the relationships are much more complex than such simple hypotheses. The factors of "suburbanity" and "regional accessibility" for workplace environs indicates that the relative location of a workplace in terms of regional distributions of urban opportunities, particularly of housing, is important in shortening auto travel times. The importance of regional compactness in shortening travel times is also related to the fact that most commuting occurs at the regional scale. The factors of "job concentration," "industrial clustering," and "commercial activity" indicates that local workplace environs, particularly local distributions of jobs, contribute to longer auto travel times. Larger centers require correspondingly larger labor market sheds. Also, denser centers have higher possibility of traffic congestion than otherwise.

Mode Choice

The mode choice model in this study is implemented by setting up a probability model that a worker will make a commuting trip by a single-occupant vehicle against other alternative modes (carpooling, pubic transit, walking/bicycling, etc.). Often, a binary choice situation is modeled through a logit function (SAS Institute Inc. 2000). A logit model assumes a linear relationship between the log of odds and explanatory variables,

$$\log \frac{p_i}{1 - p_i} = \beta x_i, \text{ or}$$

$$p_i = \frac{\exp(\beta x_i)}{1 + \exp(\beta x_i)}$$

where p_i is the probability that individual i will make a choice (drive-alone commuting), x_i is a vector of explanatory variables including socioeconomic characteristics of individual i and industrial and spatial characteristics of the workplace in which the individual is employed, and β is a vector of parameters associated with the vector x. The maximum likelihood estimation is used to estimate the model parameters.

Like the previous travel time model, the mode choice model consists of two types: one without spatial factors, the other with both spatial and non-spatial factors to see the incremental contribution of spatial factors. While the mode choice model includes all of the independent and confounding variables used in the travel time model, it also includes travel distance in miles through the shortest path between home and work of each worker. The idea is to capture the effect of travel costs and spatial friction on mode choice, although the simple physical distance may be a weak indicator of transportation services. Before parameter estimation, stepwise logistic regression is applied to select only meaningful variables.

Table 6.14 Variables used for the mode choice model

Type	Variables
Dependent	• Travel mode: whether an employee will make a commuting trip by a single-occupant vehicle (1=yes, 0=no)
Independent	• 5 spatial factors of workplace environs (5): factor scores of job concentration, regional accessibility, suburbanity, industrial clustering, and commercial activity
Confounding	• Employee characteristics (11): age, gender (dummy), job attachment (dummy: full-time or part-time), number of persons in household, number of workers in household, number of vehicles per licensed driver in household, annual household income (dummy: 6 income groups), distance from home to CBD, MSA of residence (dummy: Dallas or Fort Worth), time of arrival at work (dummy: peak or off-peak), shortest network distance between home and work • Employer characteristics (3): industry type of workplace (dummy: retail, service, and basic), number of employees in workplace, MSA of workplace (dummy: Dallas or Fort Worth)

Logit Model without Spatial Factors

Table 6.15 presents the result of logistic regression of the likelihood of a single-occupant vehicle trip, in which only confounding variables are introduced. The model explains 22.5% (on the Nagelkerke R-square) of observed responses on mode choice. The likelihood ratio indicates that the model is significant at a 5% level. Some variables (e.g., full-time or part-time, commuting distance, industry type, etc.) were abandoned during the stepwise selection because they contribute little to estimating mode choice.

Table 6.15 Logistic regression of single-occupant vehicle mode choice to work: without spatial factors

	Coefficient	Odds ratio	Chi-square
Age	0.024	1.024	33.97**
Gender: male	0.978	2.660	137.12**
No. of persons in household	-0.493	0.611	213.31**
No. of workers in household	0.186	1.205	10.85**
No. of vehicles per licensed driver in household	2.117	8.310	144.34**
Dummy annual household income (reference category: under $15,000):			
$15,000 to <$25,000	0.311	1.365	3.08*
$25,000 to <$35,000	0.299	1.349	3.60*
$35,000 to <$50,000	0.392	1.480	5.27**
$50,000 to <$75,000	0.635	1.887	13.08**
$75,000 and higher	0.795	2.214	18.10**
Distance from home to CBD	0.025	1.025	12.03**
Dummy MSA of residence: Dallas MSA	-0.182	0.834	3.96**
Dummy time of arrival at work: peak hours	-0.520	0.594	36.14**
Number of employees in workplace	-0.0003	1.000	5.60**
Constant	-1.140		15.58**
No. of cases		4,457	
Pseudo-R square (Nagelkerke)		0.225	
Likelihood ratio		708.16**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

Most socioeconomic variables significant in explaining the likelihood of drive-alone trips are in positive signs. As shown in the parameter of the number of vehicles in household, car ownership is clearly a major force of drive-alone trips. Men make more drive-alone trips than women. Workers with higher household incomes make more drive-alone trips. Workers commuting during peak hours drive alone less than off-peak commuters.

It is interesting that, while the number of household members is negatively associated with the likelihood of single-occupant vehicle trips, the number of workers in a household is positively associated with the likelihood. The insignificance of trip distance on mode choice implies that automobile trips are widespread regardless of the distances traveled by individual workers. The number of employees in the workplace in which an employee works is only barely negatively associated with drive-alone commuting, implying that employees in larger workplaces exhibit little difference in commuting mode, even though they may possess more potential opportunities to find alternatives to drive-alone such as carpooling.

The relative importance of the variables in terms of effect on drive-alone commuting can be referenced by odds ratios. For example, the above table indicates that the odds (i.e., predicted probability of single-occupant vehicle commuting divided by 1 minus predicted probability of single-occupant vehicle commuting) being 1 are 2.66 times higher for men than for women. As the odds ratio is farther from 1, the variable is relatively more important. Thus, the odds ratios indicate that automobile availability, gender, and household income are major driving forces of automobile dependence.

Logit Model with Spatial Factors

Table 6.16 presents the result of logistic regression of the likelihood of single-occupant vehicle trip, in which both spatial and non-spatial factors are introduced. Model fitting increases to 26.7% from the 22.5% in the prior model. The likelihood ratio indicates that the model is significant at a 5% level.

Of the 5 spatial factors, 3 factors of workplace environs (job concentration, suburbanity, and commercial activity) are significant in explaining the likelihood of drive-alone commuting. Of the 3 spatial factors, only the "job concentration" factor is associated with less drive-alone commuting. As mentioned earlier, the "job concentration" factor includes the share of employment, particularly office, employment density, housing density, and land use mix as major spatial components among others (see the linear combination of individual variables in Figure 5.4, page 91). Employees in job concentrations may easily find alternative modes to work, such as public transit and carpool partners. This finding is consistent with previous studies on the positive effects of land use intensification (e.g., high density and high activity mix) on reducing automobile dependence (Cervero 1989a; Newman and Kenworthy 1989; Frank and Pivo 1994; Cervero and Kockelman 1997).

Table 6.16 Logistic regression of single-occupant vehicle mode choice to work: with spatial factors

	Coefficient	Odds ratio	Chi-square
Age	0.025	1.025	35.05**
Gender: male	1.013	2.753	137.39**
No. of persons in household	-0.518	0.596	221.31**
No. of workers in household	0.164	1.178	7.83**
No. of vehicles per licensed driver in household	2.203	9.047	147.63**
Dummy annual household income (reference category: under $15,000):			
$15,000 to <$25,000	0.379	1.461	4.37**
$25,000 to <$35,000	0.463	1.590	8.11**
$35,000 to <$50,000	0.536	1.709	9.26**
$50,000 to <$75,000	0.780	2.225	19.57**
$75,000 and higher	0.995	2.704	27.06**
Dummy time of arrival at work: peak hours	-0.490	0.613	27.05**
Shortest network distance between home and work	0.008	1.008	3.05*
Dummy industry type (reference category: retail):			
Service	0.300	1.350	6.20**
Basic	0.223	1.250	2.57
Factor "job concentration"	-0.366	0.693	89.46**
Factor "suburbanity"	0.231	1.260	11.30**
Factor "commercial activity"	0.227	1.255	23.53**
Constant	-1.498		24.25**
No. of cases		4,457	
Pseudo-R square (Nagelkerke)		0.267	
Likelihood ratio		853.31**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

The "suburbanity" factor is positively associated with the likelihood of drive-alone trips. This finding is consistent with previous studies of high rates of automobile dependence in low-density decentralized employment locations (Cervero and Wu 1997).

The "commercial activity" factor is positively associated with the likelihood of drive-alone trips. In general, regional shopping malls and strip centers are highly automobile-oriented and dictate customers to rely more on private automobiles to transport bulky purchases.

The odds ratios indicate that, while spatial factors affect commuting travel mode, socioeconomic variables such as automobile availability and income are much more important. The result speaks eloquently of how difficult it is to reduce automobile dependence.

In chapter II, this study hypothesized that a workplace in a job-rich or housing-rich area is associated with less automobile commuting. While the research result does not directly confirm the hypotheses, it indicates that land use intensification and clustering reduce drive-alone commuting. However, the result also indicates that the relationships are much more complex than such simple hypotheses. For example, local land use characteristics (e.g., density, land use mix) are more important than regional spatial structure (e.g., polycentric or dispersed metropolitan structure) in reducing automobile dependence. As shown in the "commercial activity" factor, the nature of activity (e.g., retail, office, or industrial) is related to mode choice.

It should be noted that there is an apparent conflict between different spatial factors in affecting commuting. For example, the "job concentration" factor is associated with longer auto travel times but less drive-alone commuting. The "suburbanity" factor is associated with shorter auto travel times but more drive-alone commuting. The implications for urban transportation issues are considerably complex due to such trade-offs.

Trip Chaining

Trip chaining behavior is analyzed by setting up a probability model that a worker will make any activity stops on the way home after work. As shown in the previous section, workers make more activity stops after work than before work. Activity stops made after work appear to be related to more "discretionary" activities (e.g., shopping, personal businesses) and are thus more likely influenced by land use characteristics.

Like the mode choice model, a binary logit model is used for parameter estimation. In addition to those variables used in the mode choice model, the activity stop model in this study also includes trip mode to capture the effect of personal mobility. For example, shopping activities that account for the largest portion of activity stops on the way after work are likely to heavily depend on private automobiles as retail locations are automobile-oriented and purchases become bulky.

Table 6.17 Variables used for the activity stop model

Type	Variables
Dependent	• Mode choice: whether an employee will make at least one stop during commuting trips after work (1=yes, 0=no)
Independent	• 5 spatial factors of workplace environs (5): factor scores of job concentration, regional accessibility, suburbanity, industrial clustering, and commercial activity
Confounding	• Employee characteristics (12): age, gender (dummy), job attachment (dummy: full-time or part-time), number of persons in household, number of workers in household, number of vehicles per licensed driver in household, annual household income (dummy: 6 income groups), distance from home to CBD, MSA of residence (dummy: Dallas or Fort Worth), time of leaving work (dummy: peak or off-peak), shortest network distance between home and work, trip mode (dummy: 5 modes) • Employer characteristics (3): industry type of workplace (dummy: retail, service, and basic), number of employees in workplace, MSA of workplace (dummy: Dallas or Fort Worth)

Logit Model without Spatial Factors

Table 6.18 presents the result of logistic regression of the likelihood of activity stops on the way home after work, in which only confounding variables are introduced. The model explains 14.3% (on the Nagelkerke R-square) of observed responses on activity stops. Compared to travel time and mode choice models, the model fitting tends to be lower, implying the complexity of trip chaining behavior. Nonetheless, the likelihood ratio indicates that the model is significant at a 5% level. Some location variables specific to the study area (e.g., distance from CBD to home, Dallas or Fort Worth) were abandoned during the stepwise selection because they contribute little to estimating mode choice.

Many relationships appear to be consistent with theoretical expectations. Income is clearly a major driving force, as workers with higher household incomes make more activity stops. Trip mode is also an important factor. Compared to drive-alone commuters, public transit commuters make fewer stops. But carpoolers make more stops than drive-alone commuters. Related to trip mode, automobile availability clearly contributes to trip chains, as it gives workers more flexibility and the mobility to link their work trips to various non-work trips. As the previous studies suggested, women make more activity stops than men do (Hanson and Hanson 1980; McGuckin and Murakami 1999). Full-time workers make more stops than part-time workers do.

Workers who commute during evening-peak hours make more activity stops. Since certain activity trips (e.g., grocery shopping before dinner) must be made during peak hours, they tend to burden peak-hour traffic. Trip distance between home and work is weakly associated with the likelihood of making stops.

In contrast to theoretical expectations, the number of household members makes little difference in activity stops made by a worker as a household member. Contrary to theoretical expectations, the number of workers in a household is rather negatively associated with the likelihood of stops.

Table 6.18 Logistic regression of activity stops during commuting trips after work: without spatial factors

	Coefficient	Odds ratio	Chi-square
Age	-0.025	0.976	59.57**
Gender: male	-0.815	0.443	150.04**
Dummy attachment to employer: full-time	0.443	1.558	11.98**
No. of persons in household	-0.046	0.955	2.67
No. of workers in household	-0.139	0.955	7.79**
No. of vehicles per licensed driver in household	0.447	1.564	20.14**
Dummy annual household income (reference category: under $15,000):			
$15,000 to <$25,000	0.710	2.034	18.16**
$25,000 to <$35,000	0.802	2.231	27.58**
$35,000 to <$50,000	0.864	2.372	28.24**
$50,000 to <$75,000	1.088	2.968	44.28**
$75,000 and higher	1.082	2.949	41.26**
Dummy time of leaving work: peak hours	0.175	1.191	6.94**
Shortest network distance between home and work	0.008	1.008	4.65**
Dummy trip mode (reference category: drive-alone):			
Carpool	0.502	1.652	33.47**
Bus transit	-0.407	0.666	4.90**
Walk/bike	-0.310	0.733	0.39*
Others (motorcycle, taxi, etc.)	0.608	1.836	1.19
Dummy industry type (reference category: retail):			
Service	0.419	1.521	21.82**
Basic	0.126	1.134	1.40
Number of employees in workplace	0.0003	1.000	5.64**
Constant	-0.718		8.21**
No. of cases		4,367	
Pseudo-R square (Nagelkerke)		0.143	
Likelihood ratio		421.98**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

Previous studies have explained the increase of trip chaining by more income but less disposable time due to the increase of traffic congestion and trip length (Nishi, Kondo, and Kitamura 1988; Levinson and Kumar 1995). While this study supports previous studies, trip chaining appears to be a product of increasing income and personal mobility more than an adjustment to time loss by the increase of traffic congestion and trip length.

Logit Model with Spatial Factors

Table 6.19 presents the logistic regression results of activity stops on the way home after work, in which both spatial and non-spatial factors are introduced. Model fitting is increased to 16.1% (on the Nagelkerke R-square) from the previous 14.3%. Even after the 5 spatial factors were added to the model, the improvement of model fitting seems marginal, implying that the trip chaining made by individual workers is mainly related to personal and household lifestyles. Nonetheless, all of the 5 spatial factors are statistically significant in explaining trip-chaining behavior.

While 2 factors (job concentration and commercial activity) are positively associated with the likelihood of activity stops, 3 factors (regional accessibility, suburbanity, and industrial clustering) are negatively associated with it. It is not surprising that both "job concentration" and "commercial activity" factors produce more activity stops, since the concentration of activity sites, particularly retailing, should provide the opportunity for workers to plan more activities. As in the relationship of the "industrial clustering" factor to activity stops, certain activities, such as manufacturing and warehousing, tend to discourage workers from making stops due to the less customer orientation. The findings are consistent with initial hypotheses.

Table 6.19 Logistic regression of activity stops during commuting trips after work: with spatial factors

	Coefficient	Odds ratio	Chi-square
Age	-0.026	0.974	63.57**
Gender: male	-0.797	0.451	140.39**
Dummy attachment to employer: full-time	0.422	1.525	10.71**
No. of persons in household	-0.037	0.963	1.76
No. of workers in household	-0.130	0.878	6.77**
No. of vehicles per licensed driver in household	0.463	1.589	21.21**
Dummy annual household income (reference category: under $15,000):			
$15,000 to <$25,000	0.677	1.968	16.36**
$25,000 to <$35,000	0.740	2.096	23.17**
$35,000 to <$50,000	0.792	2.209	23.47**
$50,000 to <$75,000	1.025	2.788	38.94**
$75,000 and higher	0.981	2.667	33.46**
Distance from home to CBD	0.010	1.010	2.79*
Dummy time of leaving work: peak hours	0.161	1.174	5.76**
Shortest network distance between home and work	0.006	1.006	2.73*
Dummy trip mode (reference category: drive-alone):			
Carpool	0.471	1.601	28.78**
Bus transit	-0.709	0.492	13.54**
Walk/bike	-0.336	0.715	0.46
Others (motorcycle, taxi, etc.)	0.601	1.825	1.13
Dummy industry type (reference category: retail):			
Service	0.336	1.400	12.31**
Basic	0.026	1.026	0.06
Dummy MSA of workplace: Dallas MSA	0.215	1.234	3.63*
Factor "job concentration"	0.199	1.220	37.58**
Factor "regional accessibility"	-0.148	0.863	8.57**
Factor "suburbanity"	-0.170	0.844	9.83**
Factor "industrial clustering"	-0.086	0.917	5.18**
Factor "commercial activity"	0.075	1.078	4.31**
Constant	-0.839		10.17**
No. of cases		4,367	
Pseudo-R square (Nagelkerke)		0.161	
Likelihood ratio		486.10**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

The factors of "regional accessibility" and "suburbanity" are negatively associated with the likelihood of activity stops. It is interesting that these were associated with shorter auto travel times in the previous analysis. Because of the relatively shorter commute travel times, the necessity and opportunity of trip chaining during commuting trips may be less in the workplaces with high levels of "regional accessibility" and "suburbanity." If we assume that every worker needs a fixed amount of daily or weekly non-work trips, home-based non-work trips may substitute for trip chains during commuting trips in the case of workers who make fewer trip chains, for example, employees of workplaces in suburbs.

In chapter II, this study hypothesized that a workplace in a job-rich area is associated with more trip chaining, and a workplace in a housing-rich area is associated with less trip chaining. While the research result generally supports the hypothetical expectations, the relationships are much more complex than such simple hypotheses. Like drive-alone commuting, local activity intensity factors (e.g., job concentration, commercial activity) are associated with more trip chaining, and regional spatial factors (e.g., suburbanity, regional accessibility), particularly regional housing factors, are associated with less trip chaining.

The result of the trip-chaining model indicates that workers take advantage of potential activity sites by linking commuting trips to non-work activities (Crane 1996; Handy 1996b). Yet, these evolving activity-travel patterns are clearly driven by increasing income, widespread automobile use, and changing lifestyle. The odds ratios indicate that, compared to the spatial factors, socioeconomic factors are much more important in explaining trip chaining behavior.

Summary

This chapter examined commuting characteristics of employees of workplaces in relation to their environs. A comparative analysis of commuting patterns by workplace location type shows that the differences of commute travel times by automobiles are more distinct between those workplaces in major employment centers and those outside of centers than between those workplaces in central parts of the metropolitan area and those in suburbs. Employees of workplaces in larger and denser centers travel longer by automobile in duration. This suggests that longer commuting is a product of the way in which workplaces are developed, such as low-density and scatteration, rather than a product of the decentralization of jobs.

Suburban workplaces in general are associated with shorter auto travel times. The result lends support to the "co-location" hypothesis denoting that jobs-housing balance is part of evolutionary development process as firms and households locate each other. But, the result does not mean that the "co-location" can be applied as a policy or planning prescription in an indiscriminate manner. The result also suggests that decentralized workplaces beyond a certain degree of decentralization (approximately 16-20 miles from the regional center in the Dallas-Fort Worth area) are associated with longer auto travel times.

Except for some workplaces in central areas, most workplaces exhibit overwhelming automobile dependence, particularly in regards to drive-alone commuting. Employees of workplaces in central areas make less drive-alone commuting and more carpooling and public transit than employees of other workplace locations. Although workplaces in suburban centers attain some levels of compact development patterns, employees of those workplaces are far more automobile dependent than their counterparts in older primary centers. The least resource intensive trip modes such as walking and cycling are quite homogeneous across the different workplace types due to overwhelming automobile dependence. Yet, there is a weak indication that employees of small and residence-based workplaces make slightly more walking and cycling trips.

Frequency of activity stops made on the way home after work show wider variations among different workplace location types than the activity stops made on the way before work. This result suggests that, while activity stops on the way to the workplace are generally related to regular activities (e.g., pickup/drop-off), activity stops on the way home after work are generally related to discretionary activities (e.g., shopping, personal business). Therefore, discretionary stops have more implications for land use planning such as mixed use and clustering.

Employees of workplaces in larger and denser centers make more activity stops after work, indicating that workers take advantage of potential activity sites during commuting trips. Increasing travel times and traffic congestion also tend to encourage workers to link their trips to various non-work activities. Increasing income and widespread automobile availability is an important driving factor for more trip chains during commuting trips.

Major suburban employment centers show relatively similar characteristics to other suburban centers in commute travel times. Yet, mature suburban centers (e.g., Galleria) appear increasingly burdened by traffic congestion like their counterparts in the central city. Automobile dependence is also higher in mature suburban mixed-use centers. In other words, suburban centers exhibit the worst case of commuting: lengthy travel and severe automobile dependence. While most suburban centers were developed in the automobile age, the increasing inward agglomeration of jobs in larger suburban centers creates disastrous consequences in traffic: congestion, yet scarcely any choice but to drive. Of the major suburban centers, the master planned community featuring a mix of jobs and housing does relatively a good job by showing less drive-alone commuting and more carpooling.

Of the 5 suburban workplace types, small-sized residence-based workplaces exhibit less resource intensive commuting. Employees of workplaces in this type make shorter auto travel in duration and less drive-alone commuting. Employees of workplaces in medium-sized retail-based strip centers along the major highway corridors are most likely to make the longest travel in private automobiles. Employees of workplaces in this suburban type make more trip chains on the ways to work and home after work. There is a clear indication of interdependency among automobiles, highways, and activity stops.

Table 6.20 Summary of commuting characteristics by workplace type

Commuting attributes		Vehicle times traveled	Trip mode		Trip chaining (activity stops)	
			Drive alone	Other modes	Home-to-work	Work-to-home
Workplace locations	Central, inside center	Longer	Lower	Higher in public transit	Medium	Higher
	Central, outside center	Medium to shorter	Higher	Lower in carpool	Medium	Lower
	Suburban, inside center	Medium	Higher	Lower in carpool	Medium to higher	Medium
	Suburban, outside center	Shorter	Higher		Medium	Lower
Selected employment centers	Downtown Dallas (CBD)	Longer	Lower	Higher in public transit	Medium to lower	Higher
	Galleria (Suburban downtown)	Medium	Higher	Lower in carpool	Medium	Medium to higher
	Las Colinas (Master planned community)	Medium	Lower	Higher in carpool	Higher	Lower
	Telecom Corridor (High-tech corridor)	Medium to shorter	Medium		Medium	Higher
Suburban workplace types	Core	Medium	Medium to higher		Medium to lower	Medium
	Industrial	Medium to longer	Higher		Medium	Lower
	Intermediate	Medium	Higher	Lower in carpool	Medium to higher	Medium to higher
	Residential	Shorter	Medium to lower	Higher in carpool and walking/cycling	Medium to lower	Lower
	Peripheral	Medium	Medium to lower	Higher in carpool	Medium to higher	Medium

Statistical models of commuting behavior indicate that the relative importance of socioeconomic and spatial factors depends on the aspect of commuting trip being measured. Spatial factors tend to do a better job in explaining auto travel times than in explaining travel mode and trip chaining. This implies that a spatial strategy to shape travel patterns would be more effective when addressing travel times than when addressing travel mode and trip chaining. The relative importance of socioeconomic characteristics of individual workers is evident in explaining travel mode and trip chaining, particularly trip chaining. But, in spite of the relative importance, both spatial and non-spatial factors play a role in explaining travel. This implies that both factors could be complementary.

It is important to note that most socioeconomic variables are positively associated with travel times, drive-alone trips, and activity stops after work. For example, household income and automobile ownership are significantly and positively associated with all of the three dependent variables. The results speak eloquently of how difficult it is to cope with urban transportation problems.

Concerning commute travel times by automobile commuters, regional spatial factors (regional accessibility to housing and jobs, suburbanity) are associated with shorter commuting, while local job-related spatial factors (job concentration, industrial clustering, and commercial activity) are associated with longer commuting. For drive-alone commuting trips, only the "job concentration" factor is associated with less drive-alone commuting, while the factors of "commercial activity" and "regional accessibility to housing and jobs" are associated with more drive-alone commuting. For activity stops after work, activity intensity factors (job concentration, commercial activity) are associated with more activity stops, while other spatial factors (regional accessibility to housing and jobs, suburbanity, and industrial clustering) are associated with fewer activity stops.

There are apparent conflicts between travel outcomes in relation to spatial factors. For example, the "job concentration" factor is associated with longer travel times but less drive-alone commuting. The "suburbanity" factor is associated with shorter travel times but more drive-alone commuting. The implications for transportation policies are quite complex since a land use policy should consider the possibility of unintended consequences resulting from the trade-offs among travel outcomes in relation to spatial factors.

Table 6.21 Summary relationships between spatial factors for workplaces and commuting characteristics

	Commute travel time	Drive-alone commuting	Activity stops after work
Job concentration	+	–	+
Regional accessibility	–	0	–
Suburbanity	–	+	–
Industrial clustering	+	0	–
Commercial activity	+	+	+

+ positive relationship; – negative relationship, 0 no relationship

CHAPTER VII
CONCLUSIONS

There has been a lively debate over using land use strategies to address urban transportation and air quality issues over the past decades. While much research focuses on neighborhood-scale land use patterns, less research has been done on workplace locations. Moreover, a majority of employment-based studies have focused on overall metropolitan structure using aggregate data, providing limited implications for constructing interpretable theories and practical land use policies. To fill the gap, this study investigated the spatial characteristics of 270 workplaces in the metropolitan Dallas-Fort Worth. Using individual-level commute travel data, the relationship between workplace environs and commuting patterns was explored in terms of travel time, travel mode, and trip chaining. This section highlights major findings and policy implications from this study.

Summary

Compared to other US metropolitan regions, the Dallas-Fort Worth area has two vital regional centers. Yet, this area has also experienced rapid suburbanization in both population and employment over the recent decades. Suburbs have gained more shares of new jobs than central cities. Employment growth concentrates on a few affluent suburbs in the northern Dallas area. Suburban centers are increasingly competing with the prestigious role of older primary centers in the central city by utilizing the advantage of improved mobility through highways and automobiles. The morphology of suburban jobs is complex, as a large share of suburban jobs is located in low-density scattered sites throughout the suburbs and exurbs.

Given that most commuting occurs between home and work, workplace environs are defined by a number of spatial factors around individual workplaces, including the local and regional distributions of jobs, housing, and transportation provisions. The distributions reflect the magnitude, density, variety, and accessibility of the opportunities.

In measuring workplace environs, this study utilizes a number of GIS and statistical tools. Customized areal units defined by the researcher are used as much as possible in order to reduce arbitrariness and aggregation problems resulting from using Census geographies. The customized geographies make it possible to characterize workplace environs specific to each work site. This strategy was not completely successful because the measurements were still constrained by the availability of fined-grained GIS data. Furthermore, the newly generated spatial units do not necessarily guaranty the homogeneity and functional integrity within each areal unit. Nonetheless, the attempt should be promising since many local governments and regional organizations increasingly provide various fine-grained GIS data sources.

Factor analysis is used to reduce the complexity of using a number of initial measurements and to capture only important dimensions (or spatial factors) of workplace environs. Its theoretical basis holds that a concerted effect by various individual spatial elements may be important in affecting travel behavior. From the factor analysis with sixteen spatial elements of workplace environs, this study identifies five spatial factors: "job concentration," "regional accessibility to housing and jobs," "suburbanity," "industrial clustering," and "commercial activity." Of the five factors, "job concentration" is the most influential factor in characterizing workplace environs in different locations.

It should be noted that, in spite of the attractiveness of factor analysis in terms of identifying synergistic effects, the factors burden the interpretability. In other words, the linear combinations of spatial factors comprised of various individual spatial elements make it difficult to interpret.

Empirical Findings

A series of comparison analyses is conducted for the 270 sampled workplaces by using the five spatial factors of workplace environs. Two locational dichotomies are used to classify workplaces in different locations: "central versus suburban" and "inside versus outside major employment centers." The following summarizes major findings.

1) *While a few mature suburban centers attain some level of land use mix and regional accessibility, their land use intensity is far lower than that of the older primary center.* Suburban workplaces are not much different from those in the central areas in some spatial characteristics. A few mature suburban centers attain some level of compact development (e.g., local land use mix and regional accessibility). Yet, the degree of land use intensity (e.g., employment and housing density) of workplaces in suburban centers is far lower than their counterparts in older primary centers in the central city.
2) *The spatial characteristics of workplaces in major suburban centers are not really so "suburban", but the commuting patterns are so "suburban."* Except for some workplaces in central areas, most workplaces exhibit overwhelming automobile dependence, particularly in drive-alone commuting. Yet, employees of workplaces in central areas carpool more, take public transit more, and drive alone less, than employees of suburban workplace locations. Although workplaces in suburban centers attain some levels of compact development patterns, the employees are far more automobile dependent than those employees of workplaces in the older primary centers.
3) *Suburban workplace locations are associated with shorter auto travel times.* Employees of workplaces in larger, denser, and decentralized centers travel longer in duration. The result lends qualified support to the "co-location" hypothesis, which denotes that jobs-housing balance is part of evolutionary urban development process as firms and households locate near each other in the suburbs. But, suburban workplaces beyond a certain degree of decentralization (approximately 16-20 miles from the regional centers in the Dallas-Fort Worth area) are associated with longer travel times, suggesting that co-location of jobs and housing does not always shorten commuting travel time.

4) *Workers take advantage of potential activity sites during their commuting trips by linking their trips to various non-work activities.* Employees of workplaces in larger and denser centers make more activity stops after work. While activity stops on the way to work are related to more regular activities (e.g., pick-up/drop-off), activity stops on the way home after work are related to more discretionary activities (e.g., shopping and personal business). Activity stops made on the way home after work also show higher frequencies with wider spatial variations. Increasing income and widespread automobile availability are important driving forces for more trip chains during commuting trips.

Spatial characteristics and commuting outcomes are compared among the workplaces in three suburban centers: Galleria (suburban downtown), Las Colinas (master planned community with a mix of activities), and Telecom Corridor (high-tech corridor). The following summarizes major findings.

1) *Increasing compactness of mature suburban centers with an automobile-oriented spatial structure burden traffic flow.* While employees of workplaces in suburban centers travel shorter in duration than those employees of workplaces in Downtown Dallas, the difference are not much. Particularly, employees of workplaces in Galleria, a mature mixed-use center, exhibit higher drive-alone commuting but lower carpooling. The Galleria area also shows lower vehicle speeds (measured by dividing distance by time for vehicular trips to work). Land uses of suburban centers are structured for automobiles (e.g., highway orientation, curvilinear street pattern, superblock, and horizontal parking) as they were developed in the automobile age. But, the increasing inward agglomeration of jobs can create disastrous consequences in traffic: congestion, yet scarcely any choice but to drive.
2) *Corridor-type centers exhibit shorter auto travel in duration than cluster-type centers.* Employees of workplaces in the Telecom Corridor, a high-tech corridor,

make much shorter trips to work of average duration than those employees of workplaces in cluster-type suburban centers. This implies that, compared to cluster-type centers, corridor-type job concentration along major highways may be good for automobile-based traffic flow.

3) *Large-scale mater planned communities with a mix of activities exhibit less automobile dependence.* While employees of workplaces in Las Colinas, a master planned community with mix of activities, do not distinguishable differences in auto commute travel times from those employees of workplaces in other suburban centers, they make less drive-alone commuting but more carpooling to work. Also, they make more activity stops on the way to work (e.g., pick-up/drop-off) but fewer stops on the way home after work (e.g., shopping).

Using cluster analysis, the 138 suburban workplaces are classified into five types in terms of their environs: "core," "industrial," "intermediate," "residential," and "peripheral." The following summarizes major findings.

1) *Commuting duration of suburban workplaces reflect hierarchy and function of the workplaces.* Workplaces in the "core" and "industrial" types exhibit the longest travel times to work while workplaces in the "residential" type do the shortest travel times. The commuting duration by workplace type has something to do with the notion of central place theory in which the size, location, and function of centers are determined by the market requirements for activities and the willingness to travel by consumers. While central place theory may be more compatible with explaining non-work travel such as shopping travel, the theory also has a potential to explain work travel.
2) S*mall-sized residence-based workplaces exhibit the lowest level of automobile dependence.* While workplaces show high levels of automobile trips, small-sized residence-based workplaces show lower shares of drive-alone commuting but

higher shares of carpooling. The least resource intensive trip modes such as walking and cycling are quite homogeneous across the different workplace types due to the overwhelming automobile dependence. Yet, there is a weak indication that employees of small-sized residence-based workplaces make slightly more walking and cycling than those employees in other suburban types.

3) *Highways, automobiles, and non-work activity stops are closely interrelated.* Employees of workplaces in medium- and large-scale suburban centers along major highway corridors exhibit the highest levels of single-occupant commuting. Activity stops on the way of commuting trips are also highest in these suburban types.

What aspects of workplace environs produce the differences in commuting patterns? The following summarizes major findings from the statistical models (regression and logit models) of commuting behavior of individual employees.

1) *The importance of spatial factors in explaining commuting behavior depends on the aspect of commuting being measured.* Although not on the same criteria, the research result indicates that spatial factors do a better job in explaining travel times than in explaining travel mode and trip chaining. In estimating vehicle travel times, model fitting (R square) increases from 22.9% of the model without spatial factors to 31.4% of the model with spatial factors. In estimating drive-alone commuting, model fitting (pseudo-R square) increases from 22.5% of the model without spatial factors to 26.7% of the model with spatial factors. And, in estimating activity stops after work, model fitting (pseudo-R square) increases from 14.3% of the model without spatial factors to 16.1% of the model with spatial factors. The importance of socioeconomic characteristics of individual workers is quite evident in explaining travel mode and trip chaining. The result suggests that a spatial strategy to shape travel patterns would be more effective when it addresses travel times than when it does travel mode and trip chaining.

2) *The significance of spatial factors suggests that a concerted effort via various spatial elements is important in affecting travel patterns.* Overall, the research result shows that the spatial characteristics around workplaces are significant in explaining commuting behavior of employees there. For auto commute travel times, regional spatial factors (suburbanity and regional accessibility to housing and jobs) are associated with shorter commuting, while local job-related spatial factors (job concentration, industrial clustering, and commercial activity) are associated with longer commuting. For drive-alone commuting trips, the "job concentration" factor is associated with less drive-alone commuting, while the factors of "suburbanity" and "commercial activity" are associated with more drive-alone commuting. For activity stops after work, the factors of "job concentration" and "commercial activity" are associated with more activity stops, while other spatial factors (regional accessibility to housing and jobs, suburbanity, and industrial clustering) are associated with fewer activity stops. Given that the spatial factors are comprised of various spatial elements, the result indicates that the bundling of various land use strategies would be important in shaping travel.
3) *There are trade-offs between travel outcomes in relation to spatial factors.* While spatial factors could be complementary to each other in affecting travel behavior, the way in which a particular spatial factor affects commuting is vary, depending on the aspect of commuting being measured. There are apparent conflicts between travel outcomes in relation to spatial factors. For example, the "job concentration" factor is associated with longer vehicle travel times but less drive-alone commuting. The "suburbanity" factor is associated with shorter vehicle travel times but more drive-alone commuting. Implications for transportation policies are quite complex since a planning policy should consider unintended consequences resulting from the trade-offs between travel outcomes.
4) *Most basic socioeconomic variables including income and automobile ownership are positively, significantly, and strongly associated with auto travel times, drive-*

alone trips, and activity stops after work. We have an optimistic view on economic conditions in the near future. Therefore, we anticipate that income will be growing and that automobile travel will be more widespread. The result speaks eloquently of how difficult it is to cope with urban transportation problems.

Hypotheses Revisited

In general, the results of analysis support the hypothetical expectations. Job-related spatial factors are associated with longer commuting times, less drive-alone commuting, and more trip chaining. Housing-related spatial factors are associated with shorter commuting times and less trip chaining. Yet, it should be noted that the simplified hypotheses are not enough to accommodate the empirical complexity in the relationships. For example, shorter auto travel times are associated mainly with "regional" accessibility factors (e.g., suburbanity, accessibility to housing and jobs) while longer auto travel times are associated mainly with "local" activity concentration factors (e.g., job concentration, commercial activity). The likelihood of drive-alone commuting is negatively associated with local job concentration factors but positively associated with suburbanity and commercial activity factors. The likelihood of non-work activity stops is negatively associated with regional accessibility and industrial clustering factors but positively associated with local activity, particularly commercial, factors. The results indicate that what is measured how at what spatial scale is important in constructing hypothetical relationships.

This study uses composite variables or spatial factors that are comprised of individual spatial elements. The significance of spatial factors suggests that the synergy of various spatial elements may be much important in shaping travel. However, when looking into the individual spatial elements that construct a particular spatial factor, the relationships are considerably complex. Some spatial elements are even opposite to the hypothesized relationships. For example, highway accessibility is associated with longer commuting. This is perhaps due to the general tendency of firms to locate along highways. The share of retail land uses in the vicinity of workplaces is associated with more drive-alone commuting. This may be related to contemporary automobile-dependent retail centers and bulky purchases. Of the housing-related variables, only housing density in the vicinity of workplaces is related with less drive-alone commuting. Some individual variables such as the housing-jobs ratio, public transit accessibility, and share of industrial land uses in the vicinity of workplaces are not significant in explaining drive-alone commuting. Again, the results indicate that the way a particular spatial element (e.g., retail, office, or industrial) affects travel is highly dependent on the nature of activity and the way the spatial element is distributed and measured (e.g., magnitude, density, variety, or proximity at either local or regional level).

Policy Implications

Numerous communities across the United States are now initiating various land use strategies to reduce negative impacts of urban sprawl and to attain "smart" urban growth. Enhancing transportation choices and preserving air quality are among the top priority in those initiatives. For example, the LUTRAQ (Making the Land Use, Transportation, Air Quality Connection) project in Portland, Oregon takes an integrated approach to evaluating transportation alternatives in the major investment study. One of primary goals of emerging development models, such as transit-oriented development (TOD) and traditional neighborhood design (TND), is to reduce automobile dependence. A problem is the robustness of assumptions underlying such planning proposals. The immediacy of research is paramount.

So, what implications can be drawn from this study for the planning initiatives? This study deals with only a part of urban transportation issues: workplaces and commuting. Urban public transportation is certainly important, but it is part of numerous planning goals such as economic development and social equity. Therefore, the discussion will focus on using land use approaches to urban transportation problems from the standpoint of employment locations.

Mobility versus Travel Choice

One needs first to think about the transportation priority, mobility versus choice for example. Mobility (i.e., moving fast from one place to another) is closely related to economic productivity. Widening travel choices (e.g., public transit, pedestrian facilities) relieves the vulnerability of gasoline-dependent urban life. It also improves the opportunity for the "transportation minorities" who sometimes or always have limited options for travel. Thus, both objectives must be pursued. A dilemma is that, as this study indicated, reducing travel times and lowering automobile dependence are difficult to attain at the same time. The relative social benefits derived from shortening automobile travel times and lowering the level of automobile dependence are also not clear. At least, this study suggests that, if a community wished to shape commuting through spatial planning tools, a strategy to address travel times may be more effectual and practical.

In the suburban context, the transportation priority may be on lowering automobile dependence, rather than on enhancing mobility through fast travel. Compared to automobile dependence (e.g., the share of drive-alone commuting), the mobility crisis (e.g., longer commute travel times due to traffic congestion) seems rather benign in the suburbs. A dilemma is that, as suggested by this study, modal use is less sensitive to spatial factors. Also, there are overwhelming socioeconomic forces driving more automobile dependence: income and automobile ownership.

Even if a community chose to lower automobile dependence, modal transfer via planning tools is not an easy job. The first thing to decide is which mode to prioritize. This study implies that, for suburban workplace locations, carpooling might be more amenable to practical policies, rather than public transit, particularly bus transit. Although the absolute portion is much smaller than other commuting modes, there is an indication that employees of workplaces in small-scale residence-based centers and large-scale planned communities with a mix of jobs and housing exhibit relatively higher shares of carpooling. Major employers in suburban centers can play an important role in promoting ridesharing among their employees. Employees in large suburban centers might easily find carpool partners.

Walking and cycling are certainly the most "sustainable" modes in terms of resource consumption. There is a weak indication that small-sized residence-based centers have relatively higher shares of walking and cycling.

There is no indication that suburban centers have a minimally effective market for bus transit. Although major suburban centers attain some level of bus transit accessibility, bus ridership in the centers is far lower than the primary centers in the central city. Suburban centers also do not make any difference in bus ridership from other scattered employment sites. While a few mature suburban centers attain some level of compact development and public transit, the compactness is far lower than the primary center in the central city. The increase of density enough for public transit requires time. Furthermore, public transit requires connectivity at residences as well as jobs. The operation is obviously costly.

The light rail system might be slightly different from bus transit. The Dallas area began to serve the DART light rail transit during the latter half of 1990s. The expansions are currently going on toward major suburban centers.

Centralization versus Decentralization

This study shows that suburban workplace locations are associated with shorter commuting. Therefore, job decentralization may be helpful to shortening overall travel times and relieving traffic congestion in the older centers. But, this orientation should not be interpreted in an unconstrained manner. The study also indicates that decentralized workplaces beyond a certain degree of decentralization or approximately 16-20 miles from the regional center in the Dallas-Fort Worth area are associated with longer auto travel times. Furthermore, shorter commute travel through job decentralization is viable only when residences do not migrate out to exurban and rural areas. We saw that both commute travel times and drive-alone trips increase with residential suburbanization. Thus, a metropolitan-wide policy to contain outward expansion of urban development may be carried out at the same time.

This study also shows that suburban workplace locations are associated with more automobile dependence. Therefore, a compromise would be a middle ground between centralization and decentralization. In such a concerted strategy, major employment centers can play an important role in creating a hierarchy of places in the metropolitan region.

Local Approach versus Regional Approach

This study suggests that local land use intensification strategies in and around major employment centers may be effectual in reducing drive-alone commuting. Such intensification strategies include increasing employment and housing density, increasing activity mix, and clustering jobs. An important but indirect indication is that some commercial activities, particularly retail, may not be put in the major employment centers and highway corridors but in closer proximity to residences. This is because large-scale retail centers are closely related to automobile dependence due to bulky purchases. Also, retail centers tend to increase traffic congestion along the major corridors as they generate more non-work activity stops during peak hours.

Land use intensification strategies may have side effects. As mentioned earlier, job concentration is related to longer travel in duration, which is possibly due to congestion effects. NIMBY opposition may be a political burden. The exodus of suburbanites from older suburbs to new suburban edges might create longer travel with more automobile dependence.

This study suggests that regional and local strategies, particularly housing-related strategies, may be effectual in shortening commute travel times. First, a metropolitan-wide strategy to control the outward expansion of jobs and housing would be necessary. The suburbanization of population and the suburbanization of employment have different implications on commute travel patterns. This study shows that, while the suburbanization of employment is related to shorter automobile commuting, the suburbanization of population is related to longer automobile commuting. Therefore, a metropolitan-wide strategy may focus more on containing residential development. In coping with auto commute travel times, a metropolitan-wide strategy is a prerequisite before a local strategy. Second, new workplace locations should be in major urban activity axes in terms of housing and jobs. From the metropolitan-wide scale, there may be urban realms in which both jobs and housing are concentrated in a spatial range (e.g., the northern part of Dallas). Third, a local land use strategy to improve housing opportunities such as jobs-housing balance and inclusionary land use policies would help shorten commute travel times. Fourth, in the suburban context, commercial activities (e.g., retail) should be small-sized and in closer proximity to residences because commercial activities along the major highway corridors create a large amount of automobile-based activity stops during peak hours.

Planning strategies to reduce automobile travel times and congestion may pose some difficulties and have side effects. First, shortening travel times is not necessarily related to less automobile dependence. Second, a concerted effort between local and regional schemes seems to be necessary. However, a regionally coordinated scheme is not so easy to implement in the American context. Third, a metropolitan-wide containment policy may increase housing prices. Putting jobs in closer proximity to residences may also increase housing prices. Fourth, decentralized jobs may provide the opportunity for suburbanites to move further out to exurban and rural areas and thus further sprawl. Fifth, decentralized jobs may deteriorate the job accessibility for certain social groups, specifically low-income minorities who reside on the other side of urban development for example.

Limits of This Study and Future Research

This study uses a cross-sectional approach by comparing the association between spatial factors and travel patterns at a certain point in time. Yet, this approach is methodologically weak in drawing a causal relationship. A methodologically stronger approach may be to relate changes of land use to changes of travel behavior in a temporal sequence. However, a set of time-series data gathered consistently over a long period of time is rare. In relation to this problem, future research may investigate actual planning programs that address transportation problems through land use strategies. New urbanism and jobs-housing balancing have been implemented in some communities over the last decade. Future research should evaluate such programs by looking at changes of land use and travel behavior in a community over time.

There is a limit in securing internal validity. For example, while this study is workplace-based, the approach might be limited in addressing transportation issues in a comprehensive manner. Most travel, both work and non-work, occurs from homes, while workplaces capture only work-related travel. Further, this study minimally captures the spatial characteristics of the residence of each worker. Neighborhood spatial patterns are presumably an important factor in affecting travel. Not surprisingly, a greater majority of research on the link between urban form and travel is residence-based. If we hypothesized that urban form factors affect commuting behavior, we should fully capture the characteristics of both home and work. Therefore, future research may consider the effects of the spatial characteristics of both origin and destination simultaneously and their dynamic interactions in shaping travel.

Further with the issue of internal validity, this study does not capture the design characteristics in and around workplaces. Design factors (e.g., sidewalk and building design) may be crucial to certain types of travel such as walking and cycling. Yet, gathering this kind of spatial data tends to require a considerable amount of time and cost. Studies using a number of detailed design factors seem to be uncommon. Future research needs to give more attention to the subtle spatial factor in exploring travel behavior.

This study uses factor analysis to reduce the complexity of statistical models with a large number of individual variables and to identify important dimensions of workplace environs. While factor analysis may have benefits from identifying the synergy of individual spatial elements, the factors are rather hard to interpret from a policy standpoint. In other words, the newly created factors make the researcher difficult to interpret because they are latent variables. The choice whether to use the composite variables or to use individual variables depends on the emphasis given to the research. But, a methodological compromise should be made to draw more policy-relevant findings from the study. Statistical analyses with the individual variables of workplace environs are shown in Appendix.

This study uses travel times, travel mode, and trip chaining to measure travel characteristics. The travel time measure that is based on the shortest network path is less realistic although the travel mode and trip chaining measure partly complement its drawback. Further, to address air quality issues, VMT or other total vehicle trip indicators would be a stronger measure. Therefore, future research may use the travel indicators that are able to directly address the transportation and air quality issues.

With respect to a workplace-based travel study, trip chaining may occur on the way of commuting trips (before work and after work) and at workplace (midday travel). This study tends to explore the trip-chaining behavior in a limited manner. While this study examines trip chaining during commuting trips, the workplace-based midday travel was not included for analysis. Future research should pay a greater attention to trip chaining behavior.

Given that most commuting occurs between home and work, a complete study should take into account the location choices made by workers and businesses. Commuting patterns are largely a byproduct of residential location choice and job choice on the part of workers and location choice on the part of businesses. A study on business and residential locations can contribute to the body of research on the link between urban form and travel by providing the relative importance of accessibility as a criterion of location choice. The success of a land use policy to cope with urban transportation problems depends on how the policy adequately addresses the factors that determine location choice.

Finally, the issue of external validity should be pointed out. Since this is a case study at one period of time, there is a limit to the extent to which the findings can be generalized. More studies are required to enhance the external validity of findings and thus the robustness of theories.

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APPENDIX

A. Spatial Characteristics of Workplaces in Individual Variables

Table A.1 Mean statistics on spatial characteristics of 270 workplaces by central-suburban dichotomy

	Central	Suburban	F-statistic
Jobs distribution around workplaces			
% Employment land uses (within a quarter-mile radius)	43.9	36.0	8.40**
Employment density (per non-residential developed acre in TSZ)	161.2	17.5	16.82**
Entropy index of land use mix (within a quarter-mile radius)	0.6	0.5	14.22**
% Retail land uses (within a quarter-mile radius)	13.5	16.6	5.12**
% Office land uses (within a quarter-mile radius)	17.1	7.2	31.99**
% Industrial land uses (within a quarter-mile radius)	12.5	18.5	5.57**
Regional accessibility index to workplaces	349.2	254.4	49.82**
Distance to CBD (in miles)	3.0	13.9	347.04**
Housing distribution around workplaces			
% Residential land uses (within a quarter-mile radius)	33.1	34.6	0.26
Housing density (per residential acre in census tract)	37.6	6.9	22.87**
% Multi-family residential land uses (within a quarter-mile radius)	6.0	5.5	0.36
Median value of owner-occupied housing (in census tract)	89,530	100,850	2.95*
Ratio of housing to jobs (within four-mile radius)	0.5	0.9	50.39**
Regional accessibility index to houses	186.9	160.8	20.36**
Transportation provisions around workplaces			
% Workplaces within a quarter-mile radius from bus transit route	87.4	46.6	52.18**†
Distance to the nearest controlled-access highway (in miles)	0.5	0.8	16.55**
No. of workplace cases	132	138	

* Indicates significance at the 0.1 level and ** indicates significance at the 0.05 level
† Based on chi-square

Table A.2 Mean statistics on spatial characteristics of 270 workplaces by dichotomy of inside versus outside of major employment centers

	Inside center	Outside center	F-statistic
Jobs distribution around workplaces			
% Employment land uses (within a quarter-mile radius)	55.9	23.6	277.34**
Employment density (per non-residential developed acre in TSZ)	160.4	14.0	17.52**
Entropy index of land use mix (within a quarter-mile radius)	0.7	0.5	58.31**
% Retail land uses (within a quarter-mile radius)	15.7	14.4	0.92
% Office land uses (within a quarter-mile radius)	21.6	2.3	185.93**
% Industrial land uses (within a quarter-mile radius)	20.8	10.2	17.72**
Regional accessibility index to workplaces	359.8	240.8	87.91**
Distance to CBD (in miles)	5.8	11.3	44.59**
Housing distribution around workplaces			
% Residential land uses (within a quarter-mile radius)	21.7	46.3	97.50**
Housing density (per residential acre in census tract)	37.6	6.1	24.26**
% Multi-family residential land uses (within a quarter-mile radius)	5.8	5.7	0.02
Median value of owner-occupied housing (in census tract)	100,190	90,360	2.22
Ratio of housing to jobs (within four-mile radius)	0.4	0.9	119.91**
Regional accessibility index to houses	186.3	160.6	19.65**
Transportation provisions around workplaces			
% Workplaces within a quarter-mile radius from bus transit route	88.2	46.5	49.4**†
Distance to the nearest controlled-access highway (in miles)	0.4	0.8	41.63**
No. of workplace cases	136	134	

* Indicates significance at the 0.1 level and ** indicates significance at the 0.05 level
† Based on chi-square

Table A.3 Mean statistics on spatial characteristics of workplaces in Downtown Dallas, Galleria, Las Colinas, and Telecom Corridor

	Downtown Dallas	Galleria	Las Colinas	Telecom Corridor	F-statistic
Jobs distribution around workplaces					
% Employment land uses (within a quarter-mile radius)	58.8	62.9	19.1	59.0	5.01**
Employment density (per non-residential developed acre in TSZ)	320.0	41.1	25.0	19.2	3.70**
Entropy index of land use mix (within a quarter-mile radius)	0.7	0.7	0.6	0.6	1.34
% Retail land uses (within a quarter-mile radius)	15.9	21.5	1.4	13.2	2.46*
% Office land uses (within a quarter-mile radius)	34.2	23.1	21.2	10.1	9.23**
% Industrial land uses (within a quarter-mile radius)	6.4	26.6	15.4	39.9	12.69**
Regional accessibility index to workplaces	422.2	371.3	290.6	264.4	45.06**
Distance to CBD (in miles)	0.8	11.6	13.0	13.3	1193.21**
Housing distribution around workplaces					
% Residential land uses (within a quarter-mile radius)	12.4	25.2	23.9	36.4	8.81**
Housing density (per residential acre in census tract)	86.2	9.0	13.5	4.1	5.35**
% Multi-family residential land uses (within a quarter-mile radius)	5.4	9.9	9.6	2.3	4.98**
Median value of owner-occupied housing (in census tract)	109,540	127,520	182,700	102,620	3.02**
Ratio of housing to jobs (within four-mile radius)	0.3	0.5	0.3	0.6	179.47**
Regional accessibility index to houses	200.4	193.4	157.3	162.8	11.24**
Transportation provisions around workplaces					
% Workplaces within a quarter-mile radius from bus transit route	100.0	80.6	84.5	85.5	8.67**†
Distance to the nearest controlled-access highway (in miles)	0.3	0.3	0.6	0.5	3.12
No. of workplace cases	47	23	2	8	

* Indicates significance at the 0.1 level and ** indicates significance at the 0.05 level
† Based on chi-square

Table A.4 Mean statistics on spatial characteristics by suburban workplace type

	Core	Industrial	Intermediate	Residential	Peripheral	F-statistic
Jobs distribution around workplaces						
% Employment land uses (within a quarter-mile radius)	42.2	61.3	42.7	17.4	10.5	37.02**
Employment density (per non-residential developed acre in TSZ)	26.6	15.0	21.4	10.4	6.0	7.22**
Entropy index of land use mix (within a quarter-mile radius)	0.7	0.5	0.6	0.5	0.4	8.60**
% Retail land uses (within a quarter-mile radius)	13.1	10.6	32.9	13.3	13.3	21.02**
% Office land uses (within a quarter-mile radius)	14.5	4.7	9.0	1.0	1.3	15.96**
% Industrial land uses (within a quarter-mile radius)	17.2	57.0	8.0	3.5	11.7	47.97**
Regional accessibility index to workplaces	333.5	290.6	284.1	180.2	110.6	52.11**
Distance to CBD (in miles)	11.7	13.0	12.7	11.1	24.7	36.96**
Housing distribution around workplaces						
% Residential land uses (within a quarter-mile radius)	38.4	20.6	33.7	53.9	18.2	21.37**
Housing density (per residential acre in census tract)	7.8	9.5	10.3	3.9	1.9	8.87**
% Multi-family residential land uses (within a quarter-mile radius)	9.7	3.4	6.8	2.9	0.8	12.88**
Median value of owner-occupied housing (in census tract)	133,930	84,910	90,410	85,710	85,860	9.09**
Ratio of housing to jobs (within four-mile radius)	0.6	0.5	0.9	1.1	1.5	15.49**
Regional accessibility index to houses	192.3	168.6	184.9	135.4	89.1	48.65**
Transportation provisions around workplaces						
% Workplaces within a quarter-mile radius from bus transit route	68.7	67.6	38.7	38.7	0.0	32.33**†
Distance to the nearest controlled-access highway (in miles)	0.5	0.7	0.4	1.3	1.1	12.11**
No. of workplace cases	41	23	27	27	20	

* Indicates significance at the 0.1 level and ** indicates significance at the 0.05 level

† Based on chi-square

B. Multiple Comparisons of Spatial Factors for Workplaces

Table B.1 Comparisons of workplace location types in spatial factors*

Spatial factor	Pair compared	F-statistic	(p-value)
Job concentration	Central, inside center v.s. Central, outside center	225.05	(0.0001)
	Central, inside center v.s. Suburban, inside center	71.58	(0.0001)
	Central, inside center v.s. Suburban, outside center	281.19	(0.0001)
	Central, outside center v.s. Suburban, inside center	37.94	(0.0001)
	Central, outside center v.s. Suburban, outside center	0.10	(0.7505)
	Suburban, inside center v.s. Suburban, outside center	43.05	(0.0001)
Regional accessibility	Central, inside center v.s. Central, outside center	0.33	(0.5653)
	Central, inside center v.s. Suburban, inside center	2.00	(0.1582)
	Central, inside center v.s. Suburban, outside center	29.78	(0.0001)
	Central, outside center v.s. Suburban, inside center	3.24	(0.0728)
	Central, outside center v.s. Suburban, outside center	17.74	(0.0001)
	Suburban, inside center v.s. Suburban, outside center	40.00	(0.0001)
Suburbanity	Central, inside center v.s. Central, outside center	0.76	(0.3848)
	Central, inside center v.s. Suburban, inside center	16.27	(0.0001)
	Central, inside center v.s. Suburban, outside center	136.01	(0.0001)
	Central, outside center v.s. Suburban, inside center	19.59	(0.0001)
	Central, outside center v.s. Suburban, outside center	123.48	(0.0001)
	Suburban, inside center v.s. Suburban, outside center	41.25	(0.0001)
Industrial clustering	Central, inside center v.s. Central, outside center	50.24	(0.0001)
	Central, inside center v.s. Suburban, inside center	2.15	(0.1434)
	Central, inside center v.s. Suburban, outside center	53.06	(0.0001)
	Central, outside center v.s. Suburban, inside center	61.42	(0.0001)
	Central, outside center v.s. Suburban, outside center	0.53	(0.4678)
	Suburban, inside center v.s. Suburban, outside center	64.29	(0.0001)
Commercial activity	Central, inside center v.s. Central, outside center	0.01	(0.94.27)
	Central, inside center v.s. Suburban, inside center	4.57	(0.0334)
	Central, inside center v.s. Suburban, outside center	0.60	(0.4401)
	Central, outside center v.s. Suburban, inside center	3.95	(0.0479)
	Central, outside center v.s. Suburban, outside center	0.37	(0.5448)
	Suburban, inside center v.s. Suburban, outside center	8.08	(0.0048)

* Based on 270 workplaces

Table B.2 Comparisons of four employment centers in spatial factors*

Spatial factor	Pair compared	F-statistic (p-value)
Job concentration	Downtown Dallas v.s. Galleria	27.50 (0.0001)
	Downtown Dallas v.s. Las Colinas	3.77 (0.0558)
	Downtown Dallas v.s. Telecom Corridor	34.26 (0.0001)
	Galleria v.s. Las Colinas	0.01 (0.9270)
	Galleria v.s. Telecom Corridor	4.85 (0.0306)
	Las Colinas v.s. Telecom Corridor	1.12 (0.2934)
Regional accessibility	Downtown Dallas v.s. Galleria	2.23 (0.1398)
	Downtown Dallas v.s. Las Colinas	0.00 (0.9804)
	Downtown Dallas v.s. Telecom Corridor	14.49 (0.0003)
	Galleria v.s. Las Colinas	0.24 (0.6249)
	Galleria v.s. Telecom Corridor	20.00 (0.0001)
	Las Colinas v.s. Telecom Corridor	3.48 (0.0661)
Suburbanity	Downtown Dallas v.s. Galleria	26.09 (0.0001)
	Downtown Dallas v.s. Las Colinas	9.03 (0.0036)
	Downtown Dallas v.s. Telecom Corridor	12.85 (0.0006)
	Galleria v.s. Las Colinas	1.39 (0.2415)
	Galleria v.s. Telecom Corridor	0.03 (0.8624)
	Las Colinas v.s. Telecom Corridor	1.02 (0.3155)
Industrial clustering	Downtown Dallas v.s. Galleria	3.11 (0.0819)
	Downtown Dallas v.s. Las Colinas	1.80 (0.1836)
	Downtown Dallas v.s. Telecom Corridor	3.32 (0.0723)
	Galleria v.s. Las Colinas	3.70 (0.0582)
	Galleria v.s. Telecom Corridor	0.37 (0.5469)
	Las Colinas v.s. Telecom Corridor	4.44 (0.0384)
Commercial activity	Downtown Dallas v.s. Galleria	4.88 (0.0302)
	Downtown Dallas v.s. Las Colinas	2.19 (0.1428)
	Downtown Dallas v.s. Telecom Corridor	0.32 (0.5721)
	Galleria v.s. Las Colinas	4.90 (0.0299)
	Galleria v.s. Telecom Corridor	3.60 (0.0615)
	Las Colinas v.s. Telecom Corridor	1.16 (0.2845)

* Based on 80 workplaces

Table B.3 Comparisons of five suburban workplace types in spatial factors*

Spatial factor	Pair compared	F-statistic (p-value)
Job concentration	Core v.s. Industrial	8.51 (0.0042)
	Core v.s. Intermediate	0.14 (0.7137)
	Core v.s. Residential	42.89 (0.0001)
	Core v.s. Peripheral	37.10 (0.0001)
	Industrial v.s. Intermediate	6.11 (0.0148)
	Industrial v.s. Residential	10.37 (0.0016)
	Industrial v.s. Peripheral	9.43 (0.0026)
	Intermediate v.s. Residential	35.22 (0.0001)
	Intermediate v.s. Peripheral	30.91 (0.0001)
	Residential v.s. Peripheral	0.01 (0.9327)
Regional accessibility	Core v.s. Industrial	16.92 (0.0001)
	Core v.s. Intermediate	17.64 (0.0001)
	Core v.s. Residential	87.63 (0.0001)
	Core v.s. Peripheral	154.74 (0.0001)
	Industrial v.s. Intermediate	0.01 (0.9242)
	Industrial v.s. Residential	21.69 (0.0001)
	Industrial v.s. Peripheral	62.71 (0.0001)
	Intermediate v.s. Residential	24.55 (0.0001)
	Intermediate v.s. Peripheral	68.87 (0.0001)
	Residential v.s. Peripheral	13.89 (0.0003)
Suburbanity	Core v.s. Industrial	0.00 (0.9968)
	Core v.s. Intermediate	2.33 (0.1298)
	Core v.s. Residential	1.35 (0.2474)
	Core v.s. Peripheral	195.26 (0.0001)
	Industrial v.s. Intermediate	1.98 (0.1615)
	Industrial v.s. Residential	1.15 (0.2848)
	Industrial v.s. Peripheral	169.81 (0.0001)
	Intermediate v.s. Residential	0.12 (0.7280)
	Intermediate v.s. Peripheral	147.62 (0.0001)
	Residential v.s. Peripheral	155.54 (0.0001)

Table B.3 (continued)

Industrial clustering	Core v.s. Industrial	183.85 (0.0001)
	Core v.s. Intermediate	5.11 (0.0256)
	Core v.s. Residential	11.61 (0.0009)
	Core v.s. Peripheral	0.13 (0.7215)
	Industrial v.s. Intermediate	120.61 (0.0001)
	Industrial v.s. Residential	262.47 (0.0001)
	Industrial v.s. Peripheral	155.16 (0.0001)
	Intermediate v.s. Residential	29.61 (0.0001)
	Intermediate v.s. Peripheral	5.51 (0.0205)
	Residential v.s. Peripheral	7.15 (0.0085)
Commercial activity	Core v.s. Industrial	1.44 (0.2323)
	Core v.s. Intermediate	43.66 (0.0001)
	Core v.s. Residential	6.83 (0.0101)
	Core v.s. Peripheral	4.64 (0.0332)
	Industrial v.s. Intermediate	52.44 (0.0001)
	Industrial v.s. Residential	1.56 (0.2137)
	Industrial v.s. Peripheral	0.87 (0.3516)
	Intermediate v.s. Residential	78.37 (0.0001)
	Intermediate v.s. Peripheral	62.95 (0.0001)
	Residential v.s. Peripheral	0.05 (0.8162)

* Based on 138 workplaces

C. Commuting Characteristics with Individual Variables of Workplace Environs

Table C.1 Commuting by share of employment land uses

% Employment land uses within a half-mile radius from each workplace	25% and below	Over 25% to 50%	Over 50% to 75%	Over 75% to 100%	Statistical test
Mean vehicle travel time in minutes	12.3	15.4	17.2	17.5	77.22 (0.0001)*
% Travel mode					
Drive alone	75.4	80.0	73.3	74.8	142.24 (0.0001)†
Carpool	20.2	17.9	18.2	22.5	
Bus transit	1.8	1.3	7.7	2.7	
Walk/bike	1.8	0.6	0.5	0.0	
Others	0.8	0.2	0.4	0.0	
% Making any stops					
Home-to-work trip	26.8	29.3	27.6	34.0	7.17 (0.0668) †
Work-to-home trip	42.0	47.8	48.0	46.3	12.21 (0.0067) †
No. of cases	1,113	1,403	2,232	294	

* Based on F-statistic and † based on chi-square

Table C.2 Commuting by share of retail land uses

% Retail land uses within a half-mile radius from each workplace	25% and below	Over 25% to 50%	Over 50% to 100%	Statistical test
Mean vehicle travel time in minutes	15.6	16.2	10.7	4.64 (0.0097)*
% Travel mode				
Drive alone	74.3	82.5	81.8	53.07 (0.0001) †
Carpool	19.5	15.5	9.1	
Bus transit	5.0	1.3	0.0	
Walk/bike	0.8	0.6	4.6	
Others	0.4	0.2	4.6	
% Making any stops				
Home-to-work trip	27.9	29.8	31.8	1.38 (0.5012) †
Work-to-home trip	45.6	51.1	40.9	9.13 (0.0104) †
No. of cases	4,141	879	22	

* Based on F-statistic and † based on chi-square

Table C.3 Commuting by share of office land uses

% Office land uses within a half-mile radius from each workplace	25% and below	Over 25% to 50%	Over 50% to 100%	Statistical test
Mean vehicle travel time in minutes	14.8	17.7	18.7	63.84 (0.0001)*
% Travel mode				
Drive alone	78.1	74.5	59.3	350.56 (0.0001) †
Carpool	18.7	18.2	20.6	
Bus transit	1.7	6.9	19.5	
Walk/bike	1.1	0.1	0.0	
Others	0.4	0.3	0.7	
% Making any stops				
Home-to-work trip	29.0	26.0	28.1	3.54 (0.1702) †
Work-to-home trip	44.9	50.3	50.7	12.90 (0.0016) †
No. of cases	3,573	1,017	452	

* Based on F-statistic and † based on chi-square

Table C.4 Commuting by share of industrial land uses

% Industrial land uses within a half-mile radius from each workplace	25% and below	Over 25% to 50%	Over 50% to 75%	Over 75% to 100%	Statistical test
Mean vehicle travel time in minutes	15.3	16.4	16.5	15.9	4.82 (0.0024)*
% Travel mode					
Drive alone	75.0	77.1	76.7	84.5	34.82 (0.0005) †
Carpool	18.4	20.0	20.9	13.4	
Bus transit	5.2	2.0	1.9	2.1	
Walk/bike	0.9	0.5	0.6	0.0	
Others	0.4	0.4	0.0	0.0	
% Making any stops					
Home-to-work trip	28.1	30.6	23.9	29.9	6.21 (0.1017) †
Work-to-home trip	47.9	46.8	36.0	32.0	27.23 (0.0001) †
No. of cases	3,617	964	364	97	

* Based on F-statistic and † based on chi-square

Table C.5 Commuting by share of residential land uses

% Residential land uses within one-mile radius from each workplace	25% and below	Over 25% to 50%	Over 50% to 75%	Over 75% to 100%	Statistical test
Mean vehicle travel time in minutes	17.5	14.4	11.4	11.7	105.49 (0.0001)*
% Travel mode					
Drive alone	74.4	79.2	72.4	78.5	119.84(0.0001) †
Carpool	18.8	17.5	22.3	17.0	
Bus transit	6.3	1.5	2.2	2.5	
Walk/bike	0.1	1.2	2.7	1.5	
Others	0.3	0.6	0.3	0.5	
% Making any stops					
Home-to-work trip	27.6	30.4	27.1	26.5	4.67 (0.1974) †
Work-to-home trip	48.0	45.8	42.2	44.0	7.64 (0.0541) †
No. of cases	2,800	1,447	595	200	

* Based on F-statistic and † based on chi-square

Table C.6 Commuting by share of multi-family residential land uses

% Multi-family residential land uses within one-mile radius from each workplace	25% and below	Over 25% to 100%	Statistical test
Mean vehicle travel time in minutes	15.7	14.5	3.32 (0.0684)*
% Travel mode			
Drive alone	75.5	81.3	10.71 (0.0300) †
Carpool	18.9	15.3	
Bus transit	4.4	1.5	
Walk/bike	0.7	2.0	
Others	0.4	0.0	
% Making any stops			
Home-to-work trip	28.5	22.2	3.90 (0.0483) †
Work-to-home trip	46.4	48.8	0.43 (0.5101) †
No. of cases	4,839	203	

* Based on F-statistic and † based on chi-square

Table C.7 Commuting by entropy index of land use mix

Entropy index of land use mix within a half-mile radius from each workplace	0.25 and below	Over 0.25 to 0.5	Over 0.5 to 0.75	Over 0.75 to 1	Statistical test
Mean vehicle travel time in minutes	11.4	13.3	16.1	16.8	35.95 (0.0001)*
% Travel mode					
Drive alone	80.7	77.1	75.3	75.1	91.05 (0.0001) †
Carpool	17.8	18.8	17.9	21.6	
Bus transit	0.7	1.2	6.0	2.2	
Walk/bike	0.0	2.3	0.5	0.7	
Others	0.7	0.6	0.3	0.4	
% Making any stops					
Home-to-work trip	33.3	25.6	27.6	31.8	11.51 (0.0093) †
Work-to-home trip	40.0	38.0	47.8	50.7	35.80 (0.0001) †
No. of cases	135	835	3,060	1,012	

* Based on F-statistic and † based on chi-square

Table C.8 Commuting by employment density

Employees per non-residential developed acre in TSZ	10 and below	Over 10 to 20	Over 20 to 40	Over 40	Statistical test
Mean vehicle travel time in minutes	12.8	14.9	15.2	18.0	78.44 (0.0001)*
% Travel mode					
Drive alone	79.6	76.1	77.5	72.2	157.97 (0.0001)†
Carpool	17.8	20.8	18.8	18.3	
Bus transit	1.0	1.6	2.5	8.8	
Walk/bike	1.2	0.9	1.1	0.4	
Others	0.5	0.6	0.3	0.3	
% Making any stops					
Home-to-work trip	28.6	28.9	29.3	27.1	1.98 (0.5761) †
Work-to-home trip	40.4	42.4	47.1	51.7	41.72 (0.0001) †
No. of cases	1,046	937	1,224	1,835	

* Based on F-statistic and † based on chi-square

Table C.9 Commuting by housing density

Housing units per residential developed acre in Census tract	3 and below	Over 3 to 5	Over 5 to 17	Over 17	Statistical test
Mean vehicle travel time in minutes	14.3	13.9	15.2	17.9	58.50 (0.0001)*
% Travel mode					
Drive alone	78.6	77.6	76.5	72.6	119.00 (0.0001)†
Carpool	18.2	19.2	19.1	18.5	
Bus transit	2.0	1.5	3.1	8.1	
Walk/bike	0.4	1.0	1.2	0.5	
Others	0.8	0.7	0.1	0.2	
% Making any stops					
Home-to-work trip	29.9	28.9	26.0	28.7	4.40 (0.2211) †
Work-to-home trip	44.3	43.1	44.2	51.4	27.29 (0.0001) †
No. of cases	752	1,282	1,221	1,787	

* Based on F-statistic and † based on chi-square

Table C.10 Commuting by housing-jobs ratio

Ratio of housing units to jobs within four-mile radius from each workplace	0.3 and below	Over 0.3 to 0.5	Over 0.5 to 0.9	Over 0.9	Statistical test
Mean vehicle travel time in minutes	17.9	16.8	13.7	10.6	133.10 (0.0001)*
% Travel mode					
Drive alone	70.3	79.2	78.7	77.2	245.06 (0.0001)†
Carpool	19.5	18.5	18.2	18.5	
Bus transit	9.9	1.6	1.2	1.2	
Walk/bike	0.1	0.6	1.2	2.4	
Others	0.3	0.1	0.6	0.8	
% Making any stops					
Home-to-work trip	27.4	29.4	28.4	28.0	1.58 (0.6634) †
Work-to-home trip	49.9	47.6	43.4	40.5	23.15 (0.0001) †
No. of cases	1,746	1,468	1,157	671	

* Based on F-statistic and † based on chi-square

Table C.11 Commuting by housing price range

Median price of owner-occupied housing units in census tract (10,000 $)	6 and below	Over 6 to 9	Over 9 to 12	Over 12	Statistical test
Mean vehicle travel time in minutes	17.4	14.8	15.6	14.2	30.21 (0.0001)*
% Travel mode					
Drive alone	78.2	66.4	81.4	79.9	278.78 (0.0001)†
Carpool	19.6	20.5	16.9	17.0	
Bus transit	1.5	11.2	0.6	2.1	
Walk/bike	0.6	1.2	0.7	0.7	
Others	0.1	0.6	0.5	0.4	
% Making any stops					
Home-to-work trip	27.8	29.2	30.6	25.5	7.70 (0.0525) †
Work-to-home trip	48.1	44.1	49.4	44.9	9.51 (0.0232) †
No. of cases	1,459	1,486	1,040	1,057	

* Based on F-statistic and † based on chi-square

Table C.12 Commuting by level of accessibility to all other workplaces

Accessibility index of each workplace to all other workplaces in the metropolitan area (1,000)	200 and below	Over 200 to 300	Over 300 to 400	Over 400	Statistical test
Mean vehicle travel time in minutes	15.7	12.9	14.9	17.6	67.13 (0.0001)*
% Travel mode					
Drive alone	75.6	78.9	79.1	72.4	159.60 (0.0001)†
Carpool	22.1	18.6	16.5	18.6	
Bus transit	0.9	1.0	2.6	8.4	
Walk/bike	0.9	1.1	1.1	0.4	
Others	0.4	0.5	0.6	0.2	
% Making any stops					
Home-to-work trip	29.0	30.1	25.9	28.2	4.78 (0.1886) †
Work-to-home trip	47.7	43.4	41.4	50.2	26.72 (0.0001) †
No. of cases	849	1,144	992	2,057	

* Based on F-statistic and † based on chi-square

Table C.13 Commuting by level of accessibility to housing

Accessibility index of each workplace to houses in the metropolitan area (1,000)	140 and below	Over 140 to 180	Over 180 to 200	Over 200	Statistical test
Mean vehicle travel time in minutes	16.1	14.3	15.8	16.2	12.59 (0.0001)*
% Travel mode					
Drive alone	76.4	78.7	68.1	78.2	245.27 (0.0001)†
Carpool	21.0	18.8	18.9	17.7	
Bus transit	1.3	1.3	12.3	2.8	
Walk/bike	0.9	0.7	0.3	1.1	
Others	0.4	0.6	0.5	0.2	
% Making any stops					
Home-to-work trip	27.0	31.1	25.1	29.0	11.30 (0.0102)†
Work-to-home trip	48.4	42.4	45.7	48.9	13.73 (0.0033) †
No. of cases	852	1,214	1,134	1,842	

* Based on F-statistic and † based on chi-square

Table C.14 Commuting by level of highway accessibility

Straight-line distance from each workplace to the nearest controlled-access highway in miles	0.2 and below	Over 0.2 to 0.4	Over 0.4 to 0.8	Over 0.8	Statistical test
Mean vehicle travel time in minutes	16.1	16.4	16.2	13.9	20.46 (0.0001)*
% Travel mode					
Drive alone	78.9	76.6	70.1	78.2	123.43 (0.0001)†
Carpool	17.6	19.1	19.5	18.9	
Bus transit	2.2	3.5	9.0	1.7	
Walk/bike	1.0	0.6	0.7	0.8	
Others	0.3	0.2	0.6	0.4	
% Making any stops					
Home-to-work trip	28.5	28.7	26.9	29.3	1.99 (0.5747) †
Work-to-home trip	48.1	48.6	47.4	41.9	14.17 (0.0027) †
No. of cases	1,257	1,134	1,429	1,222	

* Based on F-statistic and † based on chi-square

Table C.15 Commuting by level of public transit accessibility

Straight-line distance from each workplace to the nearest public transit route in miles	Within a quarter-mile	Out of a quarter-mile	Statistical test
Mean vehicle travel time in minutes	12.5	16.4	130.99 (0.0001)*
% Travel mode			
Drive alone	75.0	78.7	54.42 (0.0001) †
Carpool	18.8	18.6	
Bus transit	5.2	0.4	
Walk/bike	0.6	1.7	
Others	0.4	0.5	
% Making any stops			
Home-to-work trip	28.6	26.8	1.26 (0.2622) †
Work-to-home trip	48.2	39.2	24.98 (0.0001) †
No. of cases	3,452	1,590	

* Based on F-statistic and † based on chi-square

D. Travel Times by Commuting Flow

Table D.1 Vehicle travel times by commuting flow*

Home location	Workplace location	Mean	Standard deviation	No. of cases
Central	Central	11.2	6.84	895
	Suburban	15.6	7.43	379
Suburban	Central	20.6	7.02	1,557
	Suburban	13.3	9.26	1,723

* Based on the shortest network path

E. Purposes of Activity Stops during Commute Trips

Table E.1 Purposes of activity stops by workplace location type

	Central				Suburban			
	Inside center		Outside center		Inside center		Outside center	
	Home-to-work	Work-to-home	Home-to-work	Work-to-home	Home-to-work	Work-to-home	Home-to-work	Work-to-home
Work related	4.9	3.8	4.1	2.0	5.3	4.3	3.4	2.7
Meal	6.1	6.8	13.9	6.1	12.5	6.9	10.3	9.2
Recreational/social	1.1	8.5	3.0	9.4	1.4	8.8	1.1	10.5
Shopping	21.3	34.0	33.1	36.3	25.1	33.8	30.9	33.8
Personal business (bank, doctor, etc.)	12.2	18.9	11.5	17.7	17.1	22.1	13.3	17.6
Pick-up/drop-off	43.8	18.7	25.3	16.8	28.0	15.9	29.0	16.9
Other	10.6	9.4	9.1	11.7	10.8	8.2	12.1	9.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table E.2 Purposes of activity stops in four major employment centers

	Downtown Dallas		Galleria		Las Colinas		Telecom Corridor	
	Home-to-work	Work-to-home	Home-to-work	Work-to-home	Home-to-work	Work-to-home	Home-to-work	Work-to-home
Work related	4.3	3.9	8.0	5.0	-	-	4.2	2.6
Meal	5.1	6.7	9.7	6.3	19.6	4.2	16.8	3.9
Recreational/social	1.9	8.2	1.3	8.1	-	2.1	2.1	11.7
Shopping	18.8	33.1	23.6	33.2	25.5	37.5	23.2	37.7
Personal business (bank, doctor, etc.)	12.8	18.8	19.8	23.8	17.6	20.8	11.6	21.4
Pick-up/drop-off	45.4	18.8	25.3	17.2	27.5	29.2	32.6	13.0
Other	11.7	10.6	12.2	6.5	9.8	6.3	9.5	9.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table E.3 Purposes of activity stops by suburban workplace type

	Core		Industrial		Intermediate		Residential		Peripheral	
	Home-to-work	Work-to-home	Home-to-work	Work-to-home	Home-to-work	Work-to-home	Home-to-work	Work-to-home	Home-to-work	Work-to-home
Work related	5.1	3.4	1.8	3.2	6.0	4.3	3.6	2.7	4.9	3.0
Meal	12.0	7.8	12.4	7.8	13.9	7.5	9.5	11.9	4.1	6.6
Recreational/social	1.2	9.4	1.5	10.0	1.1	10.5	1.5	9.6	0.8	8.1
Shopping	24.9	35.2	35.3	32.5	24.2	33.9	20.4	32.0	36.6	34.0
Personal business (bank, doctor, etc.)	16.8	20.1	10.5	21.3	20.3	21.6	16.8	15.1	8.1	17.3
Pick-up/drop-off	30.3	15.6	27.3	16.1	22.8	15.3	35.0	18.3	31.7	19.8
Other	9.6	8.5	11.3	9.0	11.7	6.8	13.1	10.5	13.8	11.2
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

F. Statistical Estimation of Commuting Behavior with Individual Variables of Workplace Environs

Table F.1 Regression of vehicle time traveled to work

	Coefficient	Beta	t-statistic
Age	0.018	0.022	1.69*
Dummy attachment to employer: full-time	2.993	0.092	6.87**
No. of persons in household	0.587	0.091	7.08**
No. of vehicles per licensed driver in household	0.661	0.025	1.94*
Dummy annual household income (reference category: under $15,000):			
$25,000 to <$35,000	0.431	0.022	1.55
$35,000 to <$50,000	0.975	0.041	2.92**
$50,000 to <$75,000	1.297	0.056	3.98**
Distance from home to CBD	0.503	0.326	23.30**
Dummy MSA of residence: Dallas MSA	-7.158	-0.359	-18.65**
Dummy time of arrival at work: peak hours	1.137	0.063	4.57**
Dummy industry type of workplace (reference category: retail):			
Service	0.993	0.056	2.89**
Basic	1.312	0.067	3.29**
Dummy MSA of workplace: Dallas MSA	7.090	0.323	12.06**
Dummy major employment centers: workplace inside of centers	1.669	0.089	4.68**
% Office land uses within a half-mile radius from workplace	-0.055	-0.107	-5.12**
Employment density per non-residential developed acre	0.0007	0.057	3.09**
Regional accessibility of workplace to other workplaces	0.012	0.160	2.11**
Straight-line distance from workplace to CBD in miles	-0.339	-0.240	-10.74**
% Residential land uses within one-mile radius from workplace	-0.014	-0.035	-1.55
% Multi-family residential uses within one-mile radius from workplace	0.067	0.057	3.53**
Ratio of housing to jobs within five-mile radius from workplace	-1.710	-0.073	-3.65**
Median price of owner-occupied housing units in the census tract of workplace	-0.005	-0.030	-2.06**
Regional accessibility of workplace to housing	-0.035	-0.182	-2.93**
Straight-line distance to the nearest controlled-access highway	-0.679	-0.046	-2.81**
Constant	7.821		7.04**
No. of cases		4,315	
R-square (Adjusted R-square)		0.327 (0.323)	
F-statistic		86.84**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

Table F.2 Logistic regression of single-occupant vehicle mode choice to work

	Coefficient	Odds ratio	Chi-square
Age	0.025	1.026	35.34**
Gender: male	1.004	2.730	131.59**
Dummy attachment to employer: full-time	0.185	1.203	1.50
No. of persons in household	-0.529	0.589	225.48**
No. of workers in household	0.172	1.188	8.52**
No. of vehicles per licensed driver in household	2.240	9.389	149.88**
Dummy annual household income (reference category: under $15,000):			
$15,000 to <$25,000	0.370	1.448	4.14**
$25,000 to <$35,000	0.432	1.541	6.98**
$35,000 to <$50,000	0.487	1.627	7.57**
$50,000 to <$75,000	0.773	2.167	18.00**
$75,000 and higher	0.975	2.652	25.48**
Dummy time of arrival at work: peak hours	-0.469	0.625	24.18**
Shortest network distance between home and work	0.008	1.008	2.56
Dummy industry type (reference category: retail):			
Service	0.239	1.270	3.62*
Basic	0.267	1.305	3.31*
Number of employees in workplace	-0.0002	1.000	2.25
Dummy MSA of workplace: Dallas MSA	-0.051	0.951	0.18
Dummy major employment centers: workplace inside of centers	-0.388	0.679	8.81**
% Retail land uses within a half-mile radius from workplace	0.015	1.015	11.70**
Straight-line distance from workplace to CBD in miles	0.047	1.048	21.82**
Housing density per residential acre	-0.005	0.995	58.46**
Ratio of housing to jobs within five-mile radius from workplace	-0.483	0.617	9.36**
Median price of owner-occupied housing units in the census tract of workplace	-0.001	0.999	1.31
Constant	-1.332		13.71
No. of cases		4,457	
Pseudo-R square (Nagelkerke)		0.283	
Likelihood ratio		909.67**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

Table F.3 Logistic regression of activity stops during commuting trips after work

	Coefficient	Odds ratio	Chi-square
Age	-0.014	0.986	20.45**
Gender: male	-0.502	0.606	59.51**
Dummy attachment to employer: full-time	0.245	1.277	3.96**
No. of persons in household	-0.039	0.962	1.92
No. of workers in household	-0.077	0.926	2.52
No. of vehicles per licensed driver in household	0.316	1.372	10.75**
Dummy annual household income (reference category: under $15,000):			
$15,000 to <$25,000	0.333	1.395	4.63**
$25,000 to <$35,000	0.341	1.407	5.91**
$35,000 to <$50,000	0.368	1.445	6.01**
$50,000 to <$75,000	0.493	1.637	10.63**
$75,000 and higher	0.477	1.611	9.26**
Distance from home to CBD	0.017	1.017	8.25**
Dummy time of leaving work: peak hours	0.124	1.132	3.67*
Dummy trip mode (reference category: drive-alone):			
Carpool	0.547	1.728	38.68**
Bus transit	-0.492	0.611	6.82**
Walk/bike	-0.319	0.727	0.47
Others (motorcycle, taxi, etc.)	1.175	3.238	3.52*
Dummy industry type (reference category: retail):			
Service	0.194	1.214	4.20**
Basic	0.085	1.088	0.62
Dummy major employment centers: workplace inside of centers	0.110	1.116	1.45
% Industrial land uses within a half-mile radius from workplace	-0.007	0.993	11.70**
Straight-line distance from workplace to CBD in miles	-0.014	0.987	3.39*
% Residential land uses within one-mile radius from workplace	-0.003	0.997	1.90
Housing density per residential acre	-0.001	0.999	3.30*
Median price of owner-occupied housing units in the census tract of workplace	-0.001	0.999	4.04**
Public transit accessibility of workplace: within a quarter-mile radius	0.183	1.201	3.41*
Constant	-0.241		0.77
No. of cases		4,367	
Pseudo-R square (Nagelkerke)		0.101	
Likelihood ratio		278.69**	

* Indicates significance at 0.1 level and ** indicates significance at 0.05 level

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June 2002 - July 2002: Research Assistant, Texas Transportation Institute, Texas A&M University System, College Station, Texas

March 2002 - May 2002: Graduate Assistant (Non-Teaching), Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, Texas

September 1999 - February 2002: Research Assistant, Texas Transportation Institute, Texas A&M University System, College Station, Texas

May 1999 - August 1999: GIS Librarian, Texas Agricultural Extensions (TAEX)-Wildlife & Fisheries, Texas A&M University, College Station, Texas

March 1999 - August 1999: Student Technician, Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, Texas

November 1990 - December 1998: Assistant Manager, Korea Land Corporation, Seongnam, Korea

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