SPATIAL AND TEMPORAL DYNAMICS:

RESIDENTIAL DEVELOPMENT PROCESS

A Dissertation

by

JOUNG IM PARK

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

December 2010

Major Subject: Urban and Regional Sciences

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Approved by:

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ABSTRACT

Spatial and Temporal Dynamics:
Residential Development Process. (December 2010)

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A lack of empirical evidence to understand neighborhood and residential development processes within neighborhoods has challenged urban planners' ability to influence the course of future land development. The main objectives of this study were to examine neighborhood and residential development patterns and investigate dynamic processes in northwest Harris County, Texas, along the U.S. Highway 290 transportation corridor from 1945 to 2006.

Researchers have identified different patterns of land development: leapfrog, contagion and infill development. However, because of the fuzziness in neighborhood and residential development patterns, the nominal classifications of development patterns are limited in their potential to characterize development patterns both on neighborhood and parcel levels; their applications for development processes and its impacts are even more limited. This study presents a quantitative approach for measuring development patterns by characterizing neighborhood development patterns as a function of spatial distance and temporal lapse time from the closest existing neighborhood to new neighborhood(s). The analysis in this study was based on disaggregated parcel data provided by the Harris County Appraisal District (HCAD) real estate and property records. The quantitative measures of neighborhood development patterns and processes within each pattern of neighborhood were derived by aggregating parcel level data into neighborhood level. This study developed the Long-term Trend of Development Model (LTDM) to classify neighborhood and residential development patterns based on spatial distance and temporal lapse time from existing neighborhoods to new neighborhood(s) each year to examine development processes. Regression analysis was used to identify the relationship between neighborhood patterns and residential development processes.

This study found that development patterns can be measured quantitatively with spatial and temporal relationships between prior and new development at the neighborhood level. Empirical evidence supported the hypothesis that leapfrog neighborhood development triggers neighborhood development, contagion follows leapfrog neighborhood quickly, and infill follows contagion after a lapsed time. Residential development patterns in each pattern of neighborhood showed discrete development processes. Age of neighborhood can be used to predict development pressures and growth. In this process, physical and social infrastructure is involved, therefore, development process is best observed on the neighborhood level.

DEDICATION

To my mom

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Many people have helped me complete this dissertation. It has taken a long time to get to this point, and I could not have accomplished it without their support and help. I would like to extend my gratitude and appreciation to those who stood by me and encouraged me in many different ways.

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I would like to thank the many people I work with at the Department of Landscape Architecture and Urban Planning who offered financial support during my entire education. Very special thanks go to Dr. Ndubisi, my department head, for financial and executive support. I owe a great thanks to Dr. Rodiek for believing that I could accomplish my goals, and inspiring me to go beyond my personal limits.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Land development as a spatial phenomenon encompasses dynamic processes. New neighborhood development occurs first by spilling over existing neighborhoods and then by filling vacant land between them (Heim, 2001). As outlying boundaries become saturated, the first stage of expansion, leapfrogging, initiates another cycle of land development. Leapfrogging is a temporary condition, and vacant or available land left by leapfrogging is soon filled with new development. These patterns of land development change across space and time and these processes involve spatial distance from the prior development and temporal time when the parcel was developed.

Current urban growth and development pattern studies, however, haven’t fully considered the spatial attributes on a neighborhood level. Neighborhood development is a product of economics, social and human activities and infrastructure. But questions like “how can we quantitatively identify leapfrog, contagious and infill development patterns?” or “how do types of land development patterns contribute to the growth process?” have never been studied in terms of neighborhood development patterns and processes with planning concerns.

This dissertation follows the style of Landscape and Urban Planning.

Traditional urban forms and development models have been extensively studied during the past century and, subsequently, many urban theories were developed, for example, the concentric zone theory, the sector theory and the multiple nuclei theory (Archer, 1973; Zhu et al., 2006). These ecological models of urban form explain the spatial patterns involving the distribution of people, buildings, and activities across a city's terrain. But these models have been criticized as static snapshots of one stage (Herold et al, 2003; Lopez and Hynes, 2003). Although these concepts and ideas are widely accepted and applied to measure urban growth, describing the spatial and temporal dynamics of urban patterns has remained hypothetical (Zhu et al., 2006). Planners and economists are aware that development takes place beyond urbanized boundaries, but there is no standardized method to precisely measure how, when and where a neighborhood has been created and developed by adding new buildings in and outside the neighborhood (Sheppard, 2007). Also, Harvey and Clark (1965) suggest that growth represents a stage in development processes, rather than a static condition. Parts of an urban area may be in a beginning stage or be dominated by specific types of development, but eventually they change to a thickening pattern of stable neighborhoods (Galster et al., 2001).

1.2 Problem Statement

The pattern of urban sprawl and growth has continued throughout the United States for more than three decades (Frenkel and Ashkenazi, 2008). Since 1980, suburban population has grown ten times faster than central city populations in larger metropolitan areas in the U.S. Today, 8 out of 10 Americans live in metropolitan areas, and among them, 6 of 8 Americans reside in suburban areas. The concentration of population in urban areas led to a growing needs for land for urban settlement as well as public infrastructure (e.g. roads, utilities and water facilities) to support it. As a result of human activities, open space and rural land use in these areas have evolved into urban land use. This use has resulted in a large scale modification of the environment and has significantly affected both the structure and function of urban areas (Forman, 1995). Land use changes associated with the processes of urban growth can change ecosystem properties- for example, ecological diversity and climate conditions from local to regional scales (Johnson, 2001; McDonnell et al, 1997). The existing study has found that neighborhood and residential land development is a major contributor to rapid urban growth, more so than commercial or other development (Almeida, 2005).

Researchers have also identified the land development patterns associated with it: leapfrog development (Hasse and Lathrop 2003, Heim, 2001), contagious development (Weitz and Moore, 1998) and infill development (Steinacker, 2003). Leapfrog development is often cited as a trigger for urban expansion (Heim, 2001). Immediately adjacent to an urban area, contagious development occurs (Weitz and Moore, 1998) and increases impervious surfaces. Infill development slows the growth rate (Steinacker, 2003). However, because of the dynamic nature of urban land development, there is little consensus on a quantitative definition of development patterns in terms of space and time. For example, infill development is one way to decrease urban expansion and sprawl, but there is a lack of empirical evidence for this kind of development in spatial and temporal manner. In the current literature, development patterns have been characterized by researchers in planning, policy or land development fields as a static picture of land development patterns (Hammer et al., 2004; Hasse 2004). But a single snapshot of land development patterns does not capture the spatial dynamics of changing patterns nor explain the processes over time (Compas, 2007). Moreover, the distinction between contagious development and infill development is fuzzy because land development cannot be investigated at the individual parcel development level without considering surrounding neighborhood development (Suen, 1998, Wiley, 2007). Something that is largely missing from the literature is a thorough examination of physical boundaries and patterns of neighborhood development. No study has attempted to examine what kind of urban development pattern comes first and which one follows, both at a parcel and a neighborhood level. For example, contagious and infill development patterns may help to differentiate the different courses development processes take at different stages over time. So, the need to understand urban land development has culminated in analyzing the processes over a long period of time. Moreover, developments are driven by a series of interrelated processes of changes; economic, demographic, political, technological and social (Brueckner, 2000). Numerous attempts and quantitative methods have been used for measuring land development patterns. Usually, a developed urban area is measured at a given time, but these results have been limited because land development patterns normally are static. The processes take place in a physical urban environment that is later shaped by the outcomes of these processes.

To analyze the interactions and dynamic nature of land development, it is necessary to link the land development pattern with its processes. Current studies have seldom been able to ascertain how land development patterns affect development processes at the neighborhood level. Specifically, only a few of these studies have researched urban growth along a transportation corridor (Zhu et al., 2006), where most development occurs.

The existing literature has focused on landscape metrics to characterize development patterns based on aggregated data, so it hasn't included the planning profession or analyzed residential patterns (Hasse and Lathrop, 2003; Crawford 2007). Past studies have been based on case studies (Weitz and Moore 1998), but those reveal little about the spatial and temporal process, especially in quantitative terms. In this regard, a growing number of studies have applied landscape ecology as the methodological approach for urban land development (Camagni et al., 2002; Clark et al., 2009; McDonnell et al., 1990). This approach is based on a mosaic land pattern. This dimension for measuring development patterns of urban areas has used land use (land cover) data to analyze landscapes on a varying scale. In landscape ecology, urban forms and patterns are scale dependent and place specific, so this approach would apply on a local to global scale and would not be limited to a case study. In urban areas, patterns are subject to change by people and socioeconomic processes; they cannot be considered static in either space or time. In addition, in nature, the structure and function of an ecosystem is affected by patch size (e.g. neighborhood and development area), shape and the spatial and temporal relationship among different types (Clark et al., 2009; Crawford, 2007; Dietzel et al., 2005; Botequilha-Leitao and Ahern, 2002). Similarly, changes in urban form in any particular patterns and processes of the development can lead to structural changes in other patterns, spatially and temporally, altering the process of the entire area.

The static picture of urban land development arises in part from the lack of empirical evidence that focuses on the patterns and processes of development. Understanding neighborhood development facilitates residential development patterns and processes to be defined and measured quantitatively, providing a baseline for monitoring urban growth and testing growth policies. Once the residential development pattern has been described quantitatively, the relationship between the prior development pattern and future development can be analyzed.

1.3 Research Approaches

This study investigates the process of neighborhood development along the US Highway 290 from 1945 to 2006. This dissertation measures the degree of residential development patterns and examines the impact of different patterns of urban land development. This research identifies residential development processes for a popular development region over a relatively long time period compared to the existing research.

This dissertation provides quantitative measurements of neighborhood and residential developments. In this study, process refers to the sequence of changes over space and time. The lack of high quality data on the parcel level had limited the application of development pattern and process at the neighborhood and residential land development level. A new dataset to examine neighborhood and parcel development patterns and processes was created. Land development patterns, as suggested in the literature, were applied to investigate processes of residential development. The classification of neighborhood development is based on spatial and temporal patterns of development: leapfrog, contagion and infill development. To consider dynamic interactions in space and time, static and dynamic development patterns have been described. For each year, this dissertation annually classifies each neighborhood in terms of the distance between existing and new development. Spatial patterns will be analyzed in temporal terms to better understand the process of residential development. In this way, the study will examine the spatial and temporal changes in a neighborhood development pattern at the system level.

In doing so, the following three research objectives have been pursued:

1. To quantitatively measure neighborhood and residential development
2. To examine the spatial and temporal patterns of neighborhood development
3. To investigate the relationship between patterns of neighborhood development and processes within the neighborhood

The general research question is: when and how does residential neighborhood development occur? Based on the research purposes and objectives above, the major research questions of this study are as follows:

1. What are the development patterns along the U. S. 290 corridor in Houston, TX? How can they be measured and observed annually?
2. How do the patterns of neighborhood development contribute to residential

development within each pattern of neighborhood over the study period?

3. How does the process of land development influence the outcomes or pattern of development that results?

1.4 Significance of Research

This dissertation investigates the spatial and temporal dynamics of urban land development processes through residential parcel data with a landscape ecological approach. The direct beneficiaries of this study are urban planners and policy makers, landscape architects and master planners, and land developers.

This study is the first attempt to measure spatial and temporal development processes with disaggregated historical data. For example, this study explores how leapfrog, contagious and infill development increase urban growth and which spatial attributes (e.g. parcel size and distances to major transportation) are associated with development.

By examining the relationship between the spatial and temporal dynamics of residential development, this dissertation provides insight into how residential land may be developed within a neighborhood temporally, and how a neighborhood grows spatially. The results of this study will enhance the understanding of neighborhood growth and development processes. It will provide insight into the root causes of the resulting pattern of residential development and, thereby, offer effective planning mechanisms to manage urban growth.

Third, this study also provides a quantitative measurement for urban land development based on landscape ecology. Because urban land developments are associated with new development and human processes, they cannot be studied as a static phenomenon.

The combined method of using Geographic Information System (GIS) and analysis of disaggregated real estate appraisal data allows us to examine both spatial and temporal relationships between residential development patterns and processes that cannot be explained by a simple approach (Dietzel et al., 2005). Using digital parcel data and GIS techniques, this study applies a unique measurement to land development patterns and processes and responds to planners, designers and developers who have the needs for theory, concept and measurements for dynamic approaches in addition to demonstrating a parcel level approach to investigate land development patterns and processes.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Urban growth with its resulting urban sprawl and overall neighborhood development are dynamic spatial and temporal processes (Hasse and Lathrop, 2003; Ulfarsson and Carruthers, 2006). Nevertheless, Hammer et al. (2004) found “changes in land development patterns are usually studied as either spatially or temporally static.” Spatial studies measuring urban growth or suburban sprawl have been done by selecting two or at most three points in time (Crawford, 2007; Hasse, 2004). In contrast, studies that examine trends in development over long periods of time are usually temporal analysis, investigating urban growth without spatial reference to dynamics occurring within urban boundaries (Compas, 2007; Hammer et al., 2004). In addition, limited disaggregated urban data and empirical methods for measuring and quantifying spatial and temporal changes over long periods of time in regional settings reduce the scope of the analysis (Hasse and Lathrop, 2003; Compas, 2007; Hammer et al., 2004). However, adding a new development to an existing development (both in an individual parcel and neighborhood level) is neither simply spatial nor simply temporal, but “instead results from and exists within these interlinked processes” (Hammer et al., 2004). Current reviews of the literature suggest that spatial and temporal dynamics could be examined based on patterns of land development and processes of land development (Galster et al, 2001). Early studies of urban sprawl and urban growth have primarily focused on conceptual and descriptive research, rarely addressing urban dynamics with quantitative measurements. Along with smart growth and sustainable development strategies, a growing number of studies describe and examine the various spatial and temporal dimensions of land development patterns and processes (Hasse and Lathrop, 2003; Willy 2007). In Chapter II, concepts, definitions and quantitative approaches for investigating patterns and processes in land development are reviewed in detail.

2.2 Land Development Patterns

Schultz and Kasen (1984) stated "The growth of a metropolitan area through the process of scattered development of miscellaneous types of land use in isolated location on the fringe, is followed by the gradual filling-in of the intervening spaces with similar use." Ideally, new growth should take place around an existing urban area, but the popularity of the single-family residence in a suburban neighborhood and the greater use of automobiles and highway systems have caused a discontinued leap rather than steady process of outward development (Cutsinger et al, 2005; Gordon and Richardson, 1997; Turner, 2007). In addition, less expensive land is more attractive to developers and also to home buyers, this process, called leapfrogging, is one manifestation of the broader phenomenon in a metropolitan area (Heim, 2001). Heim (2001) describes "leapfrogging, in which developers skip over properties to obtain land at a lower price farther out despite the existence of utilities and other infrastructure that could serve the bypassed parcels." In addition to excessive infrastructure costs, it has also been accused of environmental degradation such as loss of open space and habitat fragmentation (Johnson, 2001). In the literature, it has been cited as a trigger for rapid urban expansion (Heim, 2001) and criticized as causing excessive infrastructure costs such as more highways and water causing utilities to be extended to remote areas (Hasse, 2004; Suen, 1998; Sultana and Weber, 2007; Theobald, 2004). However, this type of development has long been studied as a concept or hypothesis behind sprawl (Harvey and Clark, 1965) and conceptually characterized as a spatial development pattern. Besides transforming the landscape surrounding urban areas, the ongoing outward expansion of land development and associated socioeconomic functions has altered people's lives and environments. So, researchers have been interested in not only its pattern, but also its cause and consequences (Brueckner, 2000; Johnson, 2001). The cost and negative impacts of urban sprawl have been widely studied (Cutsinger et al., 2005). While substantial research has addressed socioeconomic issues related to leapfrog development such as cheap land price (Heim, 2001) and suburban living (Houinen, 1977), far less research has focused on developing empirical methodologies to examine and characterize leapfrog development patterns (Hasse and Lathrop, 2003). Like the often cited expression "we know it, when we see it," there is no quantitative definition or empirical evidence to distinguish whether new residential development patterns are actually leapfrogging or sprawling in their spatial configuration and location (Cutsinger and Galster, 2006; Galster et al., 2001; Hasse and Lathrop, 2003; Mieszkowski and Smith, 1993; Song, 2005). However, with advanced technologies and growing spatial urban information, a number of measurements for leapfrog patterns have been proposed

(Frenkel and Ashkenazi, 2008; Hasse and Lathrop, 2003; Hasse 2004; Sudhira et al., 2004; Torrens, 2008). But, it is still a single snapshot of one stage of development (Hasse and Lathrop, 2003; Torrens, 2008), in other words, it remains static (Maier et al., 2006). Torrens (2008) writes “urban growth and land development is a dynamic phenomenon, but studies on development focuse on a single temporal snapshot or disjointed snapshots, rather than following longitudinally in synchrony with urban evolutions.”

On the other hand, large patches of vacant or bypassed land, resulting from leapfrog development within urban areas, have been the target of new development. A new development or redevelopment of land in existing neighborhoods is called infill development (Landis et al., 2006; Willy, 2007). This occurs where land has remained vacant, bypassed or underutilized as a result of continuing and out-spread development processes (Heim, 2001). Vacant lands can be located in central downtown, suburban neighborhoods or rural villages, and can be residential, commercial or industrial (Willy, 2007). Infill development has played a critical role in achieving downtown revitalization and reducing land consumption, providing affordable housing and an alternative to sprawl (Sheppard, 2007) or even a solution to smart growth (Steinacker, 2003). On the other hand, it also has negative consequences such as lost open space and increased population and housing density, and traffic congestion in a developed area (Farris, 2001). However, with smart growth strategies, “planners and developers hail such infill as a solution to sprawl and its many costs, while at the same time revitalizing the communities receiving the new growth and development” (New Urbanism 2006, as cited in Willy, 2007). Policies to encourage more infill development are advocated for more efficient use of land and existing infrastructure (Landis, 2006). In this regard, infill development has been discussed among planners and policy makers and even developers. However, most research has focused on downtown or arterial revitalization projects (Mejias and Deakin, 2005), or policy review at a county level (Johnston et al., 1984). Weitz and Moore (1998) point out that planning literature reveals little about quantitative methodologies for rigorously examining infill development or provides little empirical evidence for policies to guide future physical development of cities.

In general, infill development is conceptually described as new development occurring within an urban area (Sheppard, 2007); it can be residential, commercial or industrial. It has been studied based on pattern and density in urban areas- for example, in 1990 the number of new housing units and changes in permits during 1989 and 1998 in Metropolitan Statistical Area (MSA) (Farries, 2001), or the ratio of the total number of new residential units in the city to the total new residential units in the MSA, divided by the ratio of the land area in the central city to the land area in the MSA (Steinacker, 2003). Willy (2007) mentions that there is no agreement on an exact level of development within urban areas that could be an infill development. The author explains that “this debate… is exacerbated by the fact that we know little about how much of development over time could be considered infill, where such infill occurs, and how it relates to existing neighborhoods, particularly in suburban communities.” A growing number of studies have reviewed this type of development pattern, but most have focused on concepts, trends, some factors influencing infill, and barriers (Ferris, 2001; Mejias and Deakin, 2005; Phillips and Goodstein, 2000; Sheppard, 2007; Willy, 2007).

Factors influencing infill development have been studied at both the local and national level. At the local level, Mejias and Deakin (2005) examined infill development and revitalization along a major arterial, San Pablo Avenue, LA, California from a developers' perspective. In their study, developers cited accessibility to public transit, attractive landscape and pleasant streetscapes, lower property and development costs, and governmental policies as aspects that positively affect its potential for infill development. At the national level, Farries (2001) addresses positive infill factors such as easy accessibility to transit and close location to employment centers. In addition, the opportunity for infill housing is generated by growth in demographic factors. For example, a large proportion of single or childless households increases the potentials for infill development. Preference for downtown living or proximity to culture and walking neighborhoods were also found to encourage infill development (Wiley, 2007).

Barriers for infill development also have been studied on various scales. Willy (2007) and Johnstone et al. (1984) mention that the most important factor influencing infill development is opposition and resistance from local residents. So-called NIMBY (Not in My Back Yard) opposition has been widely documented (Pendall, 2000). Filling in a new development reduces open spaces near a residential area and residents are aware that nearby infill development increases traffic and service usage.

There is another development pattern- contagion development. As mentioned in the above chapter, defining sprawled patterns in ways that facilitate measurement can be difficult. According to Weitz and Moore (1998), one part of the definition that can be measured is the degree to which development touches other development, contagion development, which leads to a contagious effect on the region. Thus, continuous developments have extended the suburbs beyond the cities.

In addition, landscape ecology principles have been used to study urban growth. Forman (1995) explains exurban settlement patterns based on landscape ecology principles and its principles have been widely provided to examine urban form and pattern (Camagin et al., 2002; Hoffihine-Willson et al., 2003). In particular, it has been useful in developing spatial measures of urban sprawl (Clark et al., 2009). Camagni et al. (2002) indicates that contagion development occurs in the immediately adjacent urban fringe or is contagious to the urban cluster and strip. This concept and pattern of contagion development has primarily been studied to investigate policy impact and implementation, for example, Urban Growth Boundaries (UGBs) (Weitz and Moore, 1998).

However, current studies in contagious development have been limited (Clark et al., 2009; Noda and Yamaguchi, 2008). First of all, existing studies are mostly a single or couple of snapshots in a study time driven by data which does not capture the changes which make more sense when the concept “contagious” is applied. Without linking a pattern to a process, dynamic characteristics in urban development cannot be examined.

2.3. Spatial and Temporal Dynamics

Various approaches for measuring urban sprawl and analyzing urban landscape patterns have been developed to examine urban growth (Carrion-Flores and Irwin, 2004; Crawford, 2007; Compas, 2007; Dietzel et al, 2005; Frenkel and Ashkenazi, 2008; Hammer et al, 2004; Hasse and Lathrop, 2003; Hasse, 2004; Lopez and Hynes, 2003; Noda and Yamaguchi, 2008; Song, 2005; Sudhira et al, 2004). In the early literature sprawl and urban growth are simply described as certain patterns of land use (Corry and Nassauer, 2005; Harvey and Clark, 1965; Peiser, 1989). Later studies found urban sprawl and growth also refer to processes of land development (Herold et al, 2003, Hoffhine-Wilson et al., 2003). Galster et al. (2001) point out that sprawl can be a noun (condition) and also be a verb (process). Moreover, several studies in recent years have attempted to deal with the dynamic aspect of sprawl and urban growth (Compas, 2006; Torrens, 2008). Understanding urban dynamics requires the examination of spatial and temporal changes in time because in later years patterns can turn into other patterns, such as sprawl to compact, in later years as the pace of urban growth drives developers to fill-in previously undeveloped areas. Dynamics of urban growth can be distinguished from the causes that create such a pattern and the consequences of such a pattern (Botequilha-Leitao and Ahern, 2002; Riebsame et al., 1996; Theobald, 2001).

Significant progress has been made in measuring spatial and temporal dynamics in urban growth (Compas, 2007; Weng, 2007; Torrens, 2008; Yu et al., 2007; Zhu et al., 2006). With the combined methods of urban gradient analysis and landscape metrics, the application of landscape metrics in landscape ecology serves as methods to examine landscape changes. According to Sudhira et al. (2004), “the built-up area is commonly considered as the parameter for quantifying urban sprawl.” Carrion-Flores and Irwin (2004) mention that “these metrics have been long used in the landscape ecology area, which is the study of patterns of patches on the landscape, the interactions between patches on the landscape, and changes in both patterns and interaction with time.” Previous studies suggest several sets of metrics for land use configuration and land use composition. Weng (2007) stated that “changes of landscape pattern can be detected and described by landscape metrics which quantify and categorize complex landscape into identifiable patterns and reveal some ecosystem properties that are not directly observable.” It supports the understanding of patterns as they change dramatically reflecting the underlying processes involved (Sudhira et al., 2004).

Noda and Yamaguchi (2008) proposed a method to analyze dynamic characteristics in Toyohashi City, Japan from 1972 to 2002. The study adopted three growth categories of infill, expansion, and outlying from the work of Hoffhine-Wilson et al. (2003). Originally, those categories were referred to in the landscape fragmentation process described by Forman (1995). In their study, types of urban growth are categorized with reference to the prior non-developed landscape configuration; therefore, “types of urban growth embody a relationship between the newly developed area’s location and the existing developed area.” The study found expansion of urban growth is the most common development type; however, infill urban growth has been able to modify urban sprawl.

Parcel data have been useful in identifying factors that drive changes at a disaggregated level. However, a number of studies examining dynamics in urban growth have been made based on aggregated patterns of land development (Hasse and Lathrop 2003; Torrens, 2008; Yu et al., 2007; Zhu et al., 2006), or analyzed spatial signature based on census and economic data on a county or metropolitan level (Compas, 2007; Hasse, 2004). Hasse and Lathrop (2003) stated that fine scale information is necessary to directly link ‘from-to’ land use changes. Using finer scale data, for example parcel and roads, studies actually investigate how applied policy and planning regulation in a neighborhood area can pace or shape the development processes (Compas, 2007). Torrens (2008) stated that “methodologies are highly variable and are often data-driven rather than having a foundation in theory or practice.”

CHAPTER III

THEORY

3.1 Introduction

As a spatial phenomenon, urban growth is a dynamic process. New neighborhood development occurs first by spilling over existing neighborhoods and then by filling vacant land between them (Heim, 2001). As outlying boundaries become saturated, the early stage of expansion, leapfrogging, creates another cycle of land development. Leapfrogging is a temporary condition, and vacant or available land left by leapfrogging is soon filled with new development. These processes of land development change across space and time. Spatial and temporal attributes such as location of new neighborhood(s), number of parcels in the neighborhood(s) or socioeconomic conditions when the neighborhood(s) are developed, are involved in those changes (Mills, 1981; Nechyba and Walsh, 2004; Turner et al., 2001; Turner, 2005).

Current urban growth and land development studies, however, have not fully considered the spatial attributes on the neighborhood level. Neighborhood development is a product of economics, social and human activities and infrastructure. But questions like “how can we quantitatively identify leapfrogging, contagious and infill development patterns?” or “how do the types of land development patterns contribute to land development processes?” have never been studied in terms of neighborhood development patterns and processes.

Traditional urban forms and development models have been extensively studied during past centuries, and subsequently, many urban theories have been developed, for example, the concentric zone theory, the sector theory and the multiple nuclei theory (Camagni et al, 2002; Zhu et al., 2006). These ecological models of urban form explain the spatial patterns taken by the distribution of people, buildings, and activities across a city's terrain. But these models have been criticized as static snapshots of only one stage of development. Although the concepts and ideas are widely accepted and applied to measure urban growth, describing the spatial and temporal dynamics of urban patterns has remained hypothetical (Clawson, 1962). In addition, Harvey and Clark (1965) suggest that development patterns represent a stage in development processes, rather than a static condition. As a result, parts of an urban area may be in a beginning stage or dominated by specific types of development, but eventually they change to a thickening pattern of stable neighborhoods (Galster et al., 2001).

In this background, to define and examine land development patterns and processes, the literature provides more objective methods but still needs to be further developed with the planning profession through: (1) exploring the temporal nature of growth processes instead of static pictures (Hasse and Lathrop, 2003), (2) noting spatial aspects on a local residential development level (Galster et al., 2001), and (3) investigating residential development patterns affected by neighborhood development (Almeida, 2005). In this regard, the theory in this study classifies development patterns into neighborhood and parcel levels by considering the spatial and temporal dimensions of distance and time.

3.2 Theory

Land development theory in this study incorporates two dimensions: distance and time. This theory explains land development processes on two different levels: neighborhood (Figure 1) and parcel (Figure 2 in page 24). Planning decision making has been made on the neighborhood level. For example, developing new infrastructure such as roads and schools is highly related to the creation of new neighborhoods. On the other hand, home buyer’s decisions or market conditions have contributed to land development in existing neighborhoods.

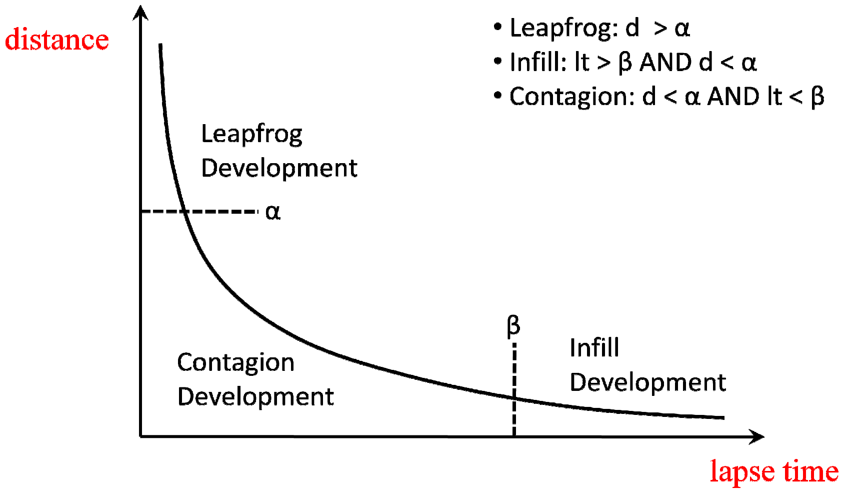

Figure 1. Theory diagram: neighborhood development

A general diagram of the neighborhood development theory in this study is seen in Figure 1. A neighborhood is a socially defined boundary engaged in planning practice. X axis (lapse time) is the year the new neighborhood(s) was developed minus the year the closest existing neighborhood was developed. Y axis (Distance) is the distance from existing neighborhoods to new neighborhood(s). The location and the creation of new neighborhoods are in response to social and human activities. Distance from the existing neighborhood to the new neighborhood reflects different socioeconomic status and the year the new neighborhood was developed is also related to the nearby physical environment. Therefore thresholds (α and β in Figure 1) may be applied to determine patterns of neighborhood development defined based on empirical methods both in space and time. Every new neighborhood developed annually could be classified as a leapfrog, infill or contagious development pattern. These patterns change over space and time at the neighborhood level. These thresholds have been utilized for analyzing at the changes in ratio of neighborhood development patterns during the residential land development process.

Leapfrogging is a matter of spatial distance. It considers geographic boundary which is called a "neighborhood." Since the first development in a new neighborhood can be leapfrog, it is defined on the neighborhood level. It is a temporary condition, so vacant or available land left by leapfrogging is later developed with other types of neighborhood development: infill or contagion development.

New neighborhood development occurs by filling the available land within existing neighborhoods. Instead of spreading out, like leapfrogging, infill concentrates new neighborhood within existing neighborhoods. In this case, the infill neighborhood is a matter of time because of the significant time lag between the new neighborhood and prior neighborhoods (Figure 1). Regardless of distance between the neighborhood developments, when development has a significantly long time-lag, it could become infill development.

New development can be contiguously built next to the existing neighborhoods. Contagion neighborhood development is characterized by relatively short lags in space and time (Figure 1). This pattern of new neighborhood continues through the existing neighborhood is connected throughout in the development processes. Neighborhood contagion development occurs when surrounding neighborhoods are developed to their highest and best use. On the neighborhood level, the pattern of contagion development provides an indication of the direction of change created by new neighborhood development within the context of its regional scale.

A general theory diagram on the parcel level in this study is seen in Figure 2.

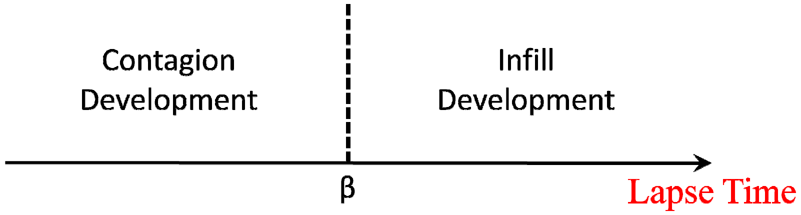

Figure 2. Theory diagram: parcel development

Parcel is a piece of land engaged in market practice. X axis (lapse time) is the year the new parcel was developed minus the year the closest existing parcel was developed. Y axis (distance) is the distance from the existing parcels to the new parcels.

Parcel development also occurs by filling in the available land within the existing neighborhood. Parcel-infill development is a new development, redevelopment, or reuse of vacant or underutilized lots near the existing infrastructure (Figure 2). On the parcel level, time means the temporal distance between the new parcels to the existing parcels.

Parcel infill development is a matter of time because of the significant time lag between the new parcels and the existing parcels. Regardless of distance between the developments, when new development takes a significantly long time, it becomes infill development.

In contrast, new parcels can be contiguously developed next to existing developments. But on the parcel level, parcel-contagion development, the same pattern as contagion patterns on the neighborhood level, is only a matter of time (Figure 2). Since every new parcel development is in the existing neighborhood, distance no longer contributes to the development processes. This pattern of new parcel development touches along the existing development and connects throughout in the development processes. Also, short lags in space and time excite similar conduct in the following development by contact. Eventually, parcel -contagion development becomes incorporated in the development process.

3.3 Long-term Trend of Development Model (LTDM)

By measuring the changes in spatial and temporal development patterns, both on neighborhood and parcel levels, land development processes can be understood. It is difficult to ascertain the patterns and processes of development with aggregated data (Hasse and Lathrop 2003), but changes in patterns reflect the land development process, which is best observed with historical data. Based on the theory in this study, a Long-term Trend of Development Model (LTDM) model has been developed (Figure 3). In

LTDM model, leapfrog pattern is a matter of distance but infill pattern is a matter of time, however, contagion pattern is a matter of distance and time.

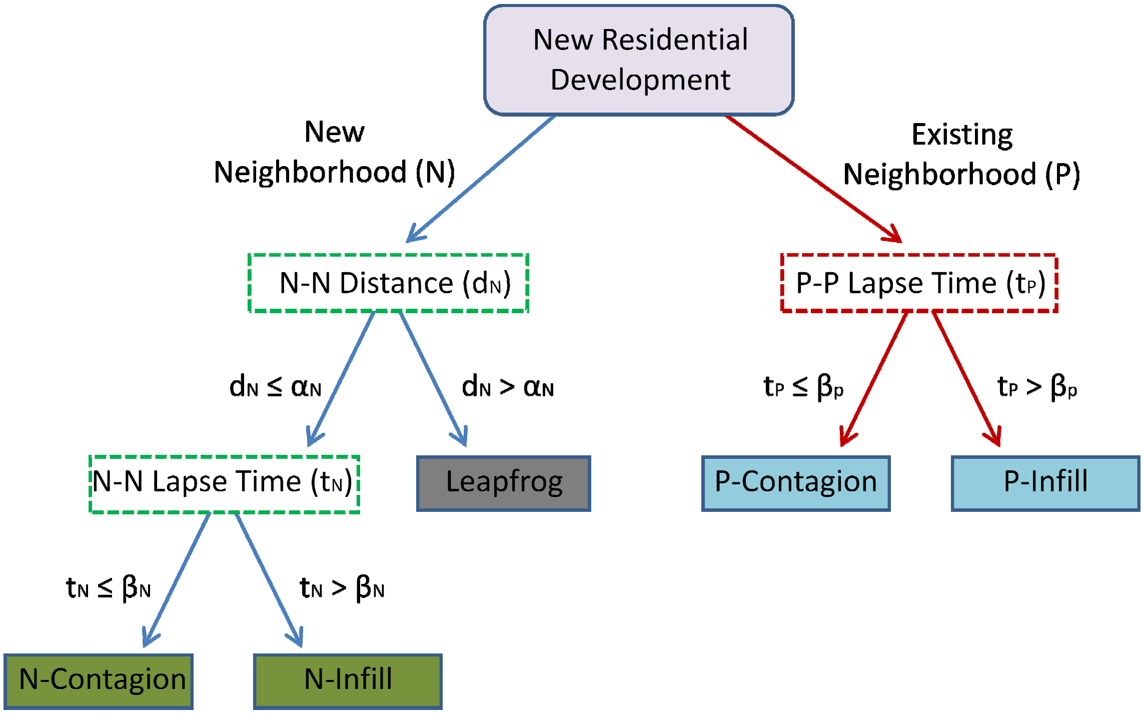

Figure 3. Long-term Trend of Development Model (LTDM)

Each of the development patterns, both neighborhood and parcel level, represents variables which have been correlated to changes in the development processes. This model was primarily developed to investigate spatial and temporal land development processes. It will apply spatial and temporal indicators specifically to show the development trend in order to determine which spatial patterns of development influence development processes on both the neighborhood and parcel level.

Neighborhood is a socially defined boundary which engages in planning practice. Parcels developed in the same neighborhood have similar properties such as value or school district. Therefore, on the neighborhood level, the LTDM model considers neighborhood to neighborhood distance in space and time. Here, distance (d_N) is neighborhood to neighborhood distance: the distance from the existing neighborhood to the new neighborhood. Lapse time (t_N) is the year the new neighborhood was developed minus the year the closest existing neighborhood was developed.

Leapfrog developments do not intersect the existing development. Among new neighborhood developments, some are built certain distances farther away from existing neighborhoods and can be identified as leapfrog development.

The literature suggests 0.6km for leapfrog development in Hunterdon County, NJ (Hasse and Lathrop, 2003). This study will use the average distance from a new parcel development to the previously existing settlement to define leapfrog development (d_N in Figure 3). Conceptually, to be leapfrog, the distance (d_N in Figure 3) is at least greater than an average distance.

New neighborhood(s) can also be created near existing neighborhoods. In this case, new neighborhood developments are infill neighborhood or contagion neighborhood. The main difference between infill and contagion development is time. Lapse time (t_N in Figure 3) is the time between the year the new neighborhood was developed and the year the closest existing neighborhood was developed. When new neighborhoods are developed, they are classified based on the distance in time relative to existing neighborhoods. For example, infill neighborhood development is new development occurring within the existing development with a long time-lag. Contagion neighborhood development is defined here as less spatial distance from the existing neighborhood with short lapse time.

New land development in the existing neighborhoods is characterized by time alone. On the parcel level, lapse time (t_P) is the time between when the new parcel was developed and the closest existing neighborhood was developed. Based on threshold (time (t_P) in Figure 3), the LTDM model in this study provides a quantitative approach to define parcel-contagion and parcel-infill. Rather than a static method, this model illustrates simple annual binary characterization of development patterns as built-out or infill. In this study, the LTDM model suggests an average time lag throughout the whole study period. There is little planning literature to suggest empirical quantitative methods for time threshold quantitatively. When new developments have below the average lapse time (t_P), they are built-out in a continuing manner.

3.4 Expected Results

Every neighborhood and parcel development from 1945 to 2006 in Harris County, Texas, along the U.S. Highway 290 transportation corridor will be examined based on three patterns of neighborhood- leapfrog, contagion, or infill. A Long-term Trend of Development Model (LTDM) has been developed to investigate the land development process based on neighborhood and residential development patterns in space and time. As the study area becomes more fully developed, the distance in space and time will change. These changes will show different processes among three patterns of neighborhood. Expected results are illustrated in Figure 4.

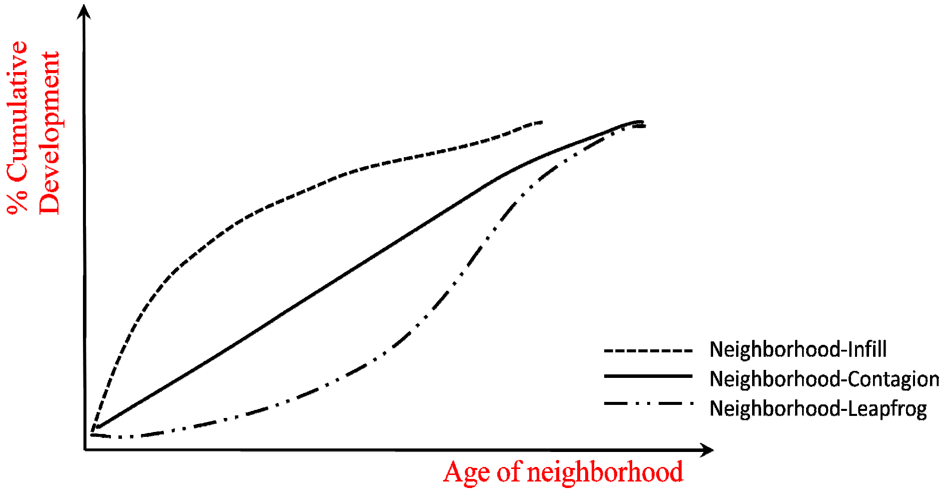

Figure 4. Expected Results

As illustrated in Figure 4, this study posits that the three patterns of neighborhood development will have discrete development processes. In addition, each pattern of neighborhood development also has different magnitudes within the neighborhood on the parcel level.

On the neighborhood level, high pressure within the existing urban area or high demand for cheap land causes neighborhood leapfrog to trigger new urban development (H_1). Large spatial gaps resulting from a leapfrog development between the prior development area and new neighborhood leapfrog will provide more available land for new development. Since a spatial dimension is involved in this process, land availability is an important factor for neighborhood leapfrog development (H_2). Where many lands are available for new development, leapfrog development can more likely occur, or the possibility for a jumping away from the existing city is higher than where less land is available for new development. In the early stage of neighborhood leapfrog development, the pressure for residential development within the neighborhood is not high because it doesn't have supporting infrastructure such as school, water, sewage etc. But once a leapfrog neighborhood has infrastructure, the neighborhood will soon be filled with residential parcel development. In other words, development speed in the leapfrog neighborhoods will show an exponential curve as seen in Figure 4 (H_3).

- Hypothesis 1: Neighborhood leapfrog development triggers land development
- Hypothesis 2: Neighborhood leapfrog development is limited to geometry (land availability)
- Hypothesis 3: There has been slow growth in leapfrog neighborhoods because they lacked supporting infrastructure in their early development stage.

Though neighborhood leapfrog is a trigger, neighborhood contagion would be the major pattern of neighborhood development throughout the entire study period because neighborhood contagion is influenced by two dimensions: spatial and temporal distances from the prior neighborhood (H_5). Therefore, after neighborhood leapfrog development, the extended boundaries and increased available land in the existing development increases opportunities for neighborhood contagion development (H_6). On the parcel level, neighborhood contagion is a process in which neighborhood is influenced by the behavior of developers or home owners through the conscious or unconscious pressure of new development by direct or indirect touching of existing developments. Proximity to the existing development and a short lapse time will maintain similar conditions for new residential development, both physically and perceivably. So the development pressure remains consistent even though neighborhood contagion gets old within the contagion neighborhood. Age of neighborhood, in other words, the years in neighborhood, won't be related to development pressures for residential development (H_7). This means that throughout the whole study period, it will show constant development speed as a linear curve (Figure 4).

- Hypothesis 4: Neighborhood contagion development leads land development
- Hypothesis 5: Neighborhood contagion is influenced by spatial distance and temporal time-gap from the existing development
- Hypothesis 6: Neighborhood leapfrog development increases neighborhood contagion development
- Hypothesis 7: In contagion neighborhoods, proximity to the existing infrastructures creates constant development pressure.

After neighborhood infill and neighborhood contagion, neighborhood infill takes place in the available areas inbetween the existing developments. In other words, neighborhood infill development is followed by neighborhood contagion (H_8). In the case of neighborhood infill, the spatial distance from the existing development does not matter, but the temporal time-lag from the existing development neighborhood is important (H_9).

Since neighborhood infill is close to the existing neighborhoods, the location of new neighborhood infill already has good access to existing infrastructure. For this reason, development pressure for new residential development is high, so neighborhood infill has many developments in the early stage. Rapid development in the early stage turn to slow development after a few years, and the development pressure within the existing infill neighborhood will be replaced by a demand to create new neighborhood infill development. Instead of developing more residential development in the existing neighborhoods, people will find another place close to the existing neighborhood with infrastructure. As a result, neighborhood infill has a shorter life cycle than other neighborhood patterns (H_{10}).

- Hypothesis 8: Neighborhood infill development is followed by neighborhood contagion
- Hypothesis 9: When an infill neighborhood is developed, a temporal lapse time is a significant factor for developing a new neighborhood
- Hypothesis 10: In infill neighborhoods, residential development has grown quickly because of available supporting infrastructure in the early development stage.

Table 1 shows all hypotheses and unit of measurements in this study.

Table 1. Hypotheses and Unit of Measurements

	Neighborhood $_{\textbf{U of NB}}$	**Parcel** $_{\textbf{U of Year}}$
Hypothesis 1	Test with lapse time variable affecting other pattern of neighborhood development	
Hypothesis 2	Test with land availability	
Hypothesis 3		Test with age of neighborhood (leapfrog neighborhood)
Hypothesis 4	Test with total land developed in contagion neighborhoods	
Hypothesis 5	Test with spatial distance and lapse time from existing neighborhoods	
Hypothesis 6	Test with lapse time variable	
Hypothesis 7		Test with age of neighborhood (contagion neighborhood)
Hypothesis 8	Test with lapse time variable	
Hypothesis 9	Test with lapse time from the existing neighborhoods	
Hypothesis 10		Test with age of neighborhood (infill neighborhood)

CHAPTER IV

METHODS

4.1 Introduction

This chapter outlines the research methods and measurements developed and employed in this study. It begins with the historical background of rapid development in the Houston area. It includes discussions of the data source, database creation, and the definition of patterns that explain the land development trends. Analytical supports for the thresholds in the classification model introduced in Chapter III is discussed. Statistical methods employed in this study are also discussed.

4.2 Study Area

The study area is the northwest part of Harris County, Texas, within the Houston-Sugar Land-Baytown metropolitan area, along the U.S. Highway 290 transportation corridor (Figure 5). Harris County, Texas is located in southeast Texas near the Gulf of Mexico. The third largest county in the United States, it was founded in 1836 as Harriburg County, and the name changed to Harris County in 1839. It is governed by the elected five member Commissioners Court, and the county seat is in the City of Houston. The Houston Metropolitan area has undergone significant growth in the past three decades and the city of Houston is now the fourth largest city in the United States. This study area has chosen for examining land development patterns and processes because different from other large U.S. cities, The city of Houston did not adopt city zoning laws in its urban planning . Therefore, spatial and temporal patterns of development in the study area do not result from urban regulations or policies. Thus the Houston Metropolitan area is a good place to investigate land development processes in response to prior and new development in terms of space and time.

The climate of Harris County is humid subtropical with has a temperate climate all year round because of its proximity to the Gulf of Mexico. The mean annual precipitation in this area is 43 inches. Because of the humidity, in summer the temperature feels hotter than it actually is. Summers are hot and humid but winters are cold and dry. The mean temperature range varies between 45°F in winter to 93°F in summer. In Harris County, the land is very flat, and its main vegetation is classified as temperate grassland. The dominant native species are oaks and pines.

Figure 5 also shows the major highway in Harris County. Harris County transportation systems serve intrastate and interstate needs with six major railroads hauling freight to distribution centers and to the port; passenger rail service is limited to Amtrak. Buses, trucks, and passenger cars utilize a network of highways, including Interstate 10 east and west, Interstate 45 north and south, U.S. Highway 59, which crosses the county from northeast to southwest and goes to the Rio Grande Valley, and U.S. 290 leading to West Texas via Austin. Loop 610 encircles the heart of Houston, and a second loop, Beltway 8, allows traffic to move around the perimeter of the urban sector. US 290 was formed in 1927 before the study period. Its whole length is 261 miles (418km) however, the length in this study area is 38 miles.

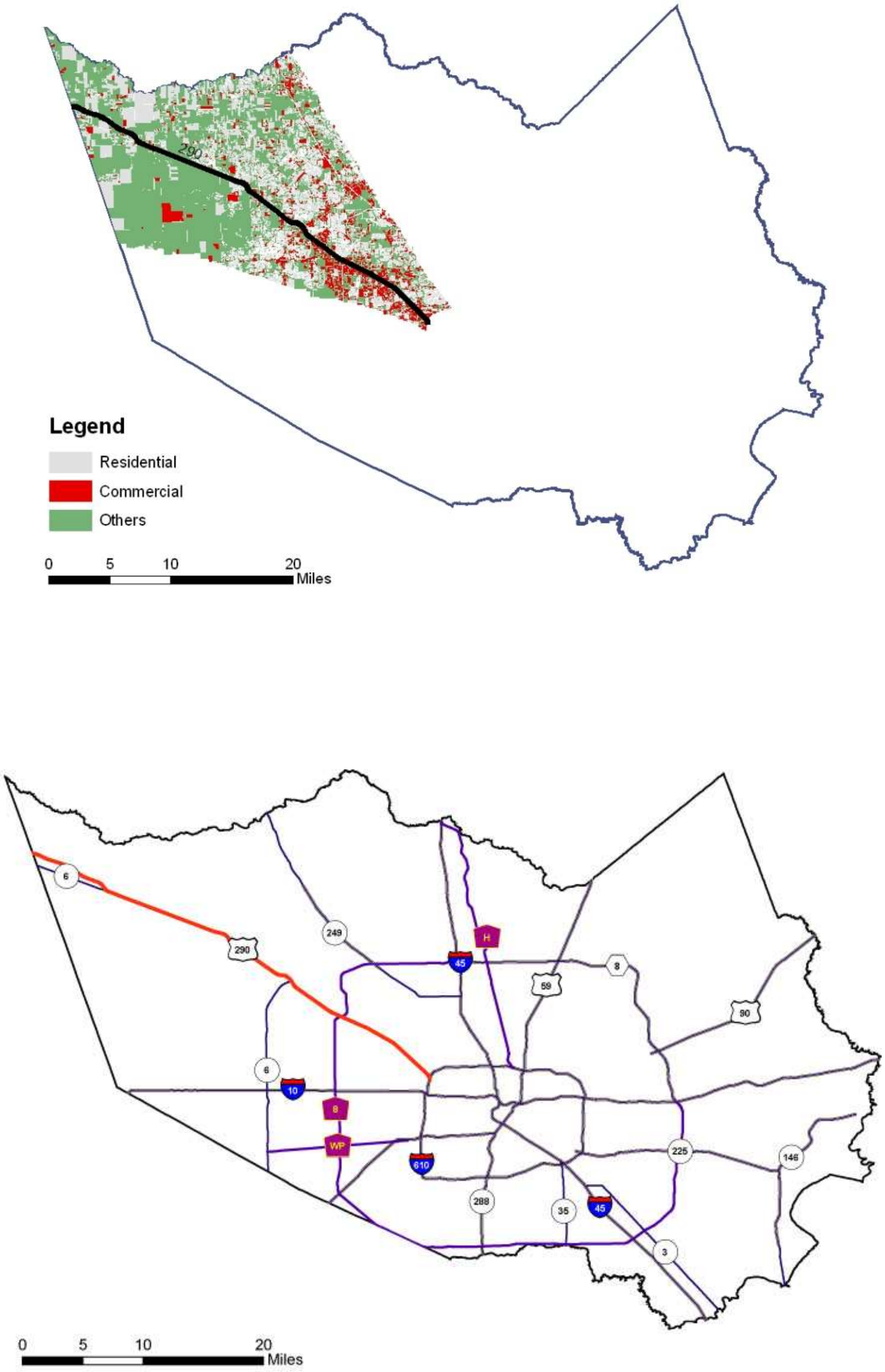

Figure 5. Study Area (upper) and Major Highways in Harris County (lower)

According to U.S. Census Bureau, Harris County has a total area of 1,778 square miles (4,604 km^2); 1,729 square miles (4,478 km^2) of it is land and 49 square miles (127km^2) is water. While the whole county size is 1,778 square miles, the selected study area covers 354.63 square miles. The residential area is 110.46 square miles, the commercial area is 203.99 sqmi and other land use is 40.17 square miles.

In 2000, the county had a population of 3,400,578 (though a 2007 estimate placed the population at 4,011,475), according to the United States Census Bureau (Figure 6). The 1945 Harris County population was 601,249, and from 1945 to 2006, the area grew by 3,644,285 people according to the Texas Almanac.

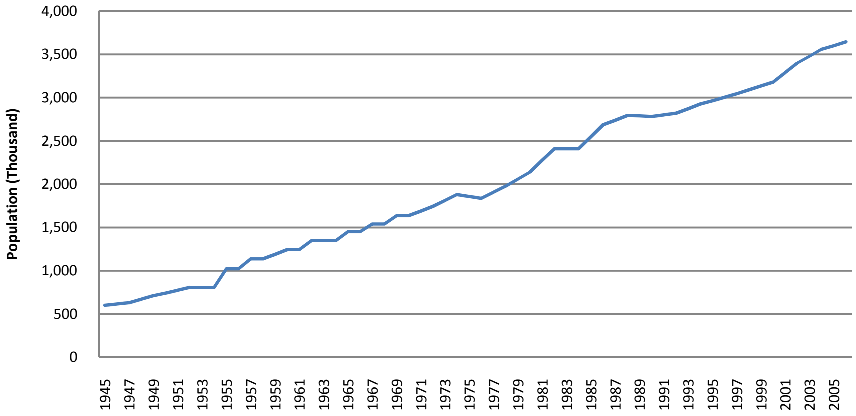

Figure 6. Population Growth in Harris County from 1945 to 2006 (source: Texas Almanac)

4.3 Data and Unit of Analysis

The Harris County Appraisal District (HCAD) supports a real and personal property database through its website (http://pdata.hcad.org). This study used a certified

2007 dataset downloaded in August, 2008. Each real property has a unique account number which remains static. In addition to general building information, data has also provided year information for building, and improvements on each parcel. Harris County also provides a parcel GIS shapefile dataset which allowed us to transform the non-spatial information into a spatial dataset. Real and property data are available for the study area from the early days of Houston (1800). Since the literature points out that sprawl is generally identified with the outward suburban growth of cities occurring after World War II, the 62-year period (1945-2006) was chosen as a reasonable representation of urban development trends.

This study has two units of analysis: spatial and temporal. The spatial units have two levels: “neighborhood” and “parcel.” The temporal unit is “year.” On www.hcad.org website, HCAD defined neighborhood code as “residential valuation neighborhoods are groups of comparable properties whose boundaries were developed based on location and similarity of property data characteristics. Each neighborhood in a school district has a unique identifier known as a residential valuation number. These neighborhood boundaries are maintained via an on-going office and field review. As neighborhoods change, neighborhood lines are redrawn to reflect the changes, and maintain the homogeneity of the neighborhood.”

The neighborhood development and parcel development patterns are analyzed spatially and then, aggregated temporally. As of 2006, along the U.S. Highway 290 corridor, there are more than 1500 coded neighborhood and 1,753,899 developed parcels. 331 coded neighborhood were used after rounding to two decimal place.

4.4 Data Procedure

The HCAD real and personal property database is provided in ASCII tab-delimited text files and must be formatted for use in a database program. This study uses GIS to manipulate and map non-spatial historical records. The dataset has various property information pieces. Particularly, this study uses three specific real estate records: “neighborhood code,” “HCAD account number” and “date erected.”

“Neighborhood code” had been applied to define neighborhood subdivision boundaries. Which were developed based on the characteristics of location and similarity of property data. These neighborhood boundaries are maintained via ongoing office and field interviews to keep the homogeneity of the neighborhood. While HCAD does not provide a GIS subdivision polygon layer, “neighborhood” boundaries are created based on the “neigbhorhood code.” On the other hand, “HCAD account number” represents individual parcel developments throughout the entire study period. Aggregate parcels based on “neighborhood code,” represent the neighborhood boundary on the neighborhood level.

“Date erected” was selected to analyze when and where a building is built on a parcel. In this record, the number in the “date erected” field is defined as the year the building or improvement occurred. The selected attributes, e.g. erected date and neighborhood code in the HCAD database, are joined into parcel polygons using GIS. For the lot size, this study calculated polygon area using GIS.

This study examines only neighborhoods and parcels in the U.S. Highway 290 corridor. To select parcels using GIS, this study used a gravity approach. Major transportation corridors are a major driving force for residential developments. All parcels were assigned to their nearest major roads using ArcInfo Near tool. Each parcel has only one driving force in terms of transportation.

In addition, this study made maps for visual inspection of development patterns based on “date erected” and “neighborhood code,” Those maps provide graphic representations of spatial patterns of residential development.

Using the ArcInfo Near tool, this study annually generated three different distances to explore development patterns based on spatial distance and lapse time: (1) parcel to neighborhood: spatial distance from the location of each new developed parcel (new parcels) to the existing neighborhood (the existing neighborhoods), (2) neighborhood to neighborhood: spatial distance from the location of each new neighborhood (new neighborhoods) to the existing neighborhood (the existing neighborhoods), and (3) parcel to parcel: distance from the location of each new developed parcel (new parcels) to previously developed parcels (the existing parcels).

4.5 Analysis Procedure

Proposed research consists of five steps.

First, historic neighborhood and parcel development patterns will be mapped based on parcel data from HCAD database for each year from 1945 to 2006.

Second, new parcel development will be investigated with respect to existing development on the neighborhood level. Based on this parcel-to-parcel and neighborhood to neighborhood distance, this study will calculate lapse time between new development and its closest developments. Table 2 shows descriptive statistics of spatial and temporal distances for neighborhood and parcel levels. When developments are adjacent to each other, the minimum distance is equal to zero. On the neighborhood level, the average time-lag was 27.35 years and the median was 16 years. On the parcel level, the average lapse time was 4.09 years and the median lapse time was 1 year. From each level, an average lapse time was selected as an indicator instead of the median lapse time (Table 2).

Table 2. Spatial and Temporal Distances on Neighborhood and Parcel Levels

Level	Measurement	Minimum	Maximum	Mean	Median	Std. Dev.
Parcel (# 156,210)	Parcel-to-Parcel lapse time (year)	1.00	116.00	4.09	1.00	7.69
	Parcel-to-Parcel distance in space (ft)	0.00	20,576.07	303.17	172.93	391.07
Neighborhood (#331)	Neighborhood-to-Neighborhood lapse time (year)	1.00	127.00	27.35	16.00	29.11
	Neighborhood-to-Neighborhood distance in space (ft)	0.00	20576.07	1755.87	1368.30	1886.50

On the parcel level, the 1-year lapse time from the existing development to new development means residential parcels were developed one year after another continuously. Therefore, the median time-lag is not a useful indicator. On the neighborhood level, 26% of the study period (16 out of 62 years) has only one new neighborhood development or no new neighborhood (Figure 7). Therefore, a median value is not a proper statistic to explain changes between the existing neighborhoods and new neighborhoods for approximately a quarter of the study period. For this reason, the average distance in space and time from the existing and new were selected to classify patterns at both the neighborhood and parcel levels.

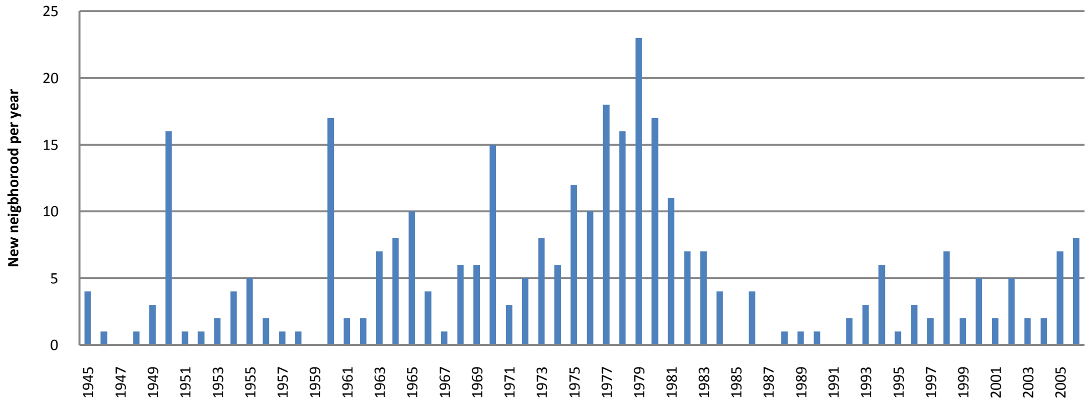

Figure 7. Neighborhood development in Harris County by Year (1945-2006)

Third, the patterns of each development will be classified as leapfrog, contagious and infill development on the neighborhood level based on the thresholds (average distance (d_N =1,758ft) and laps time (t_N = 27.38 years).

Descriptive statistics will be evaluated to correctly describe the three patterns of neighborhood: leapfrog, infill and contagion, and two patterns of parcel development will be identified: parcel infill and parcel contagion. This study analyzed the spatial relationship between the existing and new development on both levels. In this step, temporally aggregated patterns will describe annual changes in space and time. In this way, changes in space and time will be applied to explain development trends and investigate the long term land development process. The descriptive statistics included annual new development, annual average lapse time, the annual average distance both the neighborhood and parcel levels. These statistics will be used to compare development trends in each neighborhood patterns.

Fourth, regression models have been developed to examine how neighborhood development patterns affect land development processes, the dependent variable. The regression coefficient will be used to explore the relative contributions of land development patterns to the variation in the dependent variable, annual neighborhood development and annual parcel development (i.e., land development process in each pattern of neighborhood).

In addition to determining the contributions of each independent variable to the reduction of the variance of the dependent variables, the multicollinearity will be considered. Additionally, since this study is investigating long-term land development processes, the selected variable, for example age of neighborhood and year built, may be called autocorrelated if its value in a specific place and time is correlated with its value in other places and/or time (Huizingh, 2007). Correlation of a variable with itself through space leads to a statistical autocorrelation problem. This study analyzed HCAD records spatially and then aggregated values temporally, so spatial autocorrelation is not an issue. However, temporal correlation refers to the correlation between time-related variables. It reflects the fact that variables at a given time are not completely independent of prior variables, in other words, there is a high dependence. The Durbin-Watson statistics will be tested to test temporal dependency for all regression models. The value always lies between 0 and 4. If the Durbin–Watson statistic is substantially less than 2, there is evidence of positive serial correlation. As a rough rule of thumb, if

Durbin–Watson is less than 1.0, there may be cause for alarm. The Durbin-Watson statistics will be used all regression models to detect the presence of temporal autocorrelation in the residuals (Huizingh, 2007).

The multiple linear regression model for leapfrog neighborhood development is:

$$LND = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + e$$

where,

LND = Leapfrog neighborhood development in each year
β_0 = Constant
$\beta_1 \ldots \beta_7$ = Regression coefficients
X_1 = Year of new neighborhood(s) developed
X_2 = Number of parcels developed in new neighborhood(s) in given year
X_3 = Land developed in new neighborhood(s) in given year
X_4 = Average age of neighborhood(s) in years
X_5 = Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year
X_6 = Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year
X_7 = Projected land availability based on neighborhood development area in 2006
e = Error term

Based on the theory in this study and hypothesis 2, independent variable X_7, projected land availability based on neighborhood development, was used for the neighborhood contagion model.

The multiple linear regression model for contagion neighborhood development is:

$$CND = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_8 X_8 + e$$

where,

CND = Contagion neighborhood development in each pattern
β_0 = Constant
$\beta_1 \ldots \beta_8$ = Regression coefficients
X_1 = Year of new neighborhood(s) developed
X_2 = Number of parcels developed in new neighborhood(s) in given year
X_3 = Land developed in new neighborhood(s) in given year
X_4 = Average age of neighborhood(s) in years
X_5 = Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year
X_6 = Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year
X_8 = Number of leapfrog neighborhoods developed one year ago (year -1)
e = Error term

Similarly, based on the theory in this study and hypothesis 6, independent variable X_8, number of leapfrog neighborhoods developed one year ago (year -1) was used for the neighborhood contagion model.

The multiple linear regression model for infill neighborhood development is:

$$IND = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_9 X_9 + e$$

where,

IND = Infill neighborhood development in each year
β_0 = Constant
$\beta_1 \ldots \beta_9$ = Regression coefficients
X_1 = Year of new neighborhood(s) developed
X_2 = Number of parcels developed in new neighborhood(s) in given year
X_3 = Land developed in new neighborhood(s) in given year
X_4 = Average age of neighborhood(s) in years
X_5 = Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year
X_6 = Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year
X_9 = Number of contagion neighborhoods developed five year ago (year -5)
e = Error term

Besides, Based on the theory in this study and hypothesis 9, independent variable X_9 , number of contagion neighborhoods developed five-years ago (year -5), was used for the neighborhood infill model.

To describe patterns of changes, this study use HCAD records which was collected for each information for distinct time period. Neighborhood development and residential parcel development models have longitudinal data such as time or age. Year (time) is measured externally to the cases in HCAD records and age is measured internally (e.g 1 year, 20 year and 62 year) (Menard, 1991). However, in a regression analysis on parcel level, if model include year (e.g. 1945) and age (62 years) then the x matrix is singular, which means it cannot be invertible, which will result in unstable estimation of parameter. Therefore, parcel level analysis only use average age of neighborhood to describe temporal patterns of change.

In Chapter III, this study posited three discrete relationships between cumulative development and age of neighborhood. For example, development within contagion neighborhoods is linear, however, leapfrog and infill neighborhoods have a nonlinear function. To test the nonlinear effect of age of neighborhood in Hypotheses 3 and 10, (X_{12}) was transformed by using an exponential function (leapfrog neighborhood) and by using logs for infill neighborhoods. The three multiple linear regression model for residential parcel development are:

$$LRD = \beta_0 + \beta_{11} X_{11} + \beta_{12L} X_{12L} + \beta_{13L} X_{13L} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \beta_{17} X_{17} + e$$

where,

LRD = Residential development within leapfrog neighborhoods in each year
β_0 = Constant
$\beta_{11} .. \beta_{16}$ = Regression coefficients
X_{11} = Number of leapfrog neighborhood developed in year
X_{12L} = Average age of neighborhood
X_{13L} = Land developed within infill neighborhoods in year
X_{14} = Average size of parcels developed in year
X_{15} = Average distance from parcels developed to the main transportation corridor in year
X_{16} = Ln (average distance from the nearest existing development to new development) in year
X_{17} = Ln (average lapse time from the existing development to new development) in year
e = Error term

$$CRD = \beta_0 + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13c} X_{13c} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \beta_{17} X_{17} + e$$

where,

CRD = Residential development within contagion neighborhoods in each year
β_0 = Constant
β_{11}.. β_{17} = Regression coefficients
X_{11} = Number of contagion neighborhood developed in year
X_{12C} = Average age of neighborhood
X_{13C} = Land developed in leapfrog neighborhoods in year
X_{14} = Average size of parcels developed in year
X_{15} = Average distance from parcels developed to the main transportation corridor in year
X_{16} = Ln (average distance from the nearest existing development to new development) in year
X_{17} = Ln (average lapse time from the existing development to new development) in year
e = Error term

$$IRD = \beta_0 + \beta_{11} X_{11} + \beta_{12I} X_{12I} + \beta_{13I} X_{13I} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \beta_{17} X_{17} + e$$

where,

IRD = Residential development within infill neighborhoods in each year
β_0 = Constant
β_{11}.. β_{17} = Regression coefficients
X_{11} = Number of infill neighborhood developed in year
X_{12I} = Ln (Average age of neighborhood in year)
X_{13I} = Land developed within contagion neighborhoods in year
X_{14} = Average size of parcels developed in year
X_{15} = Average distance from parcels developed to the main transportation corridor in year
X_{16} = Ln (average distance from the nearest existing development to new development) in year
X_{17} = Ln (average lapse time from the existing development to new development) in year
e = Error term

As applied at the neighborhood level, this regression model also includes a variable to test trigger and follower effects at the parcel level. To link development processes with other patterns of neighborhood, total land developed in another pattern (X_3) was used for the three regression models on the parcel level. Total land developed within leapfrog neighborhoods (X_{3L}), total land development in contagion neighborhoods (X_{3C}), and total land development in infill neighborhoods (X_{3I}) were used for contagion neighborhood, infill neighborhood, and leapfrog neighborhood, respectively.

Measurements on the neighborhood level and measurements on the parcel level are introduced in Tables 3 and 4, respectively. At the neighborhood and parcel levels, four independent variables, average distance (X_5 and X_{16}) and average lapse time (X_6 and X_{17}) from existing neighborhoods to new neighborhood(s) by year, were transformed into ln(x) functional forms. Because strictly positive variables could have skewed the distribution, the log was adopted in this study to migrate it.

Fifth, how age of neighborhood development affected new residential development within each pattern of neighborhood was examined. Regression analysis reveals that each pattern of neighborhood development has discrete processes which will be explained based on coefficient terms. Independent variables, (X_{12L}), (X_{12C}), and (X_{12I}) were used for leapfrog, contagion and infill neighborhood, respectively. Cumulative percentage of residential parcels developed in each neighborhood by year was also used to explain the discrete development process among neighborhoods.

Table 3. Measurements on Neighborhood Level

Variables		**Measurements on neighborhood level (Unit of Analysis : Neighborhood)**	**Leapfrog Neighborhood**	**Contagion Neighborhood**	**Infill Neighborhood**
Dependent variable	Y_N	The number of neighborhoods developed in year	X	X	X
Independent variables	X_1	Year of new neighborhood(s) developed	X	X	X
	X_2	Number of parcels developed in new neighborhood(s) in given year	X	X	X
	X_3	Land developed in new neighborhood(s) in given year	X	X	X
	X_4	Average age of neighborhood(s) in years	X	X	X
	X_5	Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year	X	X	X
	X_6	Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year	X	X	X
	X_7	Land availability based on developed neighborhoods area in 2006	X		
	X_8	Number of leapfrog neighborhoods developed one year ago (year -1)		X	
	X_9	Number of contagion neighborhoods developed five year ago (year -5)			X

Table 4. Measurements on Residential Parcel Level

Variables		**Measurements on parcel level (Unit of Analysis : Year)**	**Leapfrog Neighborhood**	**Contagion Neighborhood**	**Infill Neighborhood**
Dependent variable	Y_P	The number of parcels developed in existing neighborhoods in year	X	X	X
Independent variables	X_{11}	Number of neighborhoods developed in year	X	X	X
	X_{12L}	Exp(average age of neighborhood) in year	X		
	X_{12C}	Average age of neighborhood in year		X	
	X_{12I}	Ln(average age of neighborhood) in year			X
	X_{13L}	Land developed within contagion neighborhoods in year	X		
	X_{13C}	Land developed within infill neighborhood in year		X	
	X_{13I}	Land developed within leapfrog neighborhood in year			X
	X_{14}	Average size of parcels developed in year	X	X	X
	X_{15}	Average distance from parcels developed to the main transportation corridor in year	X	X	X
	X_{16}	Ln(average distance from the nearest existing development to new development) in year	X	X	X
	X_{17}	Ln average of lapse time from the existing development to new development) in year	X	X	X

CHAPTER V

NEIGHBORHOOD DEVELOPMENT

5.1 Introduction

This chapter presents analyzed results describing the characteristics of neighborhood development patterns in northwest Harris County along the U.S. Highway 290 transportation corridor. When a residential parcel is developed, it can be developed in one of the existing neighborhoods or can be the first development in a new neighborhood. From 1945 to 2006, 331 new neighborhoods were developed and were classified as either leapfrog neighborhood, contagion neighborhood or infill neighborhood based on the LTDM model introduced in this study. Characterizing patterns involves measuring and quantifying neighborhood development patterns. In this chapter, the spatial and temporal patterns of new neighborhood development were examined and described in detail.

This chapter departs from descriptive statistics for the selected variables introduced in Chapter IV. The first section presents the descriptive statistics of neighborhoods development variables (i.e., the number of leapfrog, contagion or infill neighborhood in each year) as well as spatial and temporal changes over time. The second section presents the specification of multiple regression models that tests the hypothesis that changes in spatial and temporal patterns affect annual neighborhood development.

5.2 General Neighborhood Development

This study uses new neighborhood development by year as a measure of development process on the neighborhood level. The dependent variable, the number of new neighborhood(s) in each pattern, was classified based spatial distance and temporal lapse time from the existing neighborhood development to new neighborhood development. Table 5 presents descriptive statistics of neighborhoods developed across the patterns as introduced in the previous chapters. From 1945 to 2006, a total of 331 neighborhoods were developed and classified as 124 leapfrog neighborhoods, 139 contagion neighborhoods and 68 infill neighborhoods.

In terms of parcels developed, contagion neighborhood (2,268) have more parcels developed in its first year than infill neighborhood (1,122) and leapfrog neighborhood (1,299). On average, leapfrog neighborhood started with fewer parcels developed (10.5) than contagion (16.3) and infill (16.5) neighborhoods. It means that the development pressure in leapfrog neighborhoods were not much higher than the other two patterns of neighborhoods in the beginning stage, therefore, fewer parcels were involved in creating a leapfrog neighborhood development.

When leapfrog neighborhood, contagion neighborhood and infill neighborhood were compared, the leapfrog neighborhood had an average spatial distance of 3,353.6 feet from the closest existing neighborhood to new neighborhood while 818.8 feet and 758.0 feet are evidenced by contagion and infill neighborhood. In terms of lapse time, when the infill neighborhoods and contagion neighborhoods, and leapfrog neighborhoods were compared, the infill neighborhood had an average lapse time of

58.8 years from the existing neighborhood to new neighborhood while 8.3 years and 31.4 years are evidenced in the contagion and leapfrog neighborhood. This finding confirms that a leapfrog neighborhood development with greater distance, also has greater lapse time than total average lapse time (27.6 years). The average of lapse time (58.8 years) for infill development is 6 times greater than contagion neighborhood (8.3 years). On average, neighborhood contagion has a 8.3 year lapse time. This means that one neighborhood follows another neighborhood after about 10 years even though they are contiguous patterns.

The average of year built for the total neighborhood was 1975, but infill neighborhood (1980) was developed relatively recently. Sum of land developed for neighborhood development was similar across the patterns.

Table 5. Descriptive Statistics for Neighborhood Developments

Descriptive Statistics	**Infill**	**Contagion**	**Leapfrog**	**Total**
New neighborhood	68	139	124	331
Sum of land developed	1,122	2,268	1,299	4,689
Average of parcels developed in new neighborhood	16.5	16.3	10.5	14. 2
Average distance (ft)	758.0	818.8	3353.6	1755.9
Average lapse time (year)	58.8	8.3	31.4	27.4
Average year of neighborhood developed	1980	1975	1973	1975
Sum of land developed (sqft)	12,524,661.8	18,723,365.1	13,448,152.8	44,696,179.7

331 neighborhoods developed between 1945 and 2006

Neighborhood-to-Neighborhood distance: the distance from the closest existing neighborhood to new neighborhood development

Neighborhood-to-Neighborhood lapse time: the year the new neighborhood was developed minus the year the closest existing neighborhood was developed

5.2.1 Leapfrog Development Trend

Table 6 reports the summary statistics of variables for leapfrog neighborhoods. During the 62 year study period, leapfrog development was developed for only 38 years. The number of new neighborhoods developed per year varied. An average of 3.3 neighborhoods were developed among the 38 cases. (X_1) represents the calendar year when new neighborhoods were developed. The average year leapfrog neighborhoods were developed was 1972. Parcels developed in new leapfrog neighborhood(s) varied from 1 to 285. On average, 34.2 parcels were developed at one time in one neighborhood.

Table 6. Descriptive Statistics of Leapfrog Neighborhood Developments

Variables	**Pattern**	**N**	**Minimum**	**Maximum**	**Average**	**Std. Deviation**
Dependent variable	Neighborhood Leapfrog	38	1	8	3.23	2.3
Independent variable	X_1	38	1945	2006	1972.18	15.69
	X_2	38	1.0	285.0	34.2	67.7
	X_3	38	7,405.7	2,676,975.6	353,898.8	575,837.8
	X_4	38	1.0	62.0	34.8	15.7
	X_5	38	1,806.4	12,402.9	3,621.2	1,808.3
	X_6	38	2.00	125.0	33.9	22.1
	X_7	38	0.00	2,937,544,942.0	1,889,374,620.2	728,933,289.6

X_1 : Year of new neighborhood(s) built
X_2 : The number of parcels developed in new neighborhood(s)
X_3 : Sum of land developed in new neighborhood(s)
X_4 : Average age of neighborhood(s)
X_5 : Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year*
X_6 : Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year*
X_7 : Land availability (sqft) projected based on developed neighborhoods area in 2006
*Descriptive statistics of original variable

The average age of the neighborhood(s) (X4) is the number of years after the neighborhood was first developed. In Table 6, if the minimum age of neighborhood is 1, this means the neighborhood was developed in 2006. Because the study period ranges from 1945 to 2006, a neighborhood developed in 1945 is 62 years old now and a neighborhood developed in 2006 is 1 year old now. The average age of leapfrog neighborhoods is 34.8. (X_5) and (X_6) are the log transformed variables: spatial distance from the closest existing neighborhood to new neighborhood and temporal lapse time.

Before transformation, spatial distance was distributed from 1806.4 ft to 12,402.9 ft, and temporal lapse time was distributed from 2 years to 125 years. On average, (X_5) was 3621.2 ft from the prior neighborhood which was twice the distance from the average of all neighborhood patterns. In terms of temporal distance, leapfrog neighborhoods had an average 33.9 lapse time. Land availability was calculated based on the total land developed in 2006. On average, 1,889,374,620.2 sqft were available in the year when the new neighborhood was developed.

5.2.2 Contagion Development Trend

Table 7 reports the summary statistics of variables for contagion neighborhoods. During the 62 year study period, leapfrog development occurred only during 49 years. The number of new neighborhoods developed in a year can be varied; however, an average of 2.8 neighborhoods were developed among 49 cases. Compared to the other neighborhood patterns, contagion neighborhood developed more often than other neighborhood development patterns. The average contagion neighborhood was developed in 1976. The parcels developed in the new contagion neighborhood(s) varied from 1 to 317. However, an average of 46.3 parcels was developed at one time in one neighborhood.

Table 7. Descriptive Statistics of Contagion Neighborhood Developments

Variables	Pattern	N	Minimum	Maximum	Average	Std. Deviation
Dependent variable	Neighborhood Contagion	49	1	15	2.8	2.8
Independent variable	X_1	49	1945	2006	1975.65	17.81
	X_2	49	1.0	317.0	46.3	67.3
	X_3	49	7023.8	2226135.1	382109.5	481577.7
	X_4	49	1.0	62.0	31.4	17.8
	X_5	49	41.2	1,603.6	821.3	372.8
	X_6	49	1.0	24.5	10.0	6.7
	X_8	48	0.0	8.0	2.34	2.5

X_1 : Year of new neighborhood(s) built
X_2 : The number of parcels developed in new neighborhood(s)
X_3 : Sum of land developed in new neighborhood(s)
X_4 : Average age of neighborhood(s)
X_5 : Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year*
X_6 : Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year*
X_8 : Number of leapfrog neighborhoods developed one year ago (year -1)
*Descriptive statistics of original variable

(X_4) means years in neighborhood after a neighborhood was developed. As explained in the previous section, minimum age of neighborhood 1 means the new neighborhood was developed in 2006. The average age of contagion neighborhoods is 31.35.

(X_5) and (X_6) are log transformed variables: spatial distance from the closest existing neighborhood to new neighborhood and temporal lapse time. Before transformation, spatial distance was distributed from 41.2 ft to 1603.6 ft, and temporal lapse time was distributed from 1 year to 24 years. On average, (X_5) were 821.3 ft from the prior neighborhoods. An average distance of leapfrog neighborhoods at 3,600.0 ft has a four time greater average than contagion neighborhoods at 821.3 ft. In addition, the distance of contagion neighborhood was only half the average of all neighborhood patterns (Table 5). In terms of temporal distance, leapfrog neighborhoods had an average 10.0 years time lapse. Contagion neighborhoods have shown a relatively shorter lapse time than the other two patterns.

5.2.3 Infill Development Trend

Table 8 reports the summary statistics of variables for infill neighborhoods. During the 62 year study period, leapfrog development occurred for only 36 years. The number of new neighborhoods developed in year can vary; however, an average of 1.9 neighborhoods were developed among the 36 cases.

Table 8. Descriptive Statistics of Infill Neighborhood Developments

Variables	Pattern	N	Minimum	Maximum	Average	Std. Deviation
Dependent variable	Neighborhood Infill	36	1	6	1.9	1.3
Independent variable	X_1	36	1945	2006	1979.3	17.1
	X_2	36	1.0	166.0	31.8	44.7
	X_3	36	6671.4	1,849,349.2	347,907.3	523,685.3
	X_4	36	1.0	62.0	27.8	17.1
	X_5	33	0	1,603.4	708.9	428.2
	X_6	36	31	352	111.1	84.5
	X_9	35	0.0	15.0	2.6	2.9

X_1: Year of new neighborhood(s) built
X_2: The number of parcels developed in new neighborhood(s)
X_3: Sum of land developed in new neighborhood(s)
X_4: Average age of neighborhood(s)
X_5: Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year*
X_6: Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year*
X_9: Number of contagion neighborhoods developed five year ago (year -5)
*Descriptive statistics of original variable

Compared to the other patterns of neighborhoods, infill neighborhood usually did not develop often. On average, infill neighborhoods in this study area were developed in 1979. Parcels developed in the new infill neighborhood(s) varied from 1 to 166. However, an average of 31.2 parcels were developed at one time in one neighborhood.

Similar to the previous section, (X_5) and (X_6) are log transformed variables: spatial distance from the closest existing neighborhood to new neighborhood and temporal lapse time. Before transformation, spatial distance was distributed from 0 ft to 1,603.4 ft, and temporal lapse time was distributed from 31 years to 206 years. On average, (X_5) was 708.9 ft from the prior neighborhood.

Compared to other patterns of neighborhood development, infill neighborhoods had only half the average distance of leapfrog and contagion neighborhoods. In addition, it was also approximately half the average distance of all the other neighborhood patterns (Table 5). In terms of temporal distance, infill neighborhoods had an average 81. 3 time lapse. Since Harris County was founded in 1870, some neighborhoods were developed before 1900. In this case, the temporal time lag from the existing neighborhoods has a very long lapse time. In Table 8, (X_9) represents the number of contagion neighborhoods developed five-years ago (year -5).

5.3 Neighborhood Development Processes

The empirical observations of spatial and temporal patterns established the foundation to explore the relative contributions of residential development variables to the variation in the dependent variable, new neighborhood development (i.e., the number of leapfrog neighborhoods, contagion neighborhoods and infill neighborhoods in each year). In this study, three multiple regression models were developed to test the hypothesis that spatial and temporal relationships from the closes existing neighborhood to new neighborhood affects annual neighborhood development.

Regression models on the neighborhood level incorporated seven variables including year built, parcels developed, land developed, average age of neighborhood, average distance from the closes existing to new neighborhood, average lapse time from the closes existing to new neighborhood. To test these hypotheses as introduced in Chapter III, three unique variables for each pattern, land availability (leapfrog neighborhood), Number of leapfrog neighborhoods developed one year ago (year -1) (contagion neighborhood), Number of contagion neighborhoods developed five-years ago (year -5) (infill neighborhood), were included in each model.

5.3.1 Neighborhood Leapfrog Development

In Chapter III, this study posited that leapfrog neighborhood development triggers land development and this pattern of neighborhoods is associated with the geometry of the neighborhood level. Table 9 presents the result of regression analysis; however, the model was not significant in itself ($Sig.\ 0.274,\ R^2 = 0.05,\ F = 1.329,\ P < 0.05$). In other words, selected measurements in this study such as distance in space and time, years in neighborhood, land availability etc, fail to predict the leapfrog neighborhood development by year. In addition, the Durbin-Watson statistic in the leapfrog neighborhood model is 1.554. A value close to 2 indicates that there is no autocorrelation (Huizingh, 2007).

Table 9. Neighborhood Leapfrog Model

	Full Model		
	B	**Beta**	**Sig.**
(Constant)	6.269		0.517
X_2	0.000	0.008	0.989
X_3	0.000	0.443	0.474
X_4	-0.440	-3.067	0.069
X_5	-0.802	-0.133	0.497
X_6	-0.208	-0.068	0.692
X_7	0.000	3.237	0.056
N	37		
R^2	0.205		
Adjusted R^2	0.051		
F	1.329		
Sig.	0.274		
df =	6, 31		
Durbin-Watson Stat.	1.554		

$p < .05$
X_1 : Year of new neighborhood(s) built
X_2 : The number of parcels developed in new neighborhood(s)
X_3 : Sum of land developed in new neighborhood(s)
X_4 : Average age of neighborhood(s)
X_5 : Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year
X_6 : Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year
X_7 : Land availability (sqft) projected based on developed neighborhoods area in 2006

Though this was not an expected result from testing Hypotheses 1, 2 and 3 in this study, the results were interpretable in an urban context. New leapfrog neighborhood leapfrog development may be a trigger, but the predictor for the leapfrogging can be non-spatial variables (Hypothesis 1) such as socioeconomic conditions of the calendar year or lagged year. The study area was selected along the US Highway 290 corridor based on a gravity approach. The trigger effect can be applied to some locations outside the study area (Hypothesis 2). Urban growth is used to explain an outward expansion but the direction of the trigger remains unknown.

Variable (X_7), annual land availability, was projected based on total land consumption in 2006 according to HCAD real estate and property records. As of today, percentage of nonresidential land use can be calculated; however, if residential parcels have been transected from other type of land use, i.e., rural, land availability cannot capture the selected measurement (X_7) in this study (Hypothesis 2). The age effect on residential developments for example Hypothesis 3 only be tested on the parcel level, and will be explained later in Chapter VI.

5.3.2 Neighborhood Contagion Development

Two hypotheses were made for contagion neighborhood on the neighborhood level. The first full model incorporated all the variables as introduced in the method chapter (Table 10). It accounted for 60.5 percent of the variation in this variable ($R^2 = 0.60, F = 13.08, P < 0.05$). The Durbin-Watson statistics in the contagion neighborhood model is 2.266. In general, if the statistic approaches a value of 2, there may be no cause for alarm. It means prior contagion neighborhood is not correlated to future contagion neighborhood development.

The spatial distance (X_5) and temporal lapse time (X_6) were expected predictors of contagion neighborhood development, but they were not significant (Hypothesis 5). However, it can be interpreted that spatial distance and temporal lapse time from existing neighborhood to new neighborhood is not an important factor for contagion neighborhood.

Table 10. Neighborhood Contagion Models

	Full Model			Reduced Model		
	B	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**
(Constant)	22.015		0.482	0.721		0.050
X_1	-0.012	-0.072	0.467			
X_2	0.009	0.227	0.355			
X_3	0.000	0.460	0.051	0.000	0.653	0.000
X_5	0.271	0.067	0.479			
X_6	-0.073	-0.022	0.822			
X_8	0.250	0.227	0.040	0.293	0.266	0.009
N	48			48		
R^2	0.656			0.640		
Adjusted R^2	0.605			0.624		
F	13.018			40.078		
Sig.	0.000			0.000		
df =	6, 41			2, 45		
Durbin Watson Stat.	2.266			2.189		

$p < 0.05$
X_1 : Year of new neighborhood(s) built
X_2 : The number of parcels developed in new neighborhood(s)
X_3 : Sum of land developed in new neighborhood(s)
X_4 : Average age of neighborhood(s)
X_5 : Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year
X_6 : Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year
X_8 : Number of leapfrog neighborhoods developed one year ago (year -1)

Among these variables, one variable X_8, number of leapfrog neighborhoods developed one year ago (year -1), was significantly correlated with contagion neighborhood development. This is an expected result which supports Hypothesis 6 that lagged year of leapfrog neighborhood is a predictor of contagion neighborhood. This finding is highly relevant to urban planners and policy makers who consider the environmental and socioeconomic aspects of rapid growth. When a new neighborhood is developed, social and public infrastructure needs to be provided to support the new urban area. The effect of new neighborhood development unconsciously leads to neighborhood developments promoting consumption of more natural and social resources.

In order to identify a subset of independent variables that are good predictors of the dependent variable, a stepwise selection method was used in the multiple regression analysis. This procedure has many iterations of computation before a set of independent variables are entered into or removed from the regression model. During this process, multicollinearity issues are considered and minimized in the stepwise procedure.

In the reduced model, the sum of land developed in new neighborhood(s) (X_3) was entered first followed by 1 year time-lagged annual leapfrog neighborhood development (X_8). Together the two variables, the reduced model accounted for 62 percent of the variance in this variable ($R^2 = 0.62, F = 40.08, P < 0.05$). The Durbin-Watson statistics is 2.189 in the reduced contagion neighborhood model. In the reduced model, prior contagion neighborhood is not correlated to future contagion neighborhood development.

This reduced model indicates that sum of land developed and 1 year time lag are significantly correlated with contagion neighborhood development. In terms of land development, contagion neighborhood was significantly more likely to consume more land, which was an expected result (Hypothesis 4) with a strong significance at the .05 level. In other words, contagion neighborhood development occupied a huge amount of land area, therefore, this result supports the hypothesis that contagion neighborhood is the primary pattern of neighborhood development leading to land development. Descriptive statistics in Table 5 also support Hypothesis 4. Among 331 neighborhoods, 42 % (139) were contagion neighborhood while 37% (124) were leapfrog and 21% of neighborhoods (68) were infill neighborhoods.

This reduced model explains about 62 percent of the variation in the annual contagion neighborhood development. It has an F ratio of 40.08 with an observed significance level of less than 0.00. Though two independent variables were found to be significant at less than the 0.000 level, the sum of land developed (X_3) has more explanatory power with a beta weight of 0.653 when compared to 0.266 of number of leapfrog neighborhoods developed one year ago (year -1).

5.3.3 Neighborhood Infill Development

Two hypotheses were made for neighborhood infill on neighborhood level. The full model incorporated six variables (Table 11). It accounted 77.2 percent of the variation in this variable ($R^2 = 0.77, F = 14.42, P < 0.05$). The Durbin-Watson statistic in the infill neighborhood model is 1.537. The value of Durbin-Watson always lies between 0 and 4. A Durbin-Watson statistic much smaller than 2 indicates a positive autocorrelation, however, since the value is greater than 1, this statistic can be used for model specification (Huizingh, 2007).

Among the variables, average age of neighborhood(s) (X_4) and Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year (X_6) were significantly correlated with infill neighborhood development.

The age of the neighborhood (X_4) is positively related to the annual infill neighborhood i development. In other words, when the neighborhoods in the study area age, the possibility for developing an infill neighborhood became higher. (X_6) was more powerful predictor of contagion neighborhood development based on standardized beta value (0.946) than (X_4). This was an expected result which supports Hypothesis 9 that the temporal lapse time from the closest existing neighborhood development is important to new infill neighborhood development.

Table 11. Neighborhood Infill Models

	Full Model			**Reduced Model**		
	B	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**
(Constant)	-8.850		0.000	30.607		0.074
X_1				-0.018	-0.222	0.039
X_2	-0.002	-0.063	0.640			
X_3	0.000	0.060	0.688			
X_4	0.019	0.231	0.045			
X^5	0.315	0.139	0.176			
X_6	1.796	0.946	0.000	1.723	0.908	0.000
X_9	0.083	0.123	0.241			
N	32			32		
R^2	0.776			0.732		
Adjusted R^2	0.772			0.713		
F	14.421			39.527		
Sig.	0.000			0.000		
df =	6, 25			2, 29		
Durbin-Watson Stat.	1.537			1.503		

$p < .05$
X_1 : Year of new neighborhood(s) built
X_2 : The number of parcels developed in new neighborhood(s)
X_3 : Sum of land developed in new neighborhood(s)
X_4 : Average age of neighborhood(s)
X_5 : Ln (average distance from the nearest existing neighborhoods to new neighborhood(s)) in year
X_6 : Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year
X_9 : Number of contagion neighborhoods developed five year ago (year -5)

To test the effect of the contagion neighborhood pattern on infill neighborhood developments, number of contagion neighborhoods developed five-years ago (year -5) (X_9). However, (X_9) has no significant statistical bearing on the annual neighborhood infill. This result contradicts Hypothesis 8 which predicted that infill neighborhood development is followed by contagion neighborhood. This result suggests that number of contagion neighborhoods developed five year ago (year -5) is not a predictor for new infill neighborhood. However, considering an average of 27.4 lapse time of total neighborhood development during the study period (Table 5 in page 53), the 5 year lapse time is relatively short. This result suggests that to better understand the driving forces of neighborhood infill, a more detailed examination needs to be conducted on the neighborhood level.

The reduced model incorporated two variables- year built of new neighborhood(s) (X_1) and Ln (average lapse time from the nearest existing neighborhoods to new neighborhood(s)) in year (X_6). It accounted for 71.3 percent of the variation in this variable (R2 = 0.71, $F = 39.52$, $P < 0.05$). The Durbin-Watson statistic in the reduced infill neighborhood model is 1.503. This can be a sign of positive autocorrelation; however, this value still meets the assumption of independent residuals in regression analysis.

The year built of new neighborhood was excluded (X_1) in the full model, however, it was found that year built of new neighborhood is a predictor of infill neighborhood during the stepwise procedure in the reduced model. In terms of variable (X_6), as expected in Hypothesis 8, the regression result reported a positive association with the time dimension. However, (X_9) was still insignificant and excluded from the reduced model.

5.4 Conclusion

This chapter has presented the regression analysis results identifying the variables and their impacts on the variance in neighborhood development based on the study hypotheses. The regression coefficients reveal the explanatory powers and relationships in each pattern of neighborhood.

The leapfrog neighborhood model was statistically insignificant. Though analysis of the leapfrog model did not statistically support the hypotheses, the results can be implemented in urban planning. For example, the measurements for trigger effect of leapfrog development can be socioeconomic instead of spatial variables. Contagion neighborhood development was followed by leapfrog neighborhood. The amount of land developed was also significant only for neighborhood contagion developments. Infill neighborhood development results showed that this pattern of neighborhood is only a matter of time dimension. For example, the age of neighborhoods and temporal lapse time from the existing neighborhood were matters only for infill neighborhood development. This affirms that spatial and temporal measurements can capture the different aspects of neighborhood development patterns.

Multiple regression analysis further explored the relative contribution of variables in the neighborhood development patterns. Although only contagion neighborhood and infill neighborhood regression models were statistically significant, 60.5 percent and 71.3 percent of the variation in neighborhood development are explained by the selected measurements characterizing neighborhood development patterns.

Temporal autocorrelation was considered in neighborhood development models. One assumption in regression analysis is that the error terms are independent. However, when a social and demographic dataset is applied in a regression model, temporal autocorrelation is a very common phenomenon. To test the correlation between successive residuals, the Durbin-Watson statistic test was used on neighborhood models.

CHAPTER VI

RESIDENTIAL DEVELOPMENT

6.1 Introduction

This chapter presents the analyzed results describing the characteristics of residential development patterns within the existing neighborhoods in northwest Harris County along the U.S. Highway 290 transportation corridor. In the previous chapter, new neighborhood developments were examined and explained in detail. This chapter focuses on development trends only within existing neighborhoods. The spatial and temporal patterns of residential parcel development in the existing neighborhoods will explain residential development trends and also predict residential growth within the neighborhoods.

This chapter departs from descriptive statistics for selected variables introduced in Chapter IV. The first section presents empirical observations of residential developments within the four types of existing neighborhoods: leapfrog, contagion, infill and old neighborhood. This section describes summary statistics of variables for residential developments within each pattern of neighborhood (i.e., the number of parcels developed in each year, average size of parcels developed in each year etc.) as well as their spatial and temporal patterns (i.e., distance to U.S. 290 transportation corridor, spatial distance from the closest existing residential developments to new development, temporal lapse time from the closest existing residential developments to new development). The second section presents the specification of multiple regression models that identify the patterns and their impact on the variance in residential developments in each pattern of existing neighborhood.

6.2 General Residential Development

This study uses annual residential development in each pattern of neighborhood developments by year as a measure of development process on parcel level. The dependent variable, the number of parcels developed in each pattern of neighborhoods, was aggregated based on the parcel year built. Table 9 presents descriptive statistics of residential parcels developed across the patterns as introduced in the previous chapters.

While 4,689 parcels created 331 new neighborhoods between 1945 and 2006, 156,210 parcels were developed in the existing neighborhoods. The LTDM model in this study annually classified all parcels developed based on their neighborhood patterns during this study period. In addition to the three patterns of neighborhood development described in Chapter IV, 26,860 parcels were developed in the old neighborhoods which were developed before this study period. In this case, those neighborhoods are indicated as “old neighborhoods.”

Among 156,210 parcels, 129,350 parcels were developed in 331 neighborhoods which were developed from 1945 to 2006 and 26,860 parcels were developed in the 77 old neighborhoods existing before this study period. 156,210 parcels developed in the existing neighborhoods per year are illustrated in Figure 8.

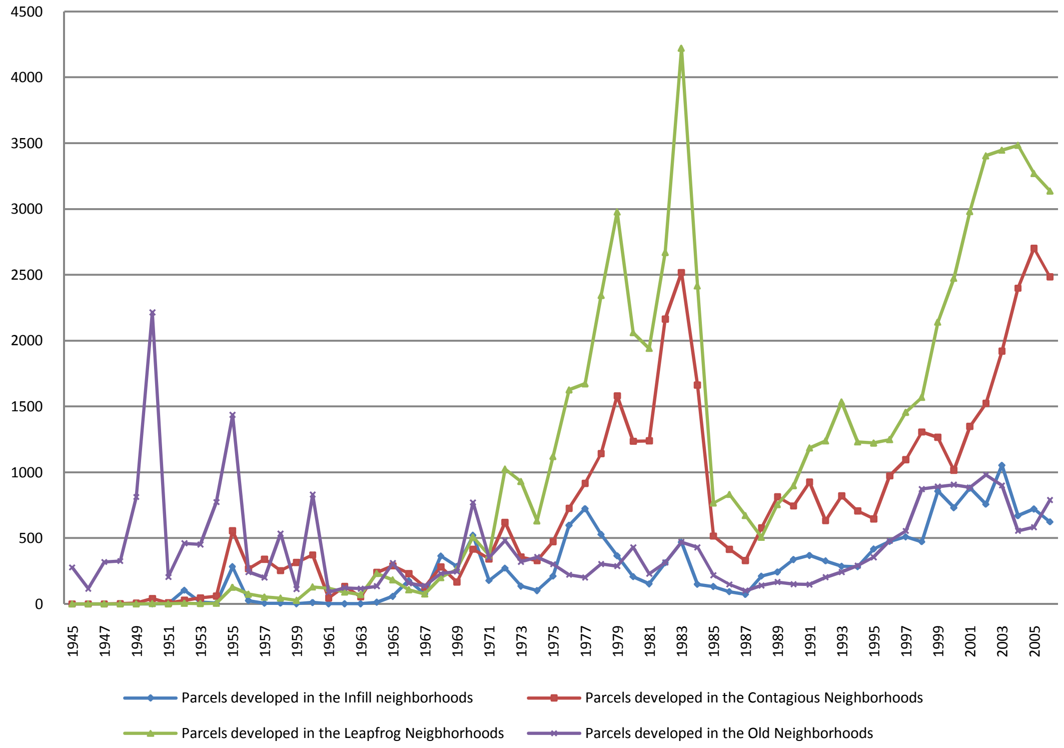

Figure 8. Parcels Developed in the Existing Neighborhoods from 1945 to 2006

Table 12 presents new parcels developed in the existing neighborhoods from 1945 to 2006. In terms of residential development, 44.08% of residential parcels (70,925) were developed within leapfrog neighborhoods; 28.00% of residential parcels (45,047) were developed within contagion neighborhoods; 11.23% of residential parcels (18,067) were developed within infill neighborhoods. 16.69% of residential parcels were developed within old neighborhoods. While neighborhood contagion (139, 41.99%) had more neighborhoods developed than leapfrog neighborhood (124, 37.46%), more parcels were developed within leapfrog neighborhoods. It means that the development pressure within leapfrog neighborhood is higher than other neighborhood patterns.

Table 12. Descriptive Statistics for Residential Developments

Measurements	Infill	Contagion	Leapfrog	Old	Total
The number of parcels developed	18,067	45,047	70,925	26,860	160,899
Sum of land developed (sqft)	475,107,480.8	542,668,933.5	810,669,190.8	1,776,047,136.7	3,604,492,741.7
Average year of parcels developed	1,989.1	1,988.6	1,989.9	1,976.5	1,987.2
Average size of parcels developed in each year (sqft)	26,297.0	12,046.7	11,430.0	66,122.4	22,402.2
Average distance from parcels developed to US 290 highway (ft)	16,278.1	15,594.6	15,647.1	15,678.7	15,708.5
Average distance from the existing parcels developed to new development (ft)	303.4	280.7	372.4	309.9	328.5
Average of lapse time from the existing parcels developed to new development (year)	4.6	3.6	3.5	7.5	4.3

160,899 residential parcels developed between 1945 and 2006

Parcel-to-Parcel distance: the distance from the closest existing development to new development

Parcel-to-Parcel lapse time: the year the new development was developed minus the year the closest existing development was developed

When the residential developments within each pattern of neighborhood are compared, residential development within leapfrog neighborhoods has an average spatial distance of 372.4 feet from the existing neighborhood to the new neighborhood while 280.7feet and 303.4 feet are evidenced by neighborhood contagion and infill.

In terms of lapse time, residential development within neighborhood infill has an average lapse time of 4.6 year from the existing development to new development while 3.6 years and 3.47 years are evidenced within contagion and leapfrog neighborhoods, respectively. The average of the total parcels developed during the study period was 4.3 years. On the neighborhood level, neighborhood infill has the greatest lapse time among neighborhoods; similarly, the same temporal development trend was found on the parcel level. This finding confirms that residential development within an infill neighborhood has greater time lag. However, unlike the neighborhood level, the average lapse time doesn’t show large differences among the three neighborhood patterns.

Though this study investigates residential developments during 1945 to 2006, the average year built for the whole parcel was 1987. Parcels developed in old neighborhoods were relatively older than other neighborhoods.

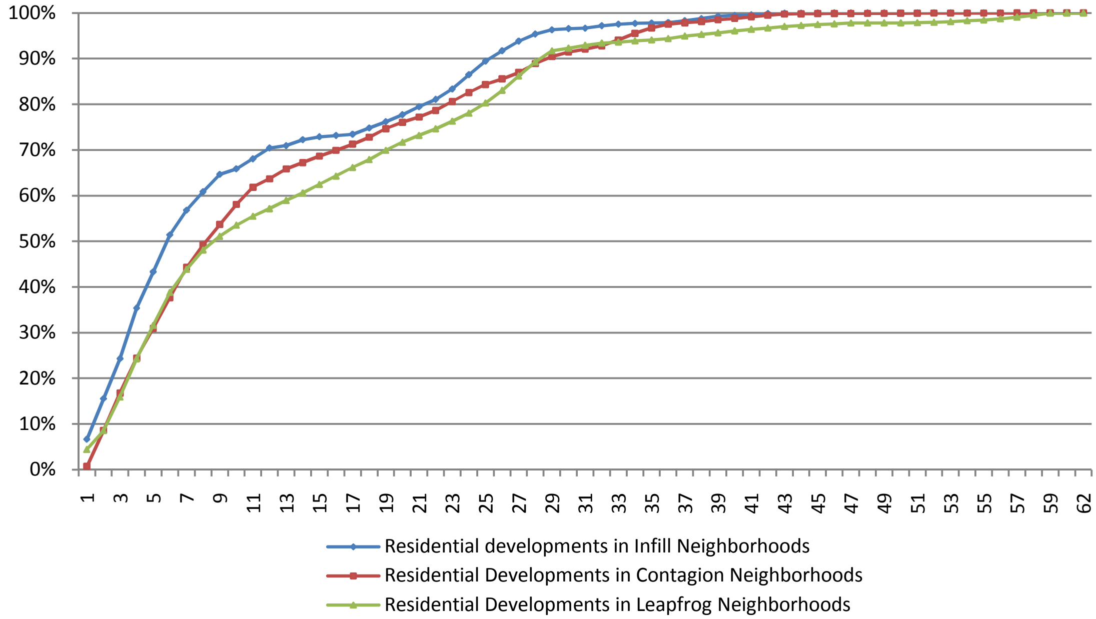

Figure 9. Age of Neighborhood and Cumulative Residential Developments within Each Neighborhood

Figure 9 illustrates residential development rate in response to the age of neighborhoods. The theory in this study posits that each pattern of neighborhood has discrete development processes. Residential development and development process are related to neighborhood patterns. For example, when 60 % neighborhoods were developed (projected based on 2006 development), it takes 8 years within infill neighborhoods. However, the same percentage of residential development takes 10 years for contagion and 15 years for infill neighborhoods.

6.2.1 Residential Development Trend in Leapfrog Neighborhoods

Table 13 reports the summary statistics of variables for residential development in leapfrog neighborhoods. An average of 1,114.0 residential parcels were developed during the 62 year study period. At least one parcel was developed in a leapfrog neighborhood each year with a maximum number of 4,224 parcels developed in a year. In leapfrog neighborhood, (X_{11}) was number of neighborhoods developed in year. During the 62 years study period, 124 leapfrog neighborhoods were developed for 38 years. Among the 38 years, an average 2 neighborhoods were developed each year. (X_{12}) was an average age of neighborhood in year. The average age of neighborhood in year varied from 1 to 31. In leapfrog neighborhoods, residential parcels were developed when the age of neighborhood was an average 10.6 years. However, transformed variable (X_{12L}) was applied in the regression model.

Table 13. Descriptive Statistics of Residential Development in Leapfrog Neighborhood

Variables	Pattern	N	Minimum	Maximum	Average	Std. Deviation
Dependent Variable	Parcels developed in Leapfrog	62	1	4224	1114.0	1,176.6
Independent Variables	X_{11}	62	0	8.0	2.0	2.4
	X_{12L}	62	1	31	10.6	6.5
	X_{13L}	62	7,316.1	116,651,742.2	7,649,745.3	17,590,560.7
	X_{14}	62	7,880.0	739,347.5	50,579.3	138,639.7
	X_{15}	62	3,750.7	40,044.1	13,631.1	5,905.0
	X_{16}	62	164.6	12,402.9	1,179.3	2,787.1
	X_{17}	62	1.2	17.5	4.4	3.8

X_{11} : Number of leapfrog neighborhoods developed in year
X_{12L}: Exp(Average age of leapfrog neighborhood) in year*
X_{13L}: Land developed within infill neighborhood in year
X_{14} : Average size of parcels developed in year
X_{15} : Average distance from parcels developed to main transportation corridor in year
X_{16} : Ln(average distance from the nearest existing development to new development) in year*
X_{17} : Ln(average of lapse time from the existing development to new development) in year*
*Descriptive statistics of original variables

(X_{13L}) was land developed in infill neighborhoods in a year. An average of 7,649,745.3 sqft of land was developed during the 62 years. However, the minimum average size of parcels developed in a year was 7,880.0 sqft and the maximum average size of parcels developed in a year was 739,347.5 sqft. However, the average size of parcels developed in a year was 50,579.3 sqft ((X_{14}).

(X_{15}) was the average distance from parcels developed to the main transportation corridor in year. The minimum average distance from parcels developed to main transportation was 3,750.7 ft and the maximum average distance from parcels developed to main transportation was 40,044.0 ft. On average, new residential parcels were developed 13,631.1 ft away from the U.S. Highway 290 transportation corridor.

(X_{16}) and (X_{17}) are the log transformed variables: spatial distance and temporal lapse time from the closest existing development to new development. Before transformation, spatial distance was distributed from 164.6 ft to 12402.9 ft, and temporal lapse time was distributed from 1.2 years to 17.6 years. On average, new residential development in leapfrog neighborhoods was 1,179.2 ft from the prior neighborhood. In terms of temporal distance, residential development in leapfrog neighborhoods had an average 4.4 time lapse (X_{17}).

6.2.2 Residential Development Trend in Contagion Neighborhoods

Table 14 reports the summary statistics of variables for residential development in contagion neighborhoods. An average of 757.9 residential parcels were developed during the 62 year study period. 2,711 was the maximum number of parcels developed in a year.

Table 14. Descriptive Statistics of Residential Development in Contagion Neighborhood

Variables	Pattern	N	Minimum	Maximum	Average	Std. Deviation
Dependent Variable	Parcels developed in Contagion	62	0	2711	757.9	729.4
Independent Variables	X_{11}	62	0	15.0	2.2	2.7
	X_{12}	62	1	23	9.3	5.7
	X_{13C}	62	57,313.7	72,865,187.9	12,871,099.2	15,321,816.3
	X_{14}	62	6,478.7	77,543.1	14,633.7	11,392.0
	X_{15}	62	768.1	19,712.7	11,716.6	5,619.4
	X_{16}	62	4.9	7.2	5.7	0.5
	X_{17}	62	136.3	1308.8	342.51	223.2
	X_{18}	62	1.6	10.0	3.7	1.7

X_{11} : Number of contagion neighborhoods developed in year
X_{12} : Age of contagion neighborhood
X_{13C}: Land developed within leapfrog neighborhood in year
X_{14} : Average size of parcels developed in year
X_{15} : Average distance from parcels developed to main transportation corridor in year
X_{16} : Ln(average distance from the nearest existing development to new development) in year*
X_{17} : Ln(average of lapse time from the existing development to new development) in year*
*Descriptive statistics of original variables

In contagion neighborhood, (X_{11}) was number of neighborhoods developed in year. During the 62 years study period, 139 leapfrog neighborhoods were developed for 49 years. Among the 49 years, an average 2.2 neighborhoods were developed each year. On average, 2.2 neighborhoods were developed each year. (X_{12}) was an average age of neighborhood in year. The average age of neighborhood in year varied from 1 to 23. In contagion neighborhoods, residential parcels were developed when the age of neighborhood was an average 9.23 years.

Land developed in leapfrog neighborhoods (X13c) averaged 12,871,099 (Rounded to the nearest sq ft). (X_{13C}) represents how much land was developed in infill neighborhoods. An average of 12,871,099.2 sqft of land was developed in infill neighborhoods during the 62 years. The minimum average size of parcels developed per year was 6,478.7 sqft and the maximum average size of parcels developed per year was 77,543.1 sqft. However, the average size of parcels developed during the 62 years was 14,633.7 sqft (X_{14}). This average value was approximately 1/3 the average size of parcels developed in leapfrog neighborhoods.

Like above paragraph, (X_{15}) was average distance from parcels developed to the main transportation corridor each year. The minimum average distance from parcels developed to main transportation was 768.1 ft and the maximum average distance from parcels developed to main transportation was 19712.7 ft. On average, new residential parcels were developed 11,716.6 ft away from the U.S. Highway 290 transportation corridor.

Spatial and temporal distances were log transformed (X16 and X17) to account for spatial distance and temporal lapse time from the closest existing development to new development. Before transformation, spatial distance was distributed from 136.3 ft to 1,308.8 ft, and temporal lapse time was distributed from 1.6 years to 10.0 years. On average, new residential development in contagion neighborhoods was 342.5 ft away from the prior neighborhood. In terms of temporal distance, residential development in contagion neighborhoods had an average 3.7 time lapse (X_{17}).

6.2.3 Residential Development Trend in Infill Neighborhoods

Table 15 reports the summary statistics of variables for residential development in infill neighborhoods. An average of 290.2 residential parcels were developed during the 62 year study period. 1,074 was the maximum number of parcels developed each year.

Table 15. Descriptive Statistics of Residential Development in Infill Neighborhood

Variables	Pattern	N	Minimum	Maximum	Average	Std. Deviation
Dependent Variable	Parcels developed in Infill	62	1	1074	290.2	285.6
Independent Variables	X_{11}	62	0	6.0	1.1	1.4
	X_{12}	62	1	20	8.6	5.0
	X_{13I}	62	15,477.7	57,614,553.8	9,003,579.5	10,199,983.8
	X_{14}	62	6,398.5	195,396.6	21,494.4	30,231.7
	X_{15}	62	3,761.8	38,874.2	14,894.0	7,612.4
	X_{16}	62	60.2	1,096.4	340.6	197.6
	X_{17}	62	1.0	20.0	4.4	4.1

X_{11} : Number of infill neighborhoods developed in year
X_{12} : Ln(average age of infill neighborhood) in year*
X_{13I} : Land developed within contagion neighborhoods in year
X_{14} : Average size of parcels developed in year
X_{15} : Average distance from parcels developed to main transportation corridor in year
X_{16} : Ln(average distance from the nearest existing development to new development) in year*
X_{17} : Ln(average of lapse time from the existing development to new development) in year*
*Descriptive statistics of original variables:

Like the above paragraphs, (X_{11}) was number of neighborhoods developed in year. In infill neighborhoods, 68 infill neighborhoods were developed for 36 years during the 62 years study period. Among the 36 years, an average 1.1 neighborhoods were developed each year. (X_{12}) was an average age of neighborhood in year. The average age of neighborhood in year varied from 1 to 20. In infill neighborhoods, residential parcels were developed when the age of neighborhood was an average 8.6 years. For the infill regression analysis, (X_{12I}) was transformed by taking logs.

(X_{13I}) represents how much land was developed in contagion neighborhoods. An average of 9,003,579.5 sqft of land was developed in infill neighborhoods during the 62 years. The minimum average size of parcels developed per year was 6,398.5 sqft and the maximum average size of parcels developed per year was 195,396. 6 sqft. However, the average size of all parcels developed during the 62 year study period was 21,494.4 sqft (X_{14}). This average value was approximately 1/3 the average size of parcels developed in leapfrog neighborhoods.

(X_{15}) was the average distance of developed parcels to the main transportation corridor each year. The minimum average distance of developed parcels to the main transportation corridor was 3,761.8 ft and the maximum average distance was 38,874.2 ft. On average, new residential parcels were developed 14,894.0 ft away from the U.S. Highway 290 transportation corridor.

(X_{16}) and (X_{17}) are the log transformed variables: spatial distance and temporal lapse time from the closest existing development to new development. Before transformation, spatial distance was distributed from 60.2 ft to 1096.4 ft, and temporal lapse time was distributed from 1 year to 20.0 years. On average, new residential development in infill neighborhoods was 340.6 ft away from the prior neighborhood. In terms of temporal distance, residential development in infill neighborhoods had an average 4.4 lapse time (X_{17}).

6.3 Residential Development Processes

Empirical observations of spatial and temporal patterns established the foundation to explore the contributions of residential development variables relative to the variation in the dependent variable, residential parcel development (i.e., the number of parcels developed within leapfrog, contagion and infill neighborhoods each year). In this study, three multiple regression models were developed to examine spatial and temporal relationships between existing development and new development within each pattern of neighborhood. Three multiple regression models for each pattern of neighborhood will show significant factors for new residential parcel developments within the neighborhood. In addition, this study posited that the average age of the neighborhoods ((X_{12L}), (X_{12C}), and (X_{12I}) in Table 4) would be related to residential development within each pattern of neighborhoods (Hypothesis 3, 7 and 10). Because age of neighborhood can be a meaningful predictor of land development process, simple regression analysis using average age of neighborhood as the independent variable was followed in the next section of this chapter. In addition, Figure 13 shows a discrete development process, i.e., rapid or slow development, in response to the age of neighborhood. Since this study involve time related data, the Dubin-Watson test for temporal autocorrelation will be applied on parcel level as well.

6.3.1 Residential Development within Leapfrog Neighborhoods

The first full model incorporating all the variables is introduced in the method chapter (Table 16). This accounted for 47.4 percent of the variation in this variable (R^2 =

0.47, F = 8.85, $P < 0.05$). Small values of the Durbin-Watson statistics indicate the presence of autocorrelation. In this model, the Durbin-Watson statistics is 0.636. Since this value is less than 1, this model shows positive autocorrelation (Table 16). In this case, one of assumption in a regression model that the error deviations are uncorrelated is not meet. It will be discussed in the conclusion later.

Table 16. Regression Model of Residential Developments in Leapfrog Neighborhood

	Full Model			**Reduced Model**		
	B	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**
(Constant)	-2097.851		0.127	-622.274		0.048
X_{11}	-36.643	-0.074	0.479			
X_{12L}	0.000	0.213	0.030	0.000	0.238	0.013
X_{13L}	0.000	0.080	0.438			
X_{14}	-0.008	-0.925	0.000	-0.006	-0.704	0.000
X_{15}	0.162	0.811	0.000	0.146	0.734	0.000
X_{16}	190.815	0.163	0.430			
X_{17}	178.471	0.091	0.574			
N	62			65.000		
R^2	0.535			0.504		
Adjusted R^2	0.474			0.478		
F	8.859			19.616		
Sig.	0.000			0.000		
df =	7, 54			3, 58		
Durbin-Watson Stat.	0.636			0.586		

$P < 0.05$

X_{11} : Number of leapfrog neighborhoods developed in year
X_{12L} : Exp(Average age of leapfrog neighborhood) in year
X_{13L} : Land developed within infill neighborhood in year
X_{14} : Average size of parcels developed in year
X_{15} : Average distance from parcels developed to main transportation corridor in year
X_{16} : Ln(average distance from the nearest existing development to new development) in year
X_{17} : Ln(average of lapse time from the existing development to new development) in year

Among variables, transformed average age of neighborhood, exp (average age of neighborhood in year) (X_{12L}) and average size of parcels developed in year (X_{14}), and average distance from parcels developed to the main transportation corridor in year (X_{15}), were significantly correlated with annual residential parcel development in leapfrog neighborhoods.

There is an *F* ratio of 8.85 with an observed significance level of less than 0.00. Though three independent variables are found to be significant at less than the 0.000 level, average size of parcels developed in year (X_{14}) has the most explanatory power with the standardarized coefficients Bata -0.925 when compared to 0.81 of distance to the main transportation corridor (X_{15}) and 0.21 of average age of neighborhood in year (X_{12}).

The regression analysis suggested that average age of neighborhood also made a unique contribution to explain residential development in leapfrog neighborhoods (Hypothesis 3). The analysis determined that age of neighborhood affected annual number of residential developments as posited in Hypothesis 3. Considering the spatial distance variable (X_{16}), the regression analysis suggested that spatial distance from existing developments to new neighborhoods is not a statistically significant predictor at the parcel level. The classification theory in this study stated that a leapfrog pattern can be defined based only on the distance from the prior developments to new development on the neighborhood level. This result supports the hypothesis that spatial distance between prior development and new development is a significant predictor for only neighborhood development. However, descriptive statistics in the previous section indicated that residential development patterns in leapfrog neighborhoods show a large spatial distance within leapfrog neighborhoods compared to other patterns. Residential development was approximately a 0.7 mile average distance (1,179.2 ft) from the closest existing development in leapfrog neighborhoods.

The reduced model incorporated three variables as in the full model. In this reduced model, transformed average age of neighborhood, exp (average age of neighborhood in year) (X_{12}) and average size of parcels developed in year (X_{14}), and average distance from parcels developed to the main transportation corridor in year (X_{15}) were significantly correlated with annual residential parcel development in leapfrog neighborhoods. Together the three variables reached a 0.47 R^2 as witnessed in the previous regression model with all seven variables. The second model accounted for ($R^2 = 0.47$, $F = 19.616$, $P < 0.05$). Same as shown in the full model, average size of parcels developed in year was negatively related to the residential development in leapfrog neighborhoods.

6.3.2 Residential Development within Contagion Neighborhoods

Table 17 presents the results of parcel development within contagion neighborhoods. The full model incorporated seven variables as introduced in the method chapter. It accounted for 86.6 percent of the variation in this variable ($R^2 = 0.86$, $F = 57.298$, $P < 0.05$). The Durbin-Watson value is 1.658 (Table 17). In contagion full model, there is no significant sign of alarm. In this contagion model, average age of neighborhood (X_{12C}), land developed within leapfrog neighborhood in year (X_{13C}), average distance to the main transportation corridor (X_{15}), Ln(average distance from the nearest existing development to new development) in year (X_{16}), and Ln(average of lapse time from the existing development to new development) in year (X_{17}) were significantly correlated with annual number of parcels developed within contagion neighborhoods.

Table 17. Regression Model of Residential Developments in Contagion Neighborhood

	Full Model			**Reduced Model**		
	B	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**
(Constant)	-1840.073		0.003	-54.752		0.449
X_{11}	11.514	0.043	0.481			
X_{12C}	43.381	0.338	0.000	35.807	0.279	0.000
X_{13C}	0.000	0.598	0.000	0.000	0.783	0.000
X_{14}	-0.001	-0.019	0.701			
X_{15}	0.028	0.219	0.010			
X_{16}	314.337	0.197	0.003			
X_{17}	-252.098	-0.144	0.024			
N	62			62		
R^2	0.881			0.847		
Adjusted R^2	0.866			0.842		
F	57.298			163.228		
Sig.	0.000			0.000		
df =	7, 54			2, 59		
Durbin-Watson Stat.	1.658			1.826		

$P < 0.05$

X_{11}	: Number of contagion neighborhoods developed in year
X_{12C}	: Average age of contagion neighborhood in year
X_{13C}	: Land developed within leapfrog neighborhood in year
X_{14}	: Average size of parcels developed in year
X_{15}	: Average distance from parcels developed to main transportation corridor in year
X_{16}	: Ln(average distance from the nearest existing development to new development) in year
X_{17}	: Ln(average of lapse time from the existing development to new development) in year

Among significant variables, temporal lapse time (X_{17}) was negatively correlated to residential parcel development in contagion neighborhoods. The theory in this study posits that average age of neighborhood has a constant effect on residential development in contagion neighborhoods. The regression analysis supported Hypothesis 7 that development pressure in contagion neighborhoods is constant.

On the neighborhood level, this study expected that a contagion neighborhood would follow after leapfrog development. Therefore, on the parcel level, the amount of land developed in leapfrog neighborhoods was used as independent variables for residential development in contagion neighborhoods. The analysis found that the land developed in leapfrog neighborhoods (X_{13C}) remains a powerful predictor; Standardized coefficient Beta (0.598) supports (X_{13C}) with more explanatory power when compared to other variables.

Spatial distance (X_{16}) was positively correlated to annual residential development but temporal lapse time (X_{17}) was negatively correlated to annual residential development. Since these variables had a linear-log relationship with the dependent variable, the shorter the spatial distance, the more residential development occurred.

In Table 17, the reduced model incorporated two variables. The second model accounted for 84.2 percent of the variation in the variable ($R^2 = 0.84$, $F = 163.228$, $P < 0.05$). The Durbin-Watson statistics is 1.829 (Table 17). A value close to 2 indicates that there is no autocorrelation. In the reduced model, two variables, average age of neighborhood (X_{12}) and sum of land developed in leapfrog neighborhoods each year (X_{13C}) were significantly correlated with the annual parcels developed within contagion neighborhoods. Land developed in leapfrog neighborhoods (X_{13C}) was also a predictor of residential development in contagion neighborhoods. Based on the standardized coefficients Beta (0.783), land developed in leapfrog neighborhoods is the most powerful predictor and also supports Hypothesis 4 that land developed in trigger neighborhoods is related to residential development in following neighborhoods.

In the reduced model, the results showed average age of neighborhood (X_{12C}) is a significant factor, however, spatial distance (X_{16}) and temporal lapse time (X_{17}) are not predictors for residential development in contagion neighborhoods.

6.3.3 Residential Development within Infill Neighborhoods

Table 18 presents the results of residential parcel development within infill neighborhoods.

The full model incorporated three variables which accounted for 38.1 percent of the variation in this variable ($R^2 = 0.38$, $F = 6.36$, $P < 0.05$). The Durbin-Watson value is 0.931 (Table 18). As explained earlier, small values of the Durbin-Watson statistic indicate the presence of autocorrelation. According to Kim et al, (2006), a value less than 0.80 indicates temporal autocorrelation. Therefore, in this model, the Durbin-Watson test shows no sign of alarm. Number of infill neighborhoods developed in year (X_{11}), Log transformed average age of neighborhood (X_{12I}), and sum of land developed in contagion neighborhoods in each year (X_{13I}) were significantly correlated with annual number of parcels developed within contagion neighborhoods.

The reduced model also incorporated three variables as in the full model. The second model accounted for 39.6 percent of the variation in the variable ($R^2 = 0.39$, $F = 19.760$, $P < 0.05$). As in the full model, number of infill neighborhoods developed in year (X_{11}), log transformed average age of neighborhood (X_{12I}), and sum of land developed in contagion neighborhoods in each year (X_{13I}) were significantly correlated with annual number of parcels developed within infill neighborhoods. This specified model decreased the standardized beta coefficient in the log transformed average age of neighborhood variable from 0.431 to 0.351.

Table 18. Regression Model of Residential Developments in Infill Neighborhood

	Full Model			**Reduced Model**		
	B	**Beta**	**Sig.**	**B**	**Beta**	**Sig.**
(Constant)	-524.605		0.171	-90.581		0.225
X_{11}	53.214	0.256	0.042	52.004	0.250	0.015
X_{12I}	149.688	0.431	0.002	121.725	0.351	0.001
X_{13I}	0.000	0.404	0.003	0.000	0.367	0.001
X_{14}	-0.001	-0.055	0.655			
X_{15}	0.002	0.048	0.664			
X_{16}	71.109	0.144	0.276			
X_{17}	-40.979	-0.104	0.468			
N	62			62		
R^2	0.452			0.426		
Adjusted R^2	0.381			0.396		
F	6.363			19.760		
Sig.	0.000			0.000		
df =	7, 54			3, 58		
Durbin-Watson Stat.	0.935			0.874		

$P< 0.05$

X_{11} : Number of infill neighborhoods developed in year
X_{12I} : Ln(Average age of infill neighborhood in year)
X_{13I} : Land developed within contagion neighborhoods in year
X_{14} : Average size of parcels developed in year
X_{15} : Average distance from parcels developed to main transportation corridor in year
X_{16} : Ln(average distance from the nearest existing development to new development) in year
X_{17} : Ln(average of lapse time from the existing development to new development) in year

In the reduced model, land developed in the contagion neighborhoods (X_{13I}) was the most powerful predictor of annual residential development in infill neighborhoods. As explained in the previous section, the more land development in contagion neighborhoods, the more residential development in infill neighborhoods. In both models, residential development within infill neighborhoods revealed that there was no relationship between spatial distance and temporal lapse time from existing development to new development. It means within a neighborhood, new development does not affect either spatial distance or temporal lapse time.

6.4 Residential Development Process and Age of Neighborhood

In the previous section, the relationships between annual residential development and spatial and temporal variables were examined with multiple regression analysis. The analysis found some factors affected annual residential development in each pattern of neighborhood. Three residential development models statistically supported that average age of neighborhood was significantly correlated to residential development. However, the multiple models showed only whether the average age of neighborhood was significant or not. It does not suggest how effects of average age of neighborhood are different in each neighborhood. In this regard, a simple regression model using average age of neighborhood as an independent variable was used to investigate the discrete land development processes among the three neighborhood developments. In Chapter III, Hypotheses 4 and 10 posited that effects of average age of neighborhood could vary from the early stage to late stage in leapfrog and infill neighborhoods. To test the nonlinear function of age effect, the original and transformed variables (X_{12L} and X_{12I}) were used as an independent variable and compared the original variables with the coefficient terms.

The cumulative percentage of residential development in leapfrog neighborhoods was expected as a curve that is concave upwards (Figure 9 in page 73). The first regression analysis for leapfrog neighborhoods accounted for 0.08 percent of the variation in this variable ($R^2 = 0.08$, $F = 6.680$, $P < 0.05$). However, regression analysis using the original variable, average age of neighborhood (X_{12}) accounted for 32.5 percent of the variation in this variable ($R^2 = 0.327$, $F = 30.630$, $P < 0.05$). In the second leapfrog models, average age of neighborhood is more significantly correlated with the annual parcels developed within leapfrog neighborhoods.

In contagion neighborhoods, the effects of age of neighborhood were expected as linear function. Regression analysis for contagion neighborhoods accounted for 29.9 percent of the variation in this variable ($R^2 = 0.29$, $F = 27.066$, $P < 0.05$).

Table 19. Test Statistics for Age Effects Compared among Neighborhood Patterns

Dependent variable		**Independent variable**	**B**	**Beta**	**Sig.**	**F**	**R^2**
Annual number of residential Development	Leapfrog Neighborhoods	X_{12L}	8.685E-11	0.317	0.012	6.680	0.085
		X_{12L} (No transformation)	105.992	0.581	0.000	30.630	0.327
	Contagion Neighborhoods	X_{12C}	71.621	0.558	0.000	27.066	0.299
	Infill Neighborhoods	X_{12I}	166.432	0.480	0.000	17.926	0.217
		X_{12I} (No transformation)	25.743	0.450	0.000	15.270	0.190

Independent variable (X_{12}) is average age of neighborhood each neighborhood.
N= 62, P<0.05

In infill neighborhoods, regression analysis using the exponent transformation (X_{12I}), infill neighborhoods accounted for 21.7 percent of the variation in this variable ($R^2 = 0.21$, $F = 17.926$, $P < 0.05$). Regression analysis using the original variable, average age of neighborhoods, infill neighborhoods accounted for 19.0 percent of the variation in this variable ($R^2 = 0.19$, $F = 15.270$, $P < 0.05$). In addition, to capture the actual age effects, the correlation between year and age effects was analyzed based on residuals (Appendix H).

Based on the coefficients' terms in Table 19, average age of neighborhood in each pattern of neighborhood revealed discrete slopes for each analysis. Analysis results and Figure 13 explain the expected relationships with annual residential development.

For example, Figure 13 supports the hypothesis that residential development in contagion neighborhoods would remain constant for the complete range of age of neighborhood (Hypothesis 7). Hypothesis 3 and 10 which showed that age of neighborhoods is related to residential developments within leapfrog neighborhoods were statistically explained in the previous chapter.

Table 19 reports the residential development in leapfrog and infill neighborhoods are associated with percentage changes in average age of neighborhood rather than absolute changes (linear). In leapfrog neighborhoods, the relationship between average age of neighborhood and residential development was expected as exponent function. However, the exponential transformation variable (X_{12L}) explained only 8 percent of the variance. In case of infill neighborhoods, log transformed average age of neighborhood variable explained slightly more than the original variable. It means the log transformation fit well and simple regression in infill neighborhood is log-linear relationship.

Table 20. Neighborhood Patterns and Development Processes

		Residential Land Development Processes		
		Early in study period	**Middle in study period**	**Late in study period**
Neighborhood Development Patterns	**Leapfrog**	Slow	Fast	Slow
	Contagion	Constant	Constant	Constant
	Infill	Fast	Moderate	Slow/ zero

Table 20 reports land development processes in each pattern of neighbood. In terms of age of neighborhood, each neigbhorhood has unique land development process within the neighborhoods. In Figure 9 in page 73, contagion development shows relatively constant slope during the whole development year. Proximity to existing neighborhoods also means proximity to the existing infrastructure, therefore, development presures within this pattern of neigbborhood remains constant. However, infill neighborhood has relatively rapid growth in the early stage (Figure 9 in page 73).

6.5 Conclusion

This chapter has presented regression analysis results identifying the variables and their impacts on the variance in residential development based on the theory and hypotheses developed in this study.

Multiple regression analysis further explored the relative contribution of the selected spatial and temporal residential development pattern variables to explain the variation in annual parcel development in each pattern of neighborhood. For example, more than 47.4 percent of variation in residential developments within leapfrog neighborhood (38.1 % for infill, 84.7 % for contagion neighborhood, respectively) is explained by spatial and temporal variables characterizing residential development patterns.

According to regression analysis, average age of neighborhood was a significant predictor for all patterns of neighborhoods. In leapfrog neighborhoods, average size of parcels (X_{14}) was negatively related to annual number of residential development. Distance to the main transportation corridor (X_{15}) was significant factor. (X_{15}) was significant in leapfrog and contagion neighborhoods. This finding supports that infill neighborhood development does not related to transportation system. In infill neighborhoods, number of new infill neighborhood(s) (X_{11}) and land developed in contagion neighborhoods (X_{13I}) were significant factors. Spatial distance from existing development to new development and temporal lapse time were a predictor of annual number of residential development in contagion neighborhoods.

Besides, the significance of the differences in parameters would indicate whether neighborhood development patterns changed by the way selected spatial and temporal pattern variables affected residential development. Therefore, the difference in parameters as explained in this chapter indicated that these spatial and temporal patterns affected the number of parcels developed in each pattern of neighborhood. In other words, neighborhood pattern seems to change the pattern of residential development within existing neighborhoods.

In addition, the Durbin-Watson statistics was used to test correlation between successive residuals. Roughly speaking, if the value is close to 2, there is no autocorrelation. Kim et al, (2006) suggested the error terms are highly positively correlated if th the a value less than 0.8. Therefore, among three neighborhoods, only residential parcel development within leapfrog neighborhoods shows serial autocorrelation. However, residential parcel development within contagion and infill development didn’t show alarm.

CHAPTER VII

CONCLUSION AND DISCUSSION

This chapter presents a summary of the major findings of this study followed by a discussion of their planning implications. Limitations in this study and recommendations for future research are also presented here.

7.1. Summaries

The LTDM model was introduced for classifying neighborhood and residential development patterns. This study developed a unique classification theory and model and also demonstrates the use of analytical statistics of regression analysis to examine neighborhood and residential development patterns and their relationship to development processes. Neighborhoods and residential development maps generated by the geographic information system proved to be very useful for visual inspections and displaying changes in the patterns over time. HCAD real estate and property records can be manipulated to create spatial datasets which allow researchers to generate historical spatial datasets.

The patterns of neighborhood development were defined based on distances in space and time. In terms of spatial distance and temporal lapse time from the existing neighborhood to new neighborhood, this study quantitatively defines the patterns of neighborhood development and measured residential development patterns within the neighborhoods based on the LTDM model developed in this study.

In the LTDM model, the average spatial distance (d_N = 1,758 ft) and the average temporal lapse time (t_N= 27.38 yr) were applied to classify neighborhood development patterns. Based on the classification model developed in this study, 331 new neighborhoods were classified either as leapfrog, contagion or infill neighborhoods. The analysis found that 124 leapfrog (34.46%), 68 infill (20.54%) and 139 contagion neighborhoods (41.99%) were developed from 1945 to 2006.

Research hypotheses for each pattern of neighborhood were made and tested with spatial and temporal measurements at both the neighborhood and parcel levels. Based on the LTDM model, this study analyzed spatial and temporal patterns with disaggregated parcel data, and then aggregated them in a temporal manner. Two measurements, neighborhood and parcel, were applied to test the hypotheses. In methodological concerns, HCAD records and the LTDM model are very unique approaches to create spatial datasets and analyze spatial information.

One of the major findings is the significance of neighborhood as a spatial unit of analysis. Neighborhood is a socially defined boundary in planning practice. But existing studies in spatial and temporal patterns of urban growth and development have not adopted neighborhood concept and geographic boundary as a unit of analysis. Since developing new homes and neighborhoods is a socioeconomic activity, this study found that neighborhood can be a good measurement unit for urban growth studies.

On the neighborhood level, the neighborhood leapfrog model didn’t explain the relationship between neighborhood developments and spatial and temporal variables. Leapfrog neighborhood was expected to be a trigger; however, the selected spatial and temporal variables didn’t predict it because this study did not adopt socioeconomic variables such as population rate or property values to connect development and economic conditions. This study posited that neighborhood contagion development followed after neighborhood leapfrog development. However, neighborhood infill development did not have any relationship with 5 year lagged neighborhood contagion development. Neighborhood infill development showed a relationship with temporal patterns such as age of neighborhoods and temporal lapse time from the existing neighborhood.

On the parcel level, this study found that neighborhood patterns affected the residential development process. For example, the age of neighborhood is not important for residential developments within contagion neighborhoods because the growth process within contagion neighborhoods is consistent from the early to the late stage. This was expected in the theory because proximity to existing neighborhood means close supporting infrastructure near contagion neighborhoods.

In the case of leapfrog and infill neighborhoods, age of neighborhood is a predictor for residential developments within infill neighborhoods. In the case of the leapfrog neighborhoods, it showed an exponential curve. In other words, very slow development in the early stage, moderate development during the middle stage, and finally, rapid growth in the late stage. However, infill neighborhood showed an inverse trend of leapfrog development- rapid development in the early stage, moderate development during the middle, but very slow development or no new development in the late stage. As expected in this study, in the late stage, the developers or homebuyers who prefer to be close to the existing neighborhoods would find available vacant land within the urban area.

7.2. Discussions and Implications

Urban sprawl has characterized land development over sixty years. Today, one of the most challenging problems in dealing with land development is how to examine the process of land development. Or, how we can apply timely policy instruments to alter the patterns of development and mitigate its impact. To answer these questions, this study has provided several policy implications to improve land development decision-making.

First, urban growth and development needs to be understood as a process that occurs in the context of urban growth dynamics. Prior studies have commonly engaged in static snapshots of development patterns with single data or a few datasets to assess changes. In this study, an advanced treatment of the temporal scale was implemented by using long term historical development on a calendar year basis. The value of this temporal approach supports the fact that land development is a dynamic process. This study helps to quantitatively define and measure development patterns. These spatial and temporal patterns of neighborhood and residential development can be linked to development processes (Bengston et al, 2004; Gobster et al, 2004).

Second, existing neighborhoods should be evaluated based on patterns for future development. It has shown that this approach can be applied to quantitatively measure leapfrog, contagion and infill development patterns as well as evaluate their effects on development patterns and processes. Each neighborhood pattern reveals a different story within each pattern of neighborhood. However, this study's findings suggest that the impact of leapfrog development remains consistent (Kline, 2000). In addition, it affects the neighborhoods that follow and future development within leapfrog neighborhoods. Therefore, neighborhood level planning and policies that incorporate urban growth and land development better project the eventual patterns resulting from the current process.

Third, consequences of leapfrog development should be addressed based on infrastructure. Leapfrog development is known as one of the causal factors for urban sprawl and is addressed as a temporary condition because surrounding open spaces eventually are developed when infrastructure is provided in leapfrog areas. To prevent leapfrog development, an ordinance was adopted to institute development impact fees requiring developers to pay some of the costs for infrastructure. But generally, developer and homebuyers in the development market are not confronted with the full social costs and benefits of their decisions which can lead to inefficient land use. In most cases, the first developer and homebuyer pay the development impact fee or rely on municipal infrastructure. This study suggests that not only leapfrog neighborhoods were areas where financing new infrastructure was important, but the following contagion neighborhoods were also affected. Based on the findings in this study, the following neighborhoods which resulted from leapfrog development were “free riders” in terms of cost of growth. Therefore, this study suggested that the development impact fee should be applied to following contagion neighborhoods (Ottensmann, 1977).

Fourth, while the results are specific to this Harris County case study, the approach can be extended to other regions. The theory and method developed in this study can be used to classify development patterns and examine the degree of development patterns from local to global. For urban management purposes, this method can be applied to other urban settlements for which there is insufficient spatial information. Non spatial historical estate property records can provide spatial development pattern information.

In short, this research is useful to land use planners and policy makers as policy adjustments can be applied to discourage sprawl development and mitigate the consequences based on empirical evidence. The approach taken in this study can be useful to test policy outcomes against negative impacts and current processes. This would facilitate improvement of current policy instruments for land development.

7.3. Study Limitations

This study has several limitations.

The first limitations of this study are related to its study area. ArcInfo near function used to select the study area (the northwest part of Harris County) based on a gravity approach to define the study area and select residential parcels along the US Highway 290 transportation corridor. During this process, some parcels may have been excluded within the same neighborhood if interstate highway I-10 or I-45 was their nearest major transportation corridor. Therefore, some neighborhoods located on the margins may not have captured the whole development process because of missing parcels.

The second limitation is the neighborhoods developed before this study period, which started after World War II and changed the way of life in our world. However, since the City of Houston was founded before 1900, there were 77 neighborhoods already developed before 1945. Residential parcel development within those pre-existing neighborhoods did not include development pressures and demands which may have affected spatial and temporal development patterns within the neighborhoods developed after 1945.

The third limitation is its spatial measurement. The study area has non developable land area, i.e., waterbodies, farms or ranches. The bivariate distance calculation between the existing development and new development each year cannot capture those nondevelopable features.

The last limitation is the socioeconomic aspects of the development process. This study did not adopt socioeconomic variables such as income or economic conditions when neighborhoods and parcels were developed. Land development is a byproduct of economic and social activity. Adding socioeconomic variables to predict development patterns will enhance the meaning of spatial and temporal patterns of development.

7.4. Further Research

Further research is needed to increase the validity of the study and to explore the relationships between neighborhood patterns and residential patterns. The theory and the LTDM model developed in this study would support quantitative approaches to measure development processes and provides solid foundation for urban planning and policies.

Further research is needed to expand the study area to cover all of Harris County. Since the county has several major transportation systems, such as I-10 and I-45, it is worth examining the development patterns and processes on a whole county scale. The analysis findings in this setting could be more than a case study. Comparing patterns and processes for each major transportation area will connect the transportation and development process in the urban metropolitan area.

Second, the scope of this study could be expanded to include a comprehensive set of socioeconomic variables representing the trigger, leader and follower of land development. For example, future research could examine the relationships between leapfrog development and socioeconomic conditions. Cheap land is known as the main reason for leapfrogging development. Whether that is true or not, economic conditions could change the directions, degrees and patterns of development.

Third, animation techniques to visualize the development patterns will be useful to understand the development process. The location of neighborhood and the growth within the neighborhoods can be identified and visualized on a map. This would allow urban planners, developers, policy makers and even homebuyers to consider the location of a trigger and following development.

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APPENDIX A

NEIGHBORHOOD DEVELOPMENT

1. Introduction

Appendix A presents the analyzed results describing the characteristics of residential development patterns at both neighborhood and parcel levels in northwest Harris County along the U.S. Highway 290 transportation corridor. In order to explain general development trends in this study area, this study explains neighborhood and parcel developments that occurred before this study period. Also, annual and cumulative developments during the study period are reviewed in detail at both levels.

Next, the results of new neighborhood development are presented to classify patterns of neighborhood development introduced in Chapter IV. The three sections give general trends of three patterns based on the summary statistics and cartographic representations of the patterns: leapfrog neighborhood, contagion neighborhood, and infill neighborhood. The final section presents the results of the LTDM analysis on parcel level, and introduces residential developments in the existing neighborhoods. The summary statistics is given to explain parcel-infill and parcel-built out developments throughout the whole study period. All parcels developed in the early neighborhoods before this study are also included in this section.

The summary statistics include annual new neighborhood development, annual parcel development in each neighborhood pattern, annual distance from existing to new neighborhood, and annual lapse time from existing to the new neighborhood. Descriptive statistics of the patterns of neighborhood development were computed to the characteristics of neighborhood development patterns across different patterns. The spatial distribution patterns of parcel and neighborhood development patterns are presented through a series of maps (Figure A-3).

2. General Development Trends

A total of 160,899 residential parcels were developed in this study area during the period 1945-2006. Since Harris County was founded in 1836, there were some existing developments in this study area before this study period. Residential development began in 1987 when 5 residential parcels were developed in one neighborhood. Development consistently grew until 1944 when the number of residential parcels totaled 844 (Figure A-1).

Neighborhoods also consistently grew until 1944 when there were 77 cumulative neighborhood developments (Figure A-2). The locations of neighborhoods developed by 1944 were spread throughout the entire study area. Total developed area in 1944 was 8.44 square miles of this study area.

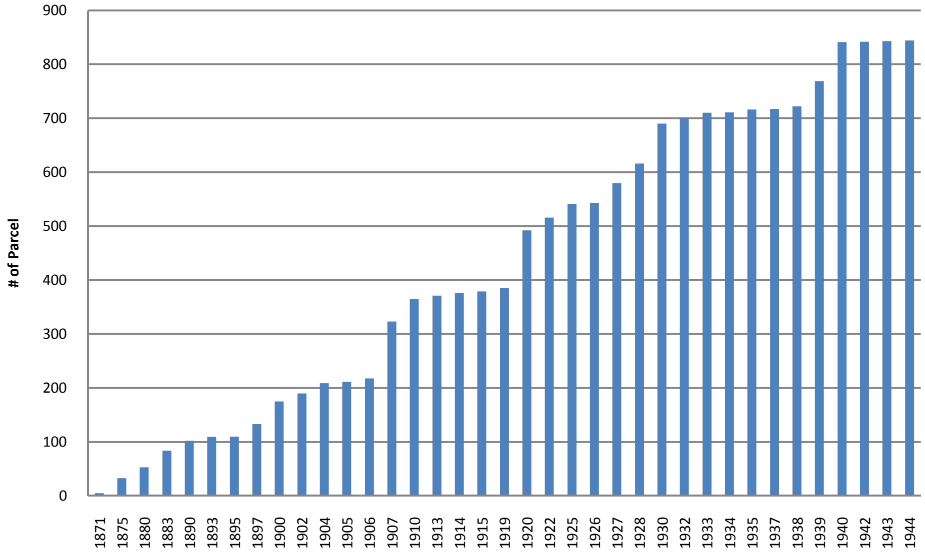


Figure A-1. Cumulative Parcel Developments by 1944

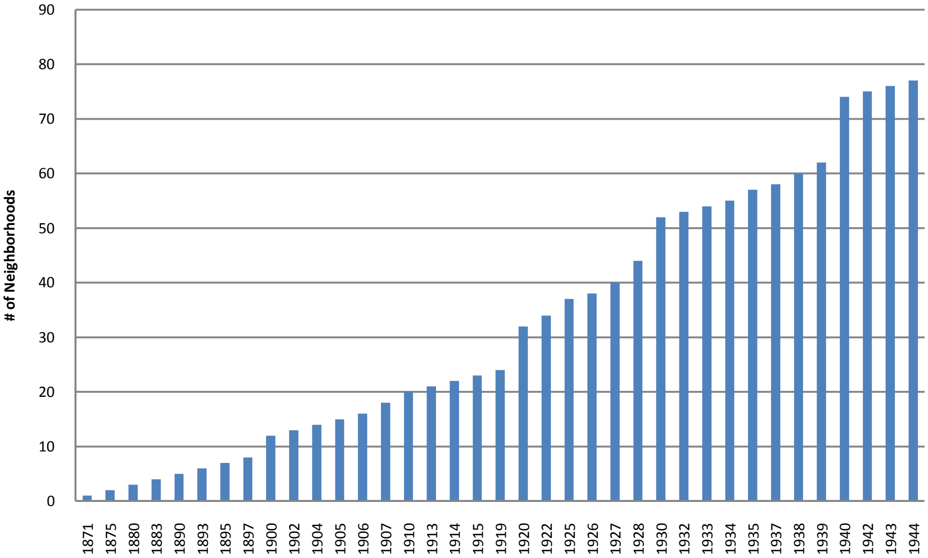


Figure A-2. Cumulative Neighborhood Developments by 1944

To visualize the changes in neighborhood development over time, a series of historical neighborhood development maps was designed based on HCAD real and property data. Figure A-3a and Figure A-3b show the progression of neighborhood development in the study area. Maps show only residential development and each color represents all neighborhoods developed in this study area. In the early study periods, neighborhoods were surrounded by available land which was later filled with new development.

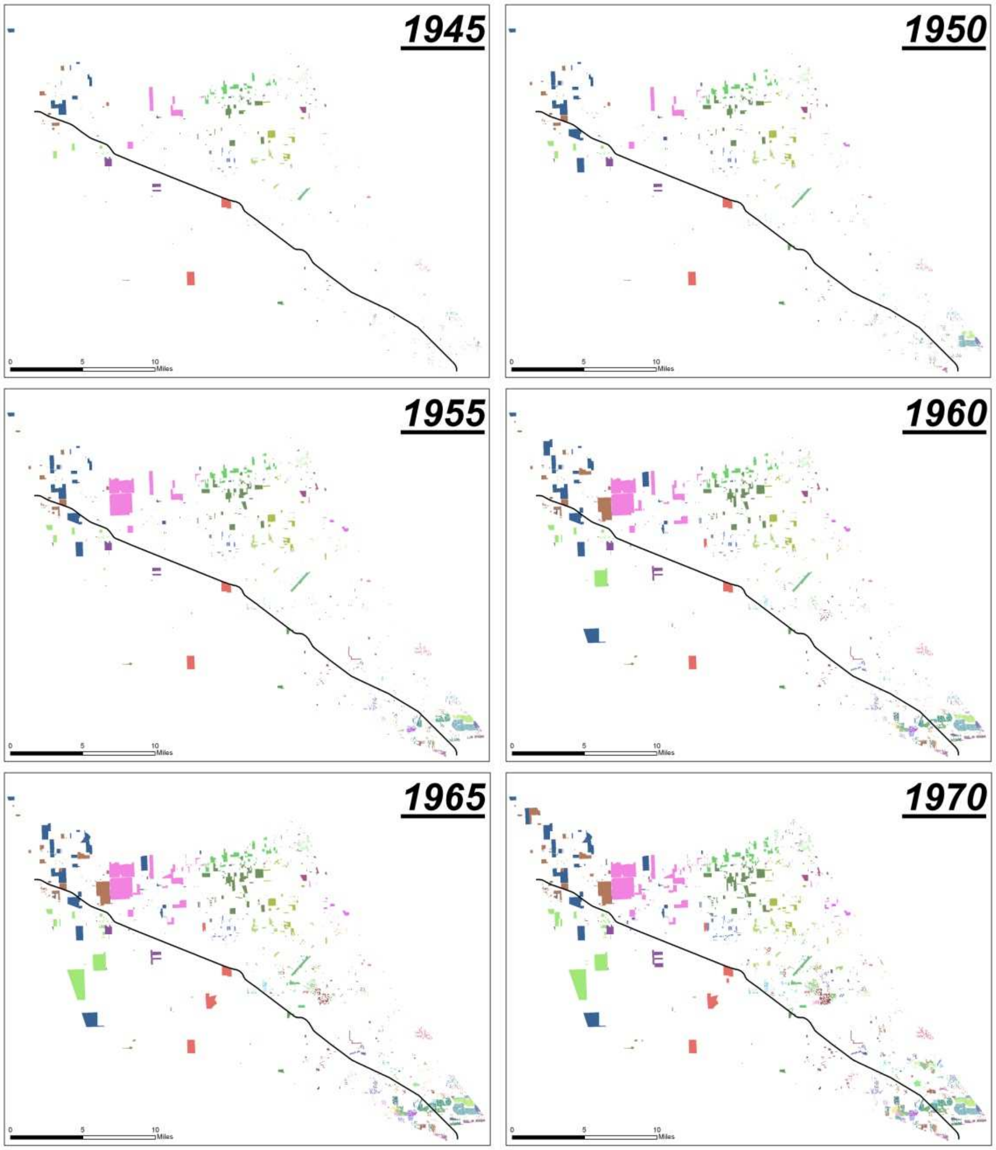


Figure A-3a. Neighborhoods Developed in Study Area from 1945-1970

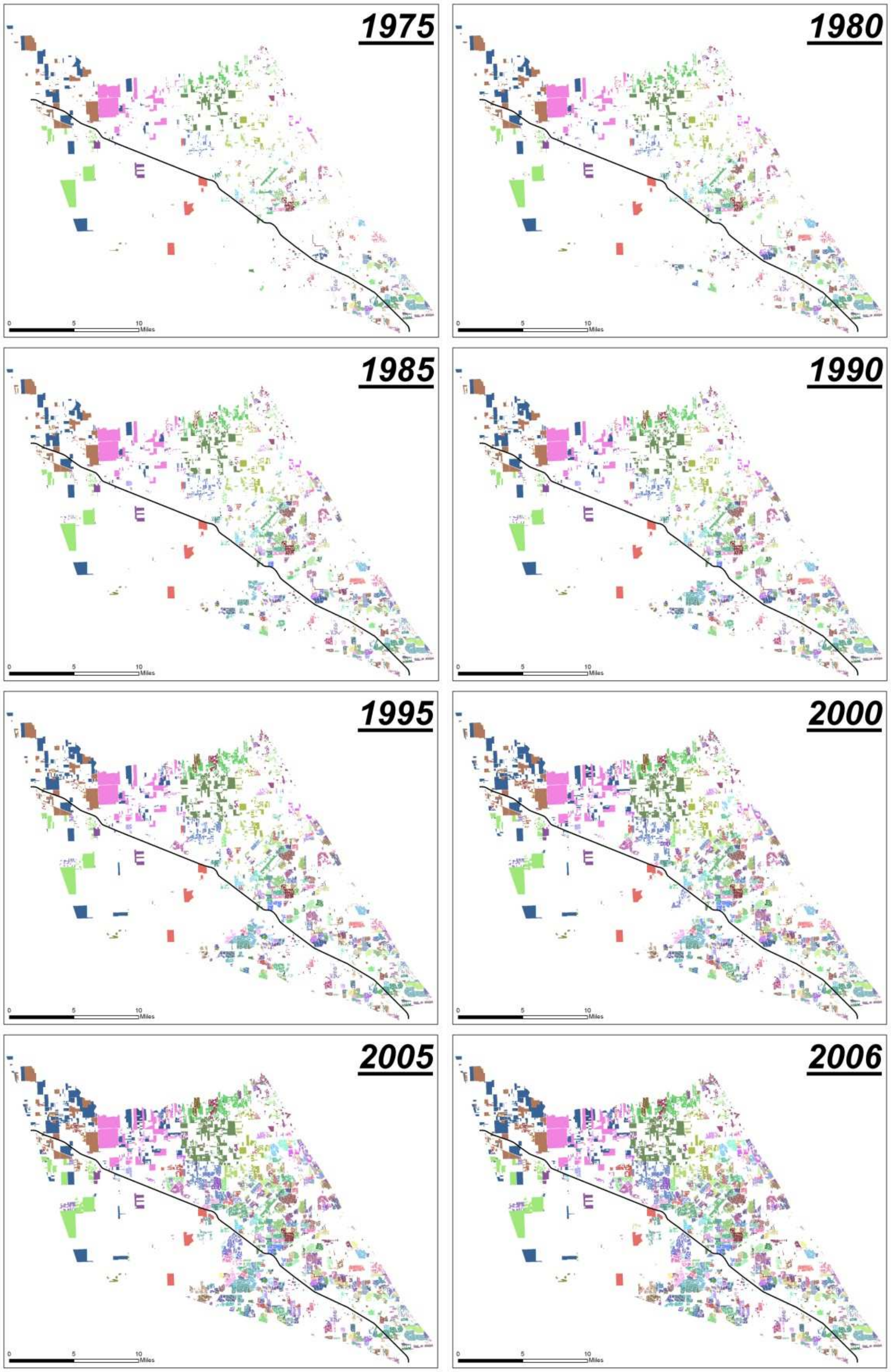


Figure A-3b. Neighborhoods Developed in Study Area from 1975-2006

Table A-1 presents spatial and temporal neighborhood development trends in this study area. After 1944, 331 new neighborhoods and 160,899 residential parcels were developed. Overall, an average of 5.33 new neighborhoods and an average of 75.63 new residential parcels were developed each year. A new neighborhood was developed most years, but no new neighborhood was developed in the years 1947, 1958, 1985, 1987 and 1991.

On the neighborhood level, the maximum number of new neighborhoods was developed in 1979. 23 new neighborhoods were developed with 247 new parcels. On the parcel level, maximum number of new parcels was developed in 1980 with 493 new parcels developed in one neighborhood.

Table A-1. New Neighborhood (N) Developments Summary Statistics

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
Neighborhood Developed per year	0	23	5.33	5.30
Parcels in New N	1	493	75.63	108.92
N-N distance (ft)	0	20576.07	1755.87	1886.46
N-N lapse time (year)	1	127	27.35	29.11

331 neighborhoods developed between 1945 and 2006
Neighborhood-to-Neighborhood distance: the distance from the closest existing neighborhood to new neighborhood development
Neighborhood-to-Neighborhood lapse time: the year the new neighborhood was developed minus the year the closest existing neighborhood was developed

Table A-1 also shows the spatial trends of new neighborhood development. N-to-N distance is the distance from the existing neighborhood to new neighborhood development each year. On average, the spatial distance between the prior neighborhoods and new neighborhood(s) was 1755. 87 ft throughout the study period.

However, there were several cases of new neighborhoods with no spatial distance. Their locations were adjacent to existing neighborhoods, so their boundaries touched each other. Therefore, the minimum N-to-N distance was 0 ft and the maximum distance was 20576.07 ft. This farthest neighborhood was developed in 1945 and one residential parcel was erected in that neighborhood.

Table A-1 also reports the temporal trends of new neighborhood development. N-to-N lapse time represents the temporal distance between the closest existing neighborhoods and a new neighborhood(s). Since HCAD real and property records have been maintained on an annual basis, the minimum N-N lapse time is 1-year. Among 331 new neighborhoods, 7% had developed one after the other (1-year), and 37% had been developed in greater than the average lapse time (27.35-years). Based on the average N-to-N distance (1755.87 ft) and the average N-N lapse time (27.35 year), the LTDM model in this study classifies new neighborhood developments as either leapfrog, infill or contagion. Table A-2 shows new neighborhood development patterns in northwest Harris County along the US Highway 290 transportation corridor between 1945 and 2006.

Table A-2. New Neighborhood Development Patterns Summary Statistics

	Leapfrog	**Infill**	**Contagion**	**Total**
New neighborhood development	124 (35.46%)	68 (20.54%)	139 (41.99%)	331 (100%)
Parcels in the new neighborhoods	1,299 (27.70%)	1,122 (23.93%)	2,268 (48.37%)	4,689 (100%)
Average neighborhood ratios	0.28	0.24	0.48	1

331 neighborhoods developed between 1945 and 2006

On the neighborhood level, the analysis found 124 leapfrog (34.46%), 68 infill (20.54%) and 139 contagion neighborhoods (41.99%) from 1945 to 2006. On the parcel level, 1,299 parcels (27.70%) were developed in leapfrog neighborhoods, 1,122 parcels (23.93%) were developed in infill neighborhoods and 2,268 parcels (48.37%) were developed in contagion neighborhoods.

Figure A-4 illustrates three patterns of neighborhood development and the yearly contribution of each. Cumulative patterns of three neighborhood developments exhibited some regularity in the temporal pattern (Figure A-5). Cumulatively, leapfrog neighborhood development was usually higher than infill and contagion neighborhood development. By 1964, leapfrog (24.19%), contagion (23.74%) and infill neighborhoods (22.06%) had similar patterns. After 1964, leapfrog (46.77%) and infill neighborhoods (45.59%) had similar patterns until 1974. In addition, after 1964, the leapfrog (89.52%) and contagion curve (89.21%) are parallel until 1993.

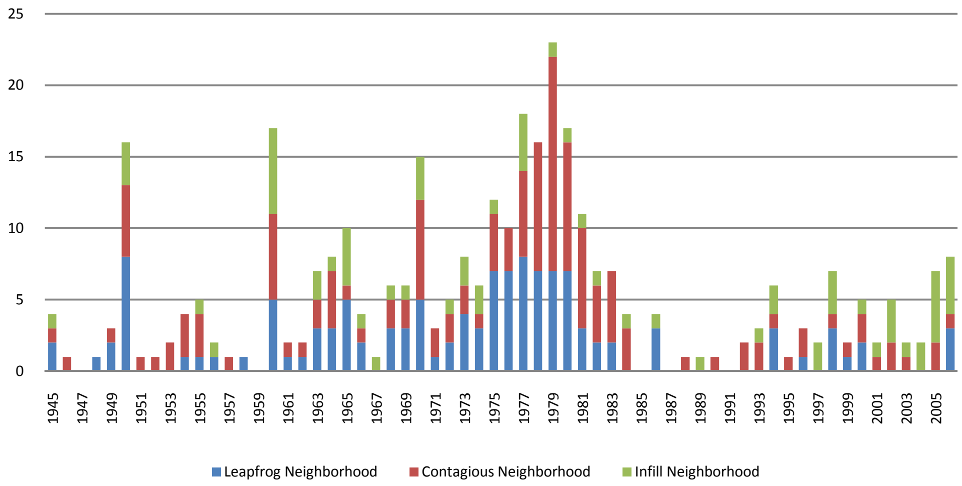


Figure A-4. New Neighborhoods Developed per Year from 1945 to 2006

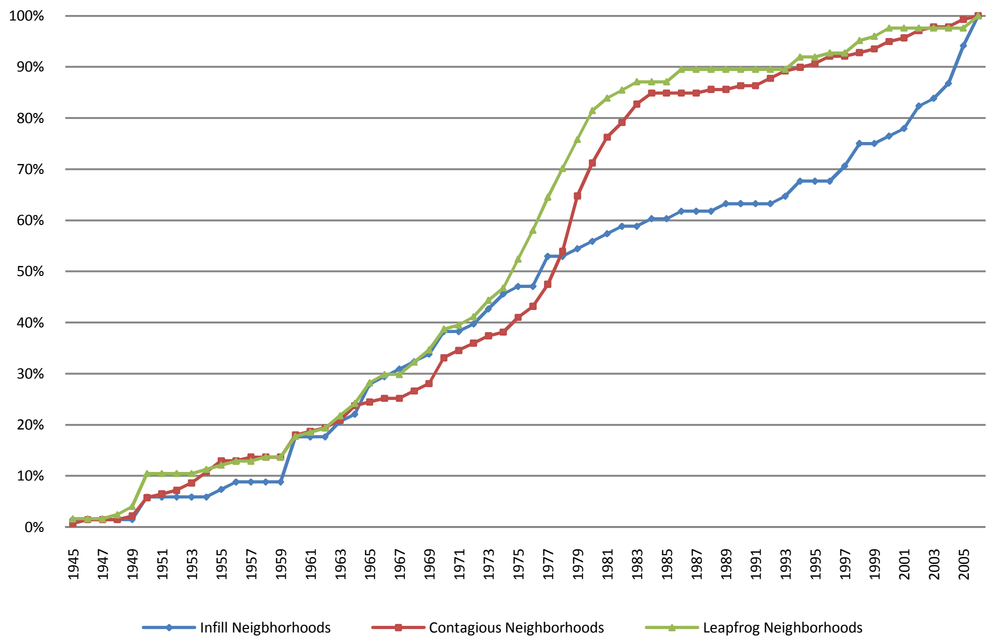


Figure A-5. Cumulative Neighborhood Developments by Year (1945-2006)

Table A-3 presents the temporal trends of residential parcel developments. An average of 2,595 parcels was developed each year during the study period. Minimum parcels (117) were developed in 1946. Maximum parcels (7,779) were developed in 1983. P-P distance is the distance from the existing parcel to new parcel development per each year. On average, spatial distance between the existing parcels and new parcels was 328.52 ft during the study period. Like neighborhood developments, the temporal unit is 1-year. When new parcels were adjacent to existing parcels, minimum P-P lapse time is 1-year. Therefore, minimum P-P lapse time was 1 and maximum distance was 116-years. Among 160,899 parcels developed during this study period, 89,451 parcels (56% of total parcels) had a 1-year Lapse time. Maximum lapse time was 116 years in 1996.

Table A-3. Residential Parcel Developments Summary Statistics

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
Parcel Developed per year	117	7779	2595.14	2222.26
P-P Distance (ft)	0	20576.07	328.52	1886.46
P-P Time_Gap (year)	1	116	4.31	8.03

160,899 Residential parcels developed between 1945 and 2006
P-P distance: the distance from the existing parcel to new parcel development
P-P lapse time: the year the new parcel was developed minus the year the closest existing parcel was developed

Figure A-6 illustrates new parcels developed per year. The HCAD real estate and property records have a 5-year fluctuation shown from the data maintenance. The reason for the rapid parcel developments in 1950, 1955 and 1960 could found in the nature of the data. After the 1960s, parcel development increased before the 1980 economic recession. Figure A-6 indicates development cycles within two periods, one between 1970 and 1985 and one starting in 1987 and currently still underway. 281 new parcels were developed in 1945; this increased to 7,779 by the year 1983 and later decreased rapidly to 1,172 from 1983 to 1987. New developed parcels increased to 7,354 by 2006.

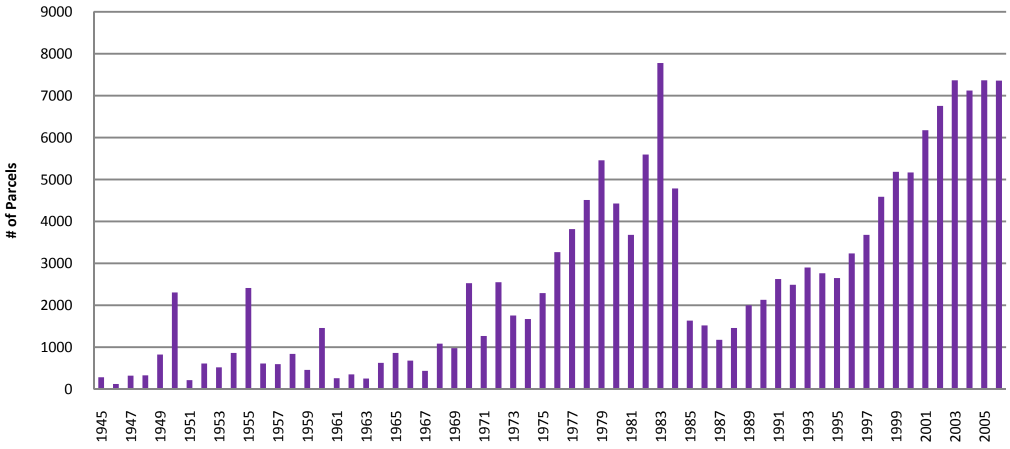


Figure A-6. All Parcels Developed per Year from 1945 to 2006

3. New Neighborhood Development

Figure A-7 shows new neighborhoods developed per year from 1945 to 2006. In 1944, 77 neighborhoods were found in this study area and they were 19% of the cumulative neighborhoods by 2006. Figure A-7 illustrates two identical cycles of new neighborhood development between the l970s and mid 1990s. From 1975 to 1981, 107 new neighborhoods were developed; these were 32.33% of the total neighborhoods developed in 2006. One new neighborhood was developed in 1967; this increased to 23 by 1979 and later decreased rapidly to zero from 1979 to 1985. After 1991, the number of new neighborhoods developed increased continuously to 2006.

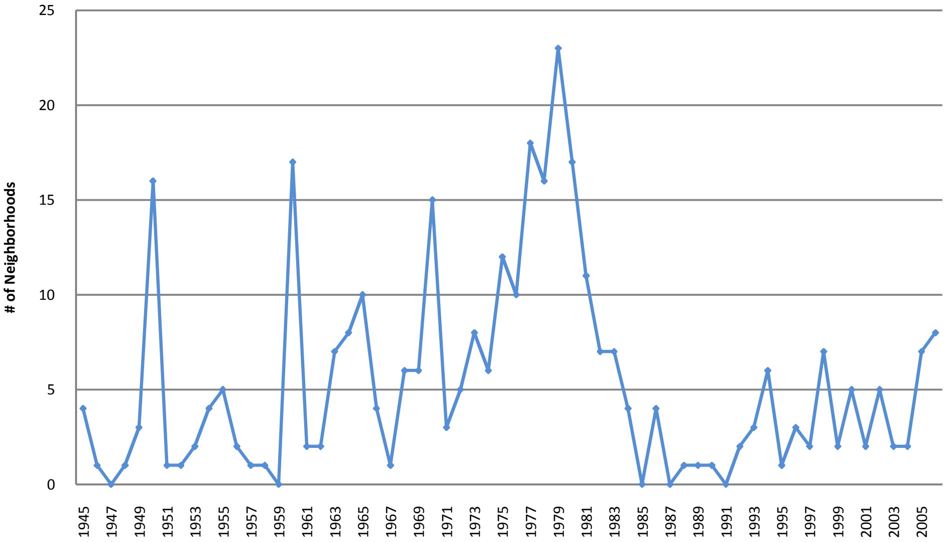


Figure A-7. New Neighborhoods Developed per year from 1945 to 2006

Figure A-7 shows new residential parcels developed per year from 1945 to 2006. 844 new parcels were developed in this study area in 1944 and they are 0.52% of the total cumulative parcels developed in 2006. In the early study periods, from 1945 to 1969, new neighborhoods had only a small number of parcels in their first year. Figure A-8 illustrates two identical cycles of new neighborhood development between l970 and the mid 1990s. Between 1975 and 1981, 107 new neighborhoods were developed; this was over 30% of the total new neighborhoods developed during the study period. In 1954, 4 new parcels were developed. This peaked at 493 in 1980, and then decreased to zero in 1985. As new neighborhoods developed, a second development cycle started in 1992.

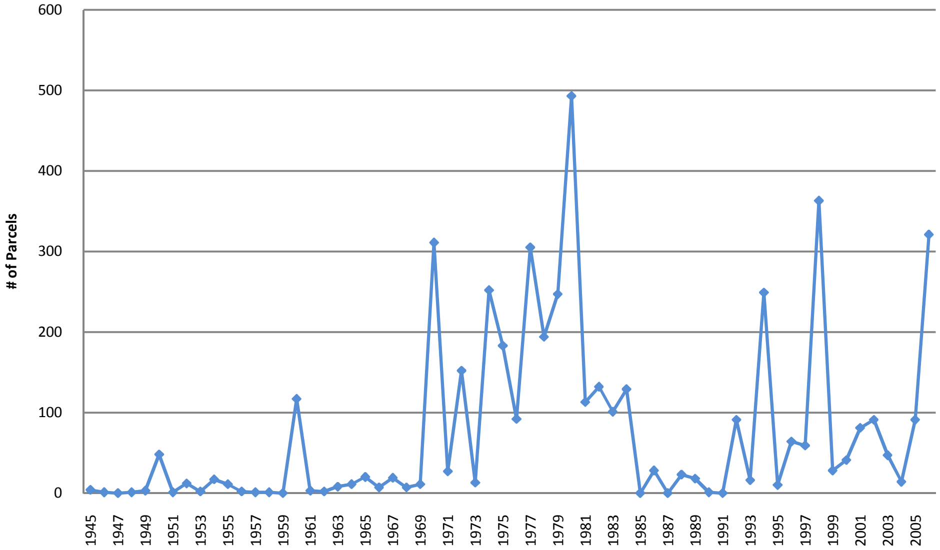


Figure A-8. Parcels Developed in New Neighborhoods per Year (1945 - 2006)

3.1 Leapfrog Neighborhood Developments

124 new neighborhoods were classified as leapfrog neighborhoods. Number of leapfrog neighborhoods developed per year is illustrated in Figure A-9. Leapfrog

development wasn't developed every year, because no leapfrog neighborhood was developed in the following years; 1946, 1947, 1951-1953, 1959, 1967, 1984-1985, 1987-1993, 1995, 1997 and 2001-2005. This graph indicates many leapfrog neighborhoods were developed during the late 1960s and 1970s.

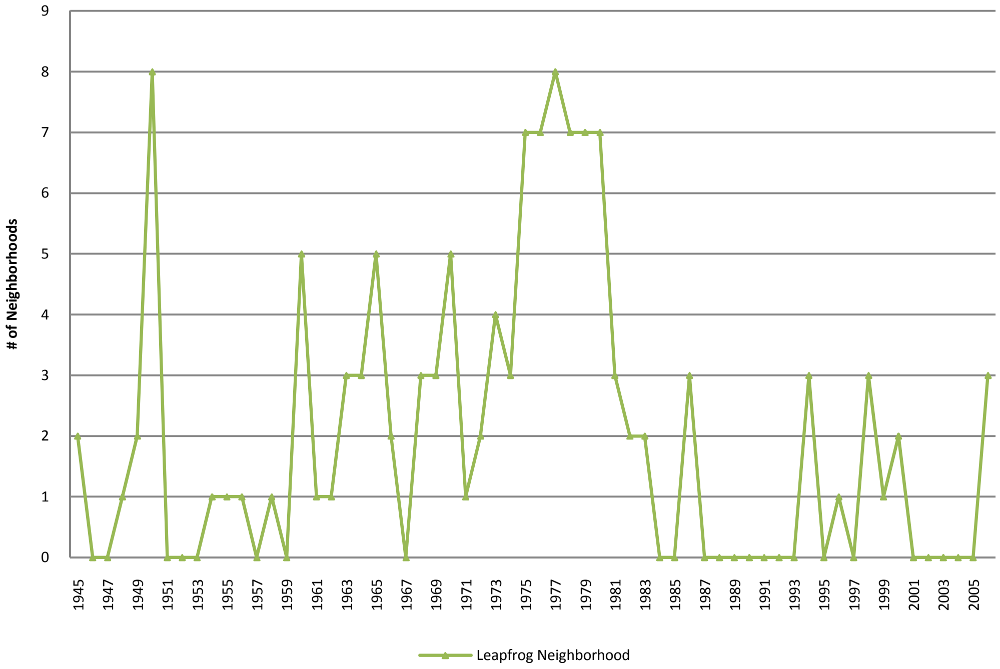


Figure A-9. Leapfrog Neighborhoods Developed per Year from 1945 to 2006

In 1968, 40 leapfrog neighborhoods were developed in the study area; these were 40% of leapfrog neighborhoods (Figure A-9). This number increased greatly- there were 48, 65, 101 and 108 for the years of 1970, 1975, 1980 and 1985 respectively, indicating that the leapfrog neighborhood development process in Harris County was accelerated during that time. After 1985, 15 leapfrog neighborhoods were developed during the next 20 years.

3.2 Contagion Neighborhood Developments

139 new neighborhoods were classified as contagion neighborhoods in this study area. Number of contagion neighborhoods developed per year is illustrated in Figure A-10. During the 62 year study period, contagion neighborhoods were developed only during 48 years (77.42%). On average, 2.24 contagion neighborhoods were developed per a year in this study area.

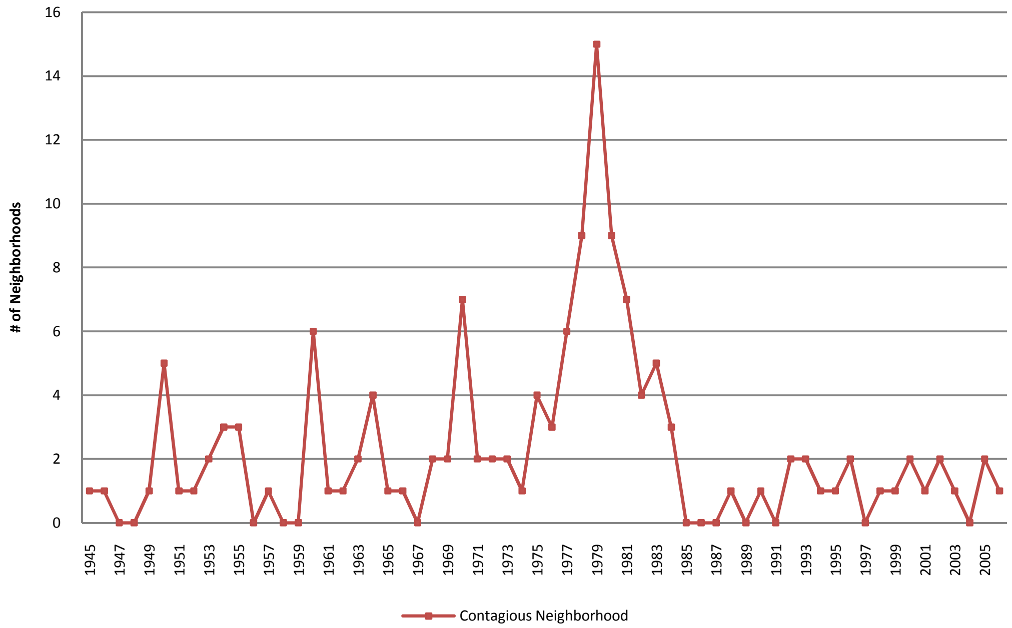


Figure A-10. Contagion Neighborhoods Developed per Year from 1945 to 2006

In Figure A-10, it is easy to see that large numbers of new contagion neighborhoods were developed between 1968 and 1984. Those 16 years, 83 contagion neighborhoods were developed which were 59.71% of the cumulative contagion neighborhoods in 2006. Two new neighborhoods were developed in 1968 was 2; this increased to 15 by 1979 and later decreased rapidly to zero from 1968 to 1985. After 1990, 1 or 2 contagion neighborhoods were consistently developed except in 1991, 1997 and 2004. Like the infill neighborhoods, this peak was roughly proportional to the high periods of development within the study area seen in Figure A-6. However, on neighborhood level, contagion neighborhoods have been the primary neighborhood development (41.99%) in this study area.

3.3 Infill Neighborhood Developments

68 new neighborhoods were classified as infill neighborhoods. Infill neighborhoods developed per year are illustrated in Figure A-11.

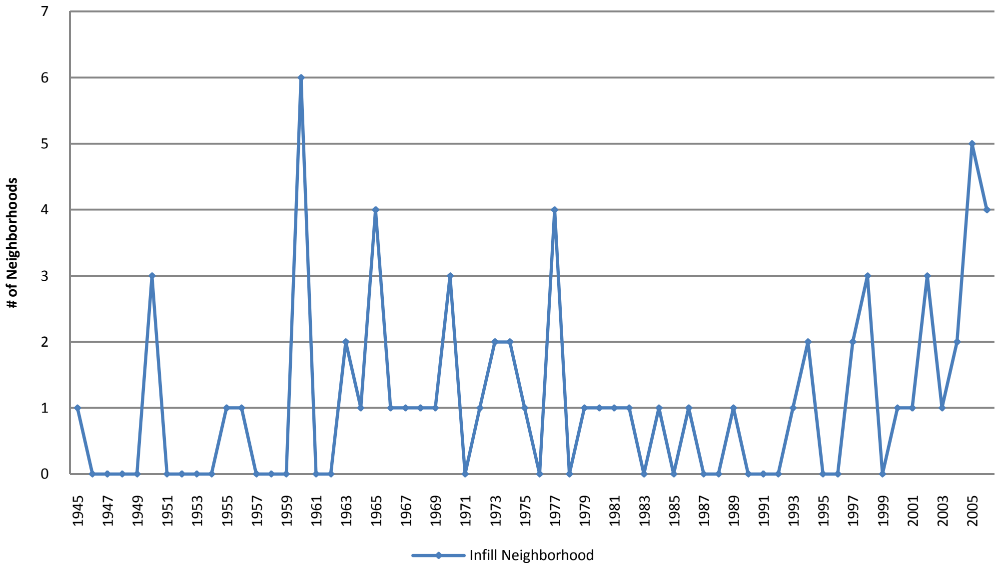


Figure A-11. Infill Neighborhoods Developed per Year from 1945 to 2006

During the 62 year study period, infill neighborhoods were developed only during 36 years (58%). On average, 1.1 infill neighborhoods were developed per a year in the 62 year period. A temporal pattern of Infill neighborhood showed large numbers of new neighborhoods in two time period- the 1960s and 2000s onward. The first peaks were roughly proportional to the high periods of development within the study area seen in Figure A-6.

APPENDIX B

REGRESSION OUTPUT- LEAPFROG NEIGHBORHOOD

Leapfrog Neighborhood Development

Descriptive Statistics

	Mean	Std. Deviation	N
Neighborhood Leapfrog developed	3.26	2.250	38
X1	1972.18	15.694	38
X2	34.18	67.729	38
X3	3.538988E5	5.7583779E5	38
X4	34.82	15.694	38
X5	8.1158	.37224	38
X6	3.3097	.73512	38
X7	1.8894E9	7.28933E8	38

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	X7, X6, X5, X3, X2, X4[a]	.	Enter

a. Tolerance = .000 limits reached.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.452[a]	.205	.051	2.193	1.554

a. Predictors: (Constant), X7, X6, X5, X3, X2, X4

b. Dependent Variable: Neighborhood Leapfrog developed

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	38.335	6	6.389	1.329	.274[a]
	Residual	149.033	31	4.808		
	Total	187.368	37			

a. Predictors: (Constant), X7, X6, X5, X3, X2, X4

b. Dependent Variable: Neighborhood Leapfrog developed

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	6.269	9.557		.656	.517		
	X2	.000	.020	.008	.014	.989	.071	14.102
	X3	1.730E-6	.000	.443	.725	.474	.069	14.519
	X4	-.440	.234	-3.067	-1.883	.069	.010	103.386
	X5	-.802	1.166	-.133	-.688	.497	.690	1.449
	X6	-.208	.521	-.068	-.400	.692	.886	1.129
	X7	9.992E-9	.000	3.237	1.988	.056	.010	103.312

a. Dependent Variable: Neighborhood Leapfrog developed

Excluded Variables[b]

						Collinearity Statistics		
Model		Beta In	t	Sig.	Partial Correlation	Tolerance	VIF	Minimum Tolerance
1	X1	.[a]	.	.	.	.000	.	.000

a. Predictors in the Model: (Constant), X7, X6, X5, X3, X2, X4

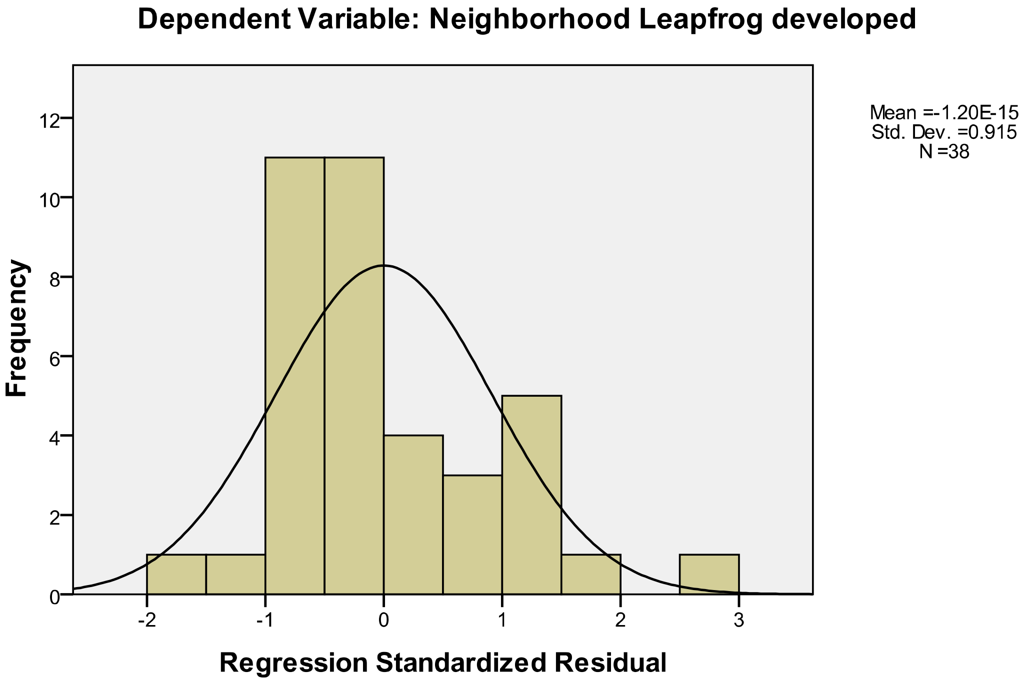
b. Dependent Variable: Neighborhood Leapfrog developed

Residuals Statistics[a]

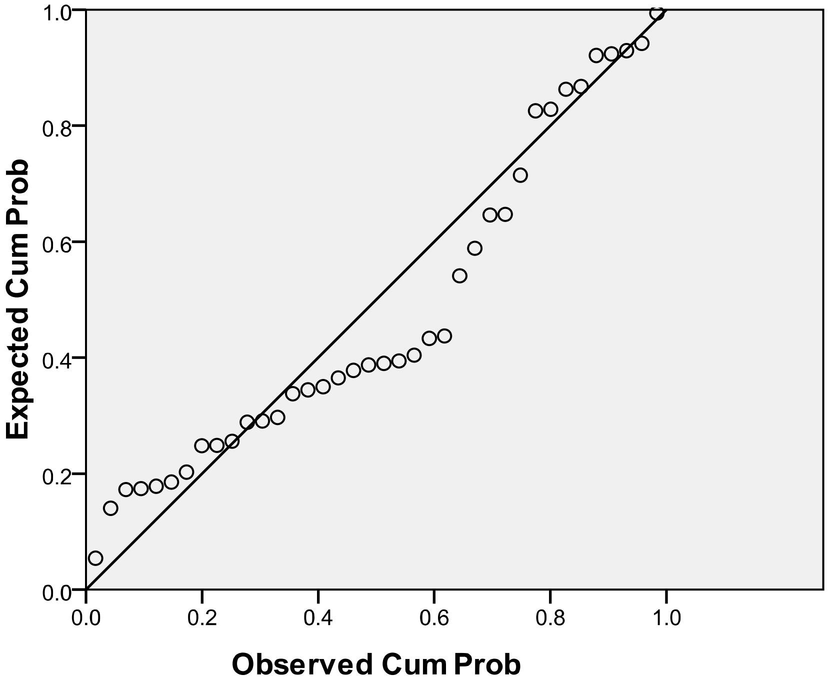
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.18	6.52	3.26	1.018	38
Residual	-3.522	5.506	.000	2.007	38
Std. Predicted Value	-2.048	3.201	.000	1.000	38
Std. Residual	-1.606	2.511	.000	.915	38

a. Dependent Variable: Neighborhood Leapfrog developed

Histogram


Dependent Variable: Neighborhood Leapfrog developed
Mean =-1.20E-15
Std. Dev. =0.915
N =38
Frequency
0
2
4
6
8
10
12
-2
-1
0
1
2
3
Regression Standardized Residual

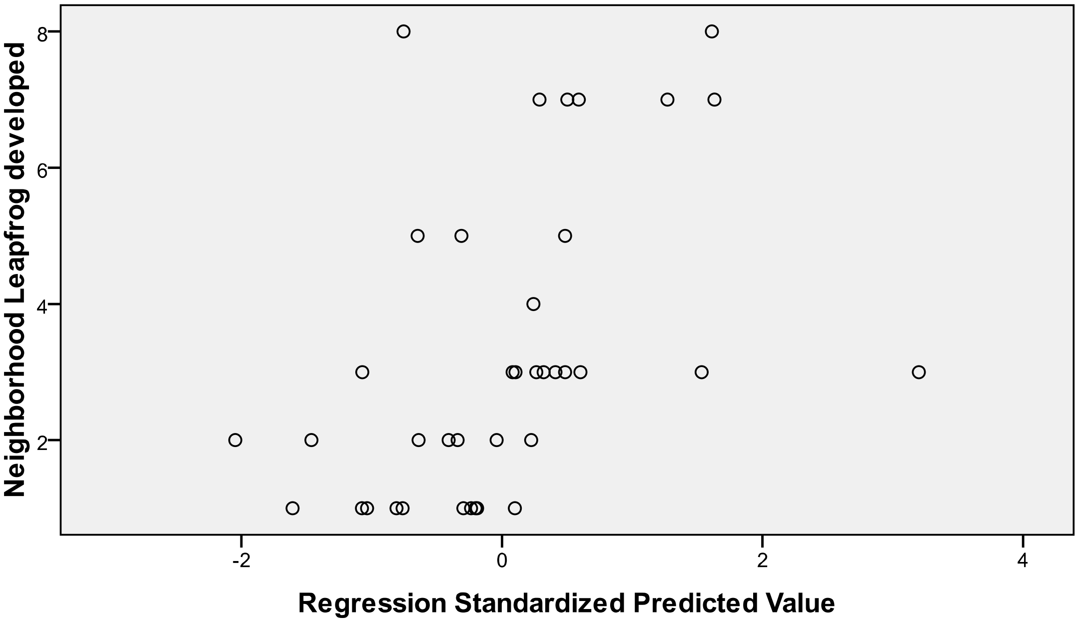
Normal P-P Plot of Regression Standardized Residual



Dependent Variable: Neighborhood Leapfrog developed

Scatterplot

Dependent Variable: Neighborhood Leapfrog developed



APPENDIX C

REGRESSION OUTPUT- CONTAGION NEIGHBORHOOD

Contagion Neighborhood Development-Full Model

Descriptive Statistics

	Mean	Std. Deviation	N
Neighborhood Contagion Developed	2.88	2.788	48
X1	1976.29	17.422	48
X2	47.23	67.644	48
X3	3.891876E5	4.8409128E5	48
X4	30.71	17.422	48
X5	6.5518	.69015	48
X6	2.0162	.84679	48
X8	2.35	2.531	48

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	X8, X5, X6, X1, X3, X2[a]	.	Enter

a. Tolerance = .000 limits reached.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.810[a]	.656	.605	1.751	2.266

a. Predictors: (Constant), X8, X5, X6, X1, X3, X2

b. Dependent Variable: Neighborhood Contagion Developed

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	239.522	6	39.920	13.018	.000[a]
	Residual	125.728	41	3.067		
	Total	365.250	47			

a. Predictors: (Constant), X8, X5, X6, X1, X3, X2

b. Dependent Variable: Neighborhood Contagion Developed

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	22.015	31.001		.710	.482		
	X1	-.012	.016	-.072	-.733	.467	.866	1.154
	X2	.009	.010	.227	.935	.355	.143	6.993
	X3	2.650E-6	.000	.460	2.008	.051	.160	6.256
	X5	.271	.379	.067	.714	.479	.952	1.051
	X6	-.073	.324	-.022	-.227	.822	.868	1.152
	X8	.250	.118	.227	2.123	.040	.736	1.358

a. Dependent Variable: Neighborhood Contagion Developed

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
						Tolerance	VIF	Minimum Tolerance
1	X4	.[a]	.	.	.	.000	.	.000

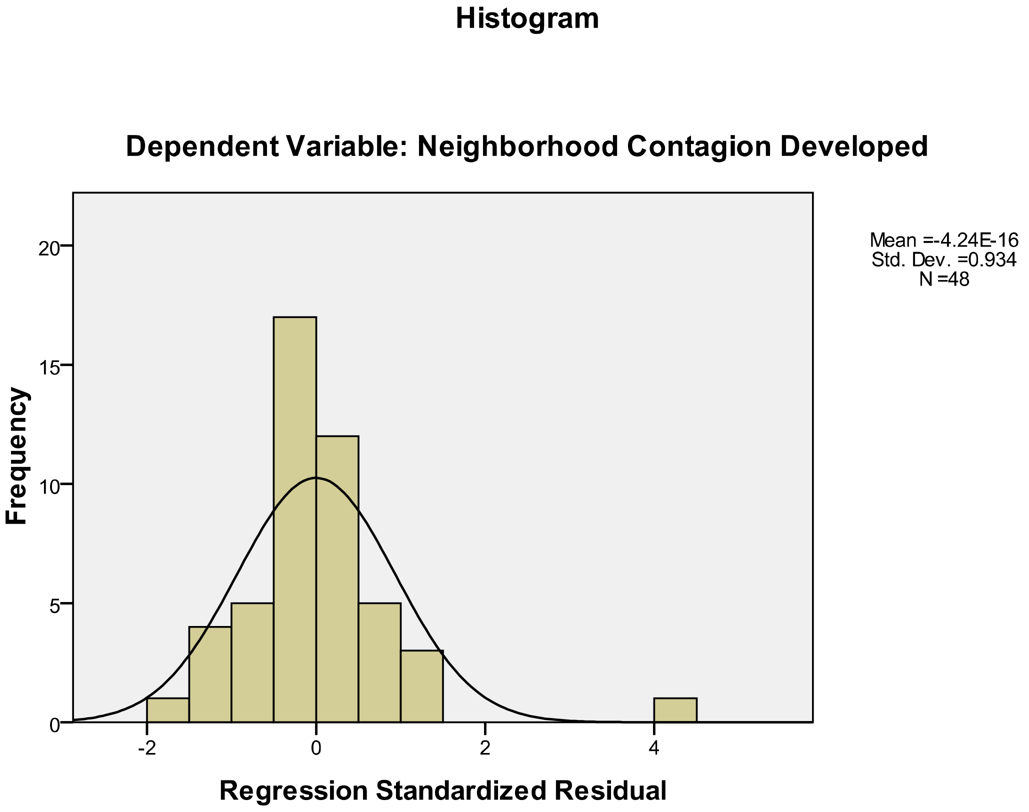
a. Predictors in the Model: (Constant), X8, X5, X6, X1, X3, X2

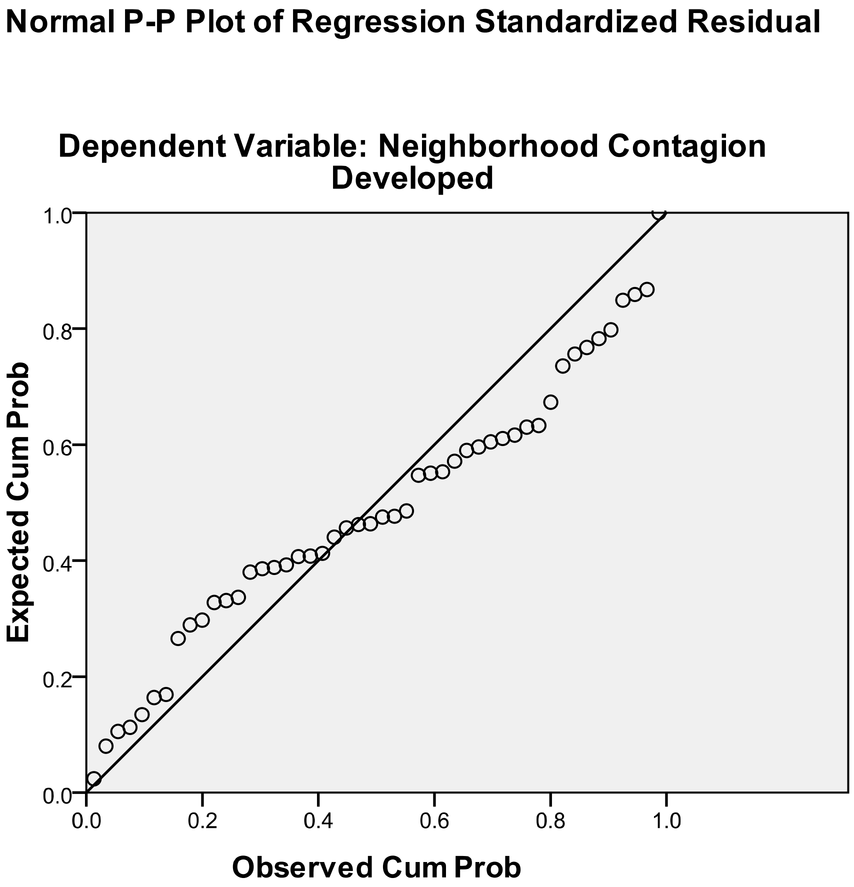
b. Dependent Variable: Neighborhood Contagion Developed

Residuals Statistics[a]

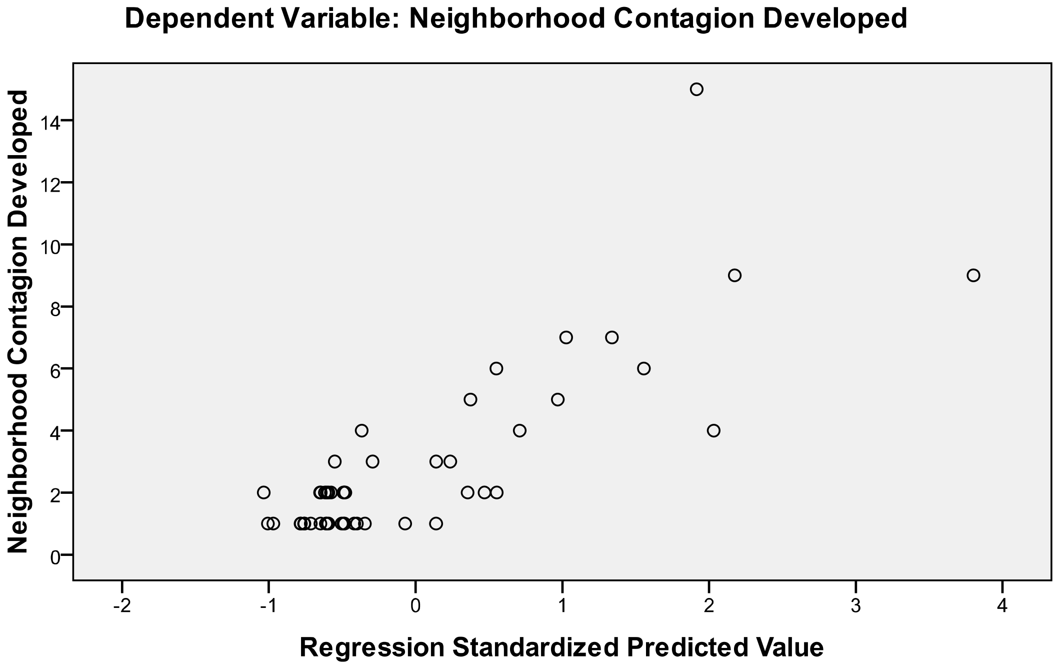
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.54	11.46	2.88	2.257	48
Residual	-3.463	7.802	.000	1.636	48
Std. Predicted Value	-1.035	3.802	.000	1.000	48
Std. Residual	-1.977	4.455	.000	.934	48

a. Dependent Variable: Neighborhood Contagion Developed


Histogram
Dependent Variable: Neighborhood Contagion Developed
Mean =-4.24E-16
Std. Dev. =0.934
N =48
Frequency
0
5
10
15
20
-2
0
2
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Neighborhood Contagion Developed
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

Scatterplot



Contagion Neighborhood Development-Reduced Model

Descriptive Statistics

	Mean	Std. Deviation	N
Neighborhood Contagion Developed	2.88	2.788	48
X1	1976.29	17.422	48
X2	47.23	67.644	48
X3	3.891876E5	4.8409128E5	48
X4	30.71	17.422	48
X5	6.5518	.69015	48
X6	2.0162	.84679	48
X8	2.35	2.531	48

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	X3	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	X8	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Neighborhood Contagion Developed

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.763[a]	.582	.573	1.823	
2	.800[b]	.640	.624	1.708	2.189

a. Predictors: (Constant), X3

b. Predictors: (Constant), X3, X8

c. Dependent Variable: Neighborhood Contagion Developed

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	212.434	1	212.434	63.946	.000[a]
	Residual	152.816	46	3.322		
	Total	365.250	47			
2	Regression	233.923	2	116.961	40.078	.000[b]
	Residual	131.327	45	2.918		
	Total	365.250	47			

a. Predictors: (Constant), X3

b. Predictors: (Constant), X3, X8

c. Dependent Variable: Neighborhood Contagion Developed

Coefficients[a]

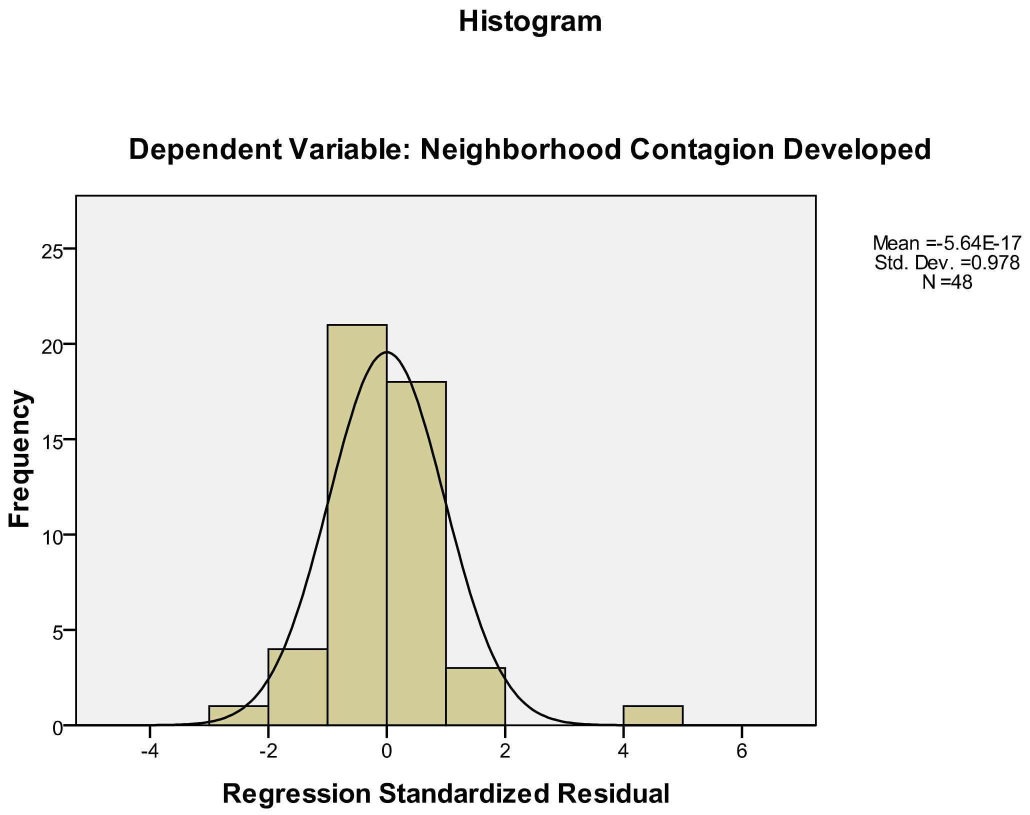
Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	1.166	.339		3.439	.001		
	X3	4.392E-6	.000	.763	7.997	.000	1.000	1.000
2	(Constant)	.721	.358		2.016	.050		
	X3	3.763E-6	.000	.653	6.666	.000	.832	1.203
	X8	.293	.108	.266	2.714	.009	.832	1.203

a. Dependent Variable: Neighborhood Contagion Developed

Residuals Statistics[a]

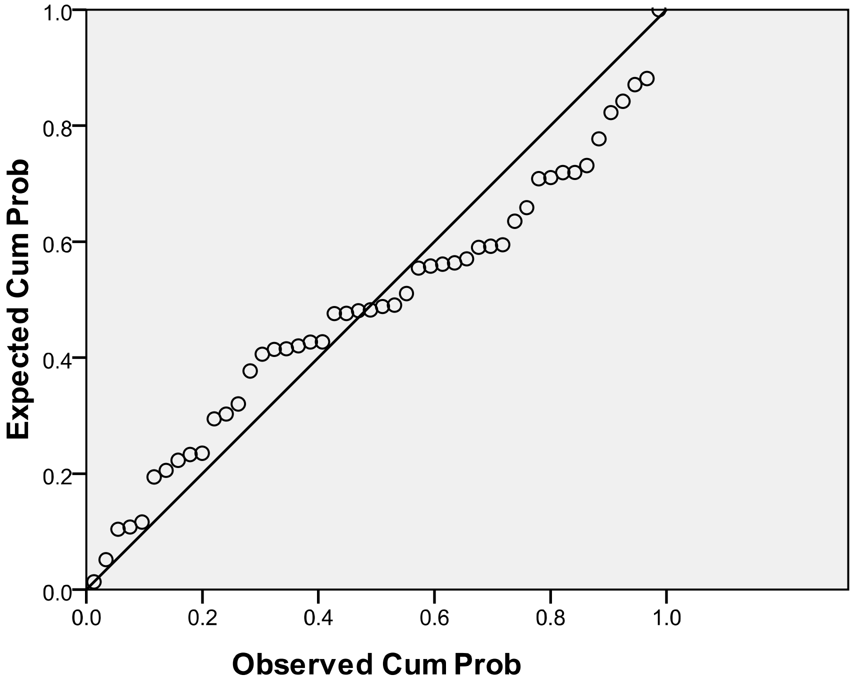
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.77	11.15	2.87	2.231	48
Residual	-3.779	7.899	.000	1.672	48
Std. Predicted Value	-.945	3.709	.000	1.000	48
Std. Residual	-2.212	4.624	.000	.978	48

a. Dependent Variable: Neighborhood Contagion Developed

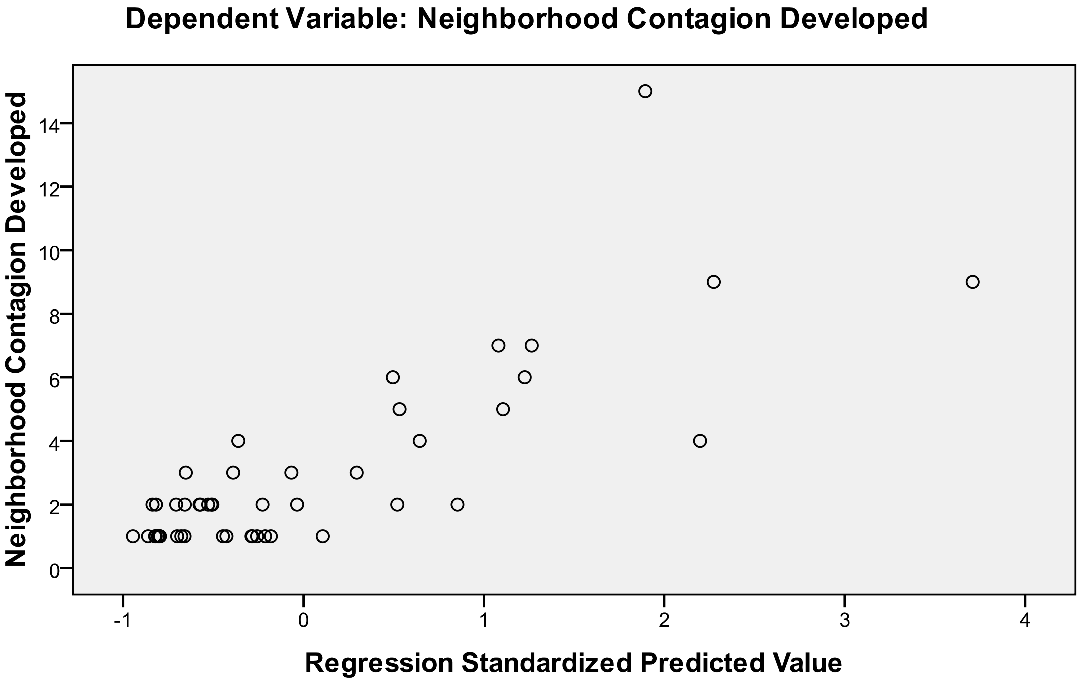

Histogram
Dependent Variable: Neighborhood Contagion Developed
Mean =-5.64E-17
Std. Dev. =0.978
N =48
Frequency
25
20
15
10
5
0
-4
-2
0
2
4
6
Regression Standardized Residual

Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Neighborhood Contagion Developed



Scatterplot



APPENDIX D

REGRESSION OUTPUT- INFILL NEIGHBORHOOD

Infill Neighborhood Development-Full Model

Descriptive Statistics

	Mean	Std. Deviation	N
Neighborhood Infill developed	2.00	1.368	32
X1	1979.41	16.535	32
X2	32.84	46.692	32
X3	3.824650E5	5.4603145E5	32
X4	27.59	16.535	32
X5	6.5041	.60292	32
X6	4.5088	.72049	32
X9	2.19	2.023	32

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	X9, X4, X5, X2, X6, X3[a]	.	Enter

a. Tolerance = .000 limits reached.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.881[a]	.776	.722	.721	1.537

a. Predictors: (Constant), X9, X4, X5, X2, X6, X3

b. Dependent Variable: Neighborhood Infill developed

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	44.998	6	7.500	14.421	.000[a]
	Residual	13.002	25	.520		
	Total	58.000	31			

a. Predictors: (Constant), X9, X4, X5, X2, X6, X3

b. Dependent Variable: Neighborhood Infill developed

Coefficients[a]

		Unstandardized Coefficients		*Standardized Coefficients*			*Collinearity Statistics*	
Model		B	Std. Error	Beta	*t*	*Sig.*	Tolerance	VIF
1	(Constant)	-8.850	1.742		-5.080	.000		
	X2	-.002	.004	-.063	-.474	.640	.500	2.002
	X3	1.511E-7	.000	.060	.406	.688	.406	2.464
	X4	.019	.009	.231	2.115	.045	.750	1.334
	X5	.315	.226	.139	1.392	.176	.903	1.108
	X6	1.796	.225	.946	7.977	.000	.638	1.568
	X9	.083	.069	.123	1.201	.241	.851	1.175

a. Dependent Variable: Neighborhood Infill developed

Excluded Variables[b]

						Collinearity Statistics		
Model		Beta In	t	Sig.	Partial Correlation	Tolerance	VIF	Minimum Tolerance
1	X1	.[a]	.	.	.	.000	.	.000

a. Predictors in the Model: (Constant), X9, X4, X5, X2, X6, X3

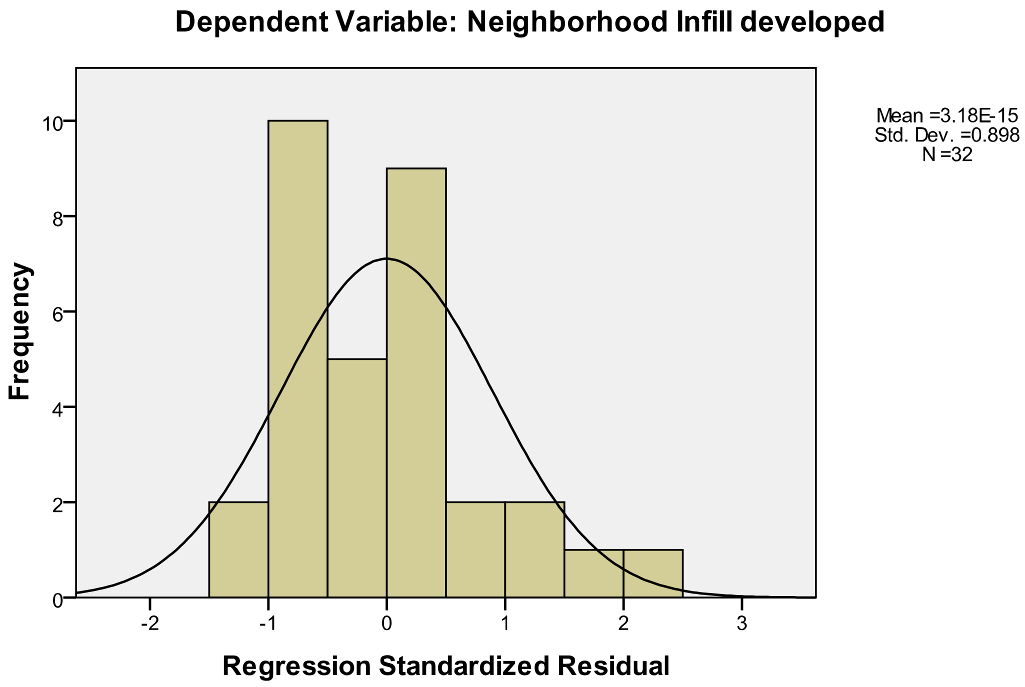
b. Dependent Variable: Neighborhood Infill developed

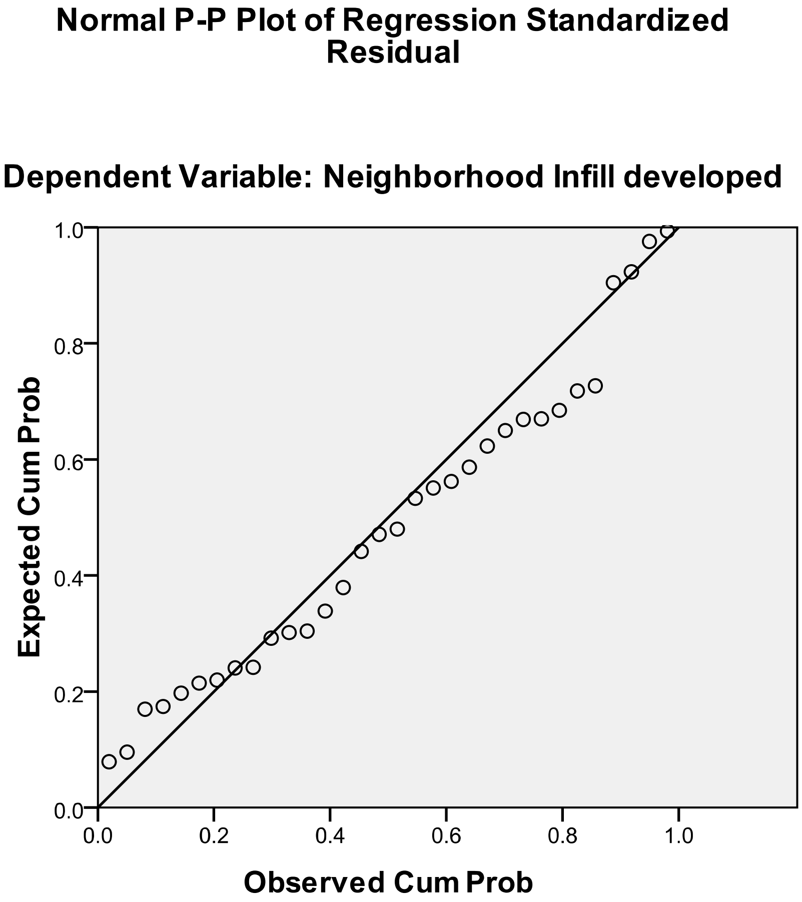
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.42	4.21	2.00	1.205	32
Residual	-1.018	1.791	.000	.648	32
Std. Predicted Value	-2.008	1.834	.000	1.000	32
Std. Residual	-1.412	2.483	.000	.898	32

a. Dependent Variable: Neighborhood Infill developed

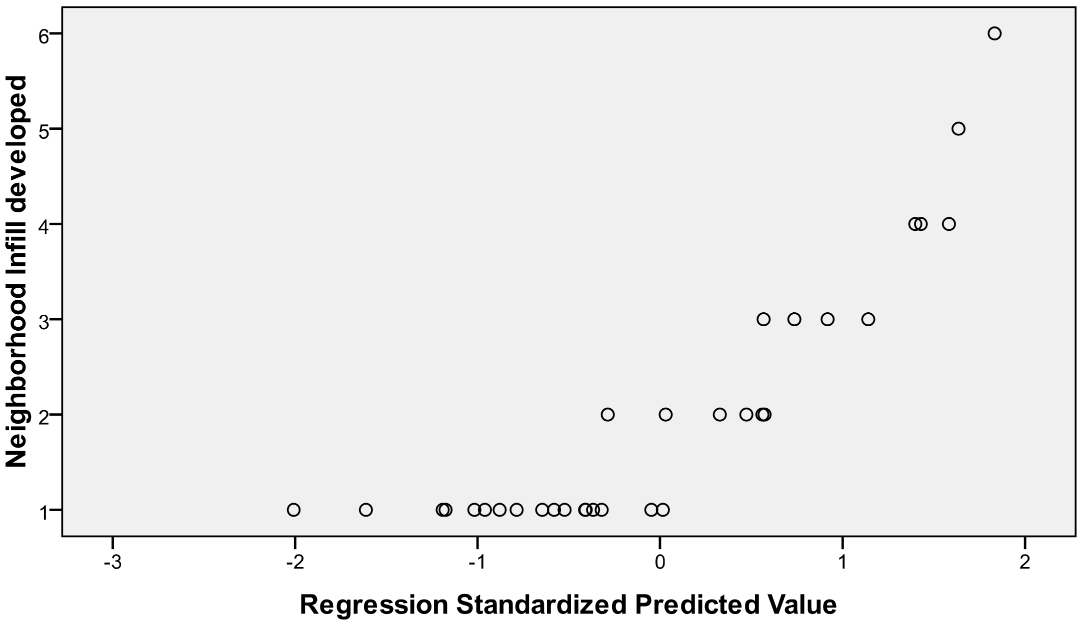
Histogram




Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Neighborhood Infill developed
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

Scatterplot

Dependent Variable: Neighborhood Infill developed



Infill Neighborhood Development-Reduced Model

Descriptive Statistics

	Mean	Std. Deviation	N
Neighborhood Infill developed	2.00	1.368	32
X1	1979.41	16.535	32
X2	32.84	46.692	32
X3	3.824650E5	5.4603145E5	32
X4	27.59	16.535	32
X5	6.5041	.60292	32
X6	4.5088	.72049	32
X9	2.19	2.023	32

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	X6	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	X1	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Neighborhood Infill developed

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.830[a]	.688	.678	.776	
2	.855[b]	.732	.713	.733	1.503

a. Predictors: (Constant), X6

b. Predictors: (Constant), X6, X1

c. Dependent Variable: Neighborhood Infill developed

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39.925	1	39.925	66.265	.000[a]
	Residual	18.075	30	.603		
	Total	58.000	31			
2	Regression	42.434	2	21.217	39.527	.000[b]
	Residual	15.566	29	.537		
	Total	58.000	31			

a. Predictors: (Constant), X6

b. Predictors: (Constant), X6, X1

c. Dependent Variable: Neighborhood Infill developed

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	-5.102	.883		-5.777	.000		
	X6	1.575	.193	.830	8.140	.000	1.000	1.000
2	(Constant)	30.607	16.538		1.851	.074		
	X6	1.723	.195	.908	8.834	.000	.876	1.141
	X1	-.018	.009	-.222	-2.162	.039	.876	1.141

a. Dependent Variable: Neighborhood Infill developed

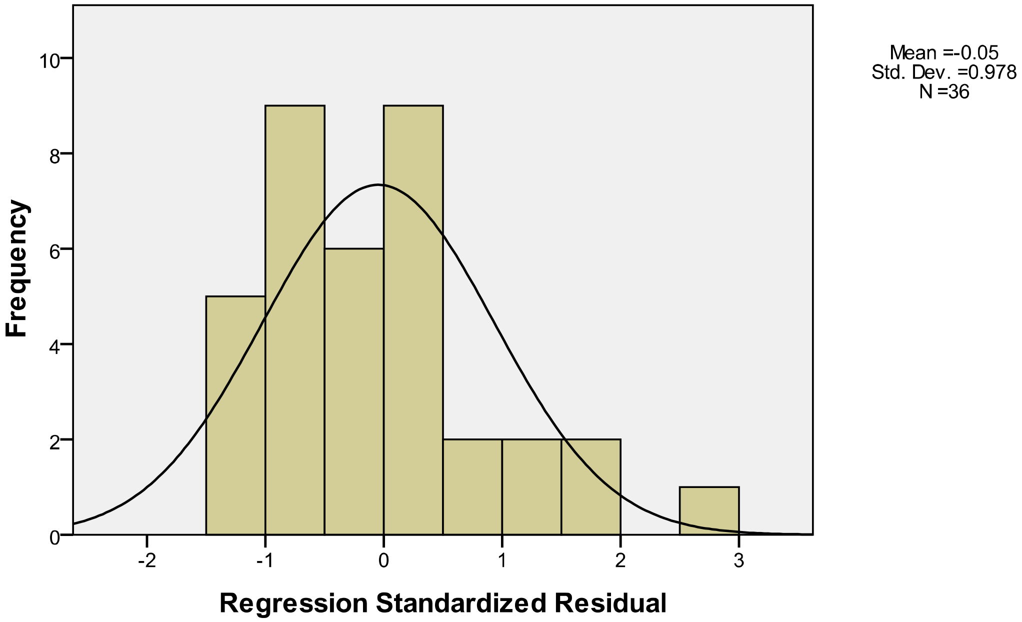
Residuals Statistics[a]

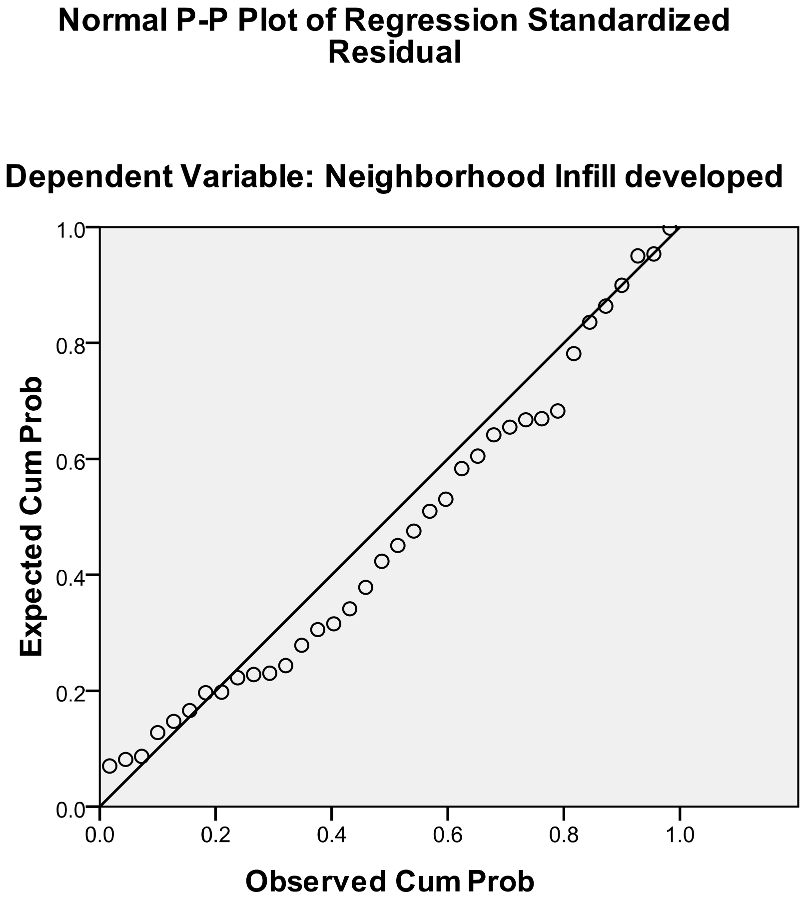
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.23	3.86	1.92	1.150	36
Residual	-1.080	2.142	-.033	.717	36
Std. Predicted Value	-1.907	1.588	-.066	.983	36
Std. Residual	-1.475	2.924	-.046	.978	36

a. Dependent Variable: Neighborhood Infill developed

Histogram

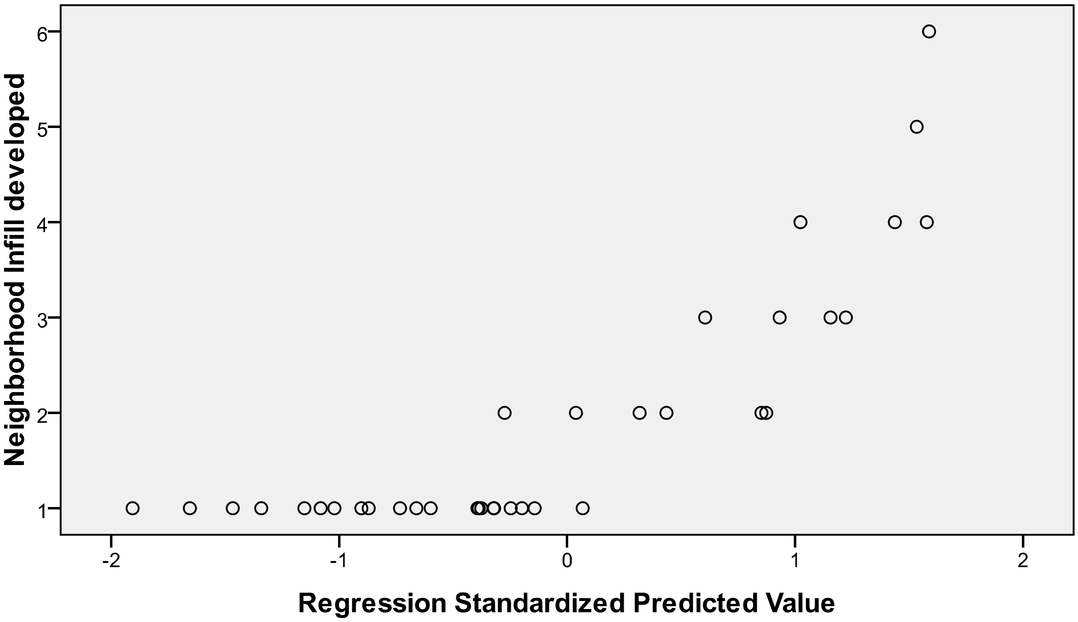
Dependent Variable: Neighborhood Infill developed




Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Neighborhood Infill developed
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob

Scatterplot

Dependent Variable: Neighborhood Infill developed



APPENDIX E

REGRESSION OUTPUT

RESIDENTIAL DEVELOPMENT WITHIN LEAPFROG NEIGHBORHOODS

Residential Parcel Development within Leapfrog Neighborhoods -Full Model

Descriptive Statistics

	Mean	Std. Deviation	N
LP_Parcels	1113.97	1176.546	62
X11_NB	2.0000	2.37473	62
X12_Age_exp_transformation	6.9679E11	4.28789E12	62
X13_Infill	7.6497E6	1.75906E7	62
X14	50579.2846	1.38640E5	62
X15	13631.0505	5904.92466	62
X16	6.1408	1.00468	62
X17	1.2583	.59996	62

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	X17, X13_Infill, X12_Age_exp_transformation, X15, X11_NB, X14, X16[a]	.	Enter

a. All requested variables entered.

Variables Entered/Removed			
Model	Variables Entered	Variables Removed	Method
1	X17, X13_Infill, X12_Age_exp_transformation, X15, X11_NB, X14, X16[a]	.	Enter

a. All requested variables entered.

Model Summary[b]					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.731[a]	.535	.474	853.147	.636

a. Predictors: (Constant), X17, X13_Infill, X12_Age_exp_transformation, X15, X11_NB, X14, X16

b. Dependent Variable: LP_Parcels

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.514E7	7	6447927.990	8.859	.000[a]
	Residual	3.930E7	54	727859.370		
	Total	8.444E7	61			

a. Predictors: (Constant), X17, X13_Infill, X12_Age_exp_transformation, X15, X11_NB, X14, X16

b. Dependent Variable: LP_Parcels

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	-2097.851	1352.560		-1.551	.127		
	X11_NB	-36.643	51.452	-.074	-.712	.479	.799	1.251
	X12_Age_exp	5.836E-11	.000	.213	2.224	.030	.943	1.061
	X13_Infill	5.383E-6	.000	.080	.782	.438	.813	1.229
	X14	-.008	.002	-.925	-4.585	.000	.212	4.721
	X15	.162	.028	.811	5.825	.000	.444	2.251
	X16	190.815	239.963	.163	.795	.430	.205	4.871
	X17	178.471	315.882	.091	.565	.574	.332	3.010

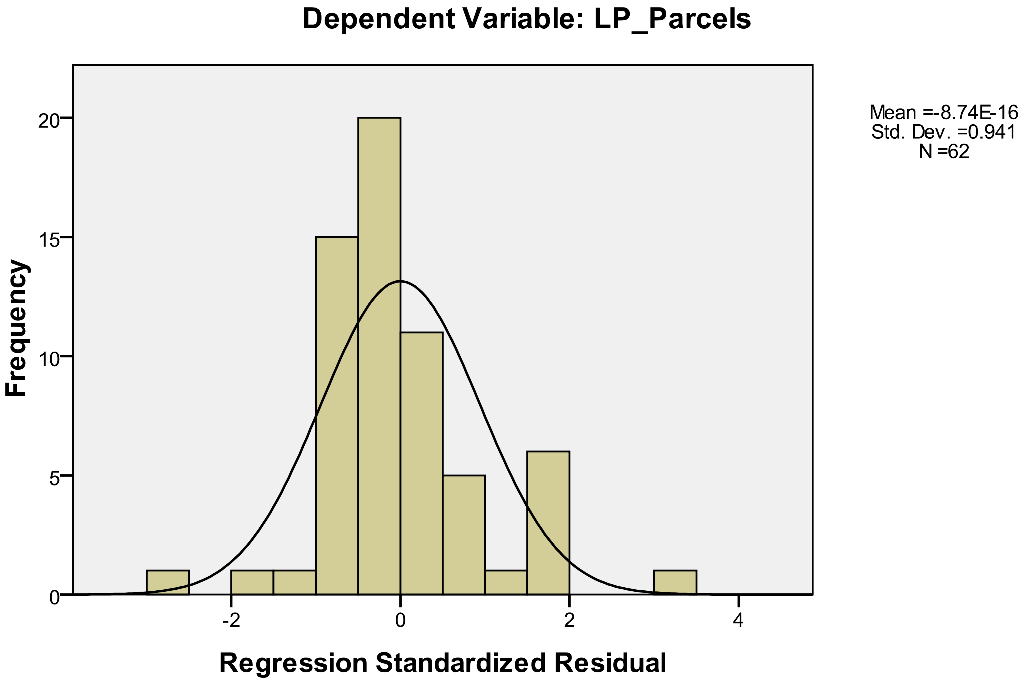
a. Dependent Variable: LP_Parcels

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-346.73	3671.10	1113.97	860.190	62
Residual	-2186.281	2770.152	.000	802.705	62
Std. Predicted Value	-1.698	2.973	.000	1.000	62
Std. Residual	-2.563	3.247	.000	.941	62

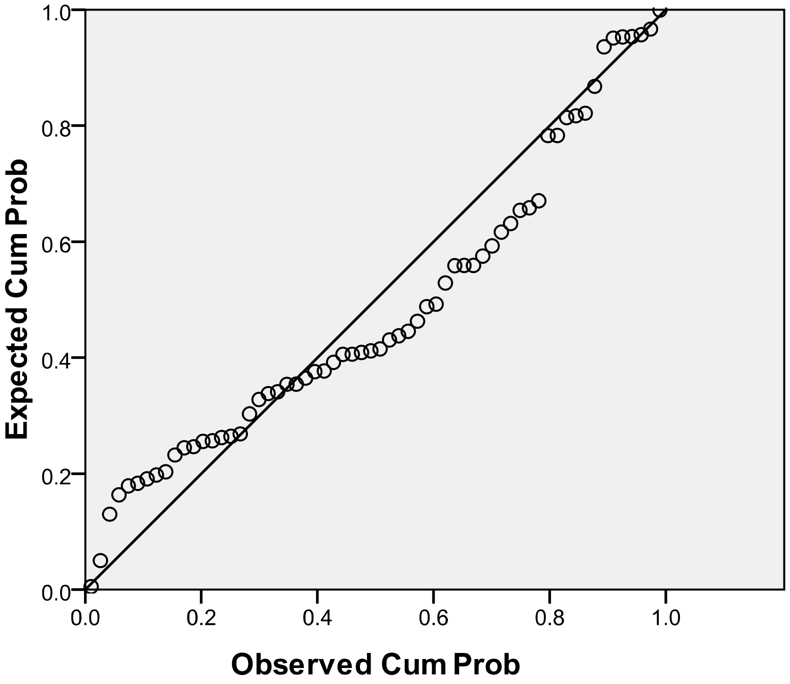
a. Dependent Variable: LP_Parcels

Histogram

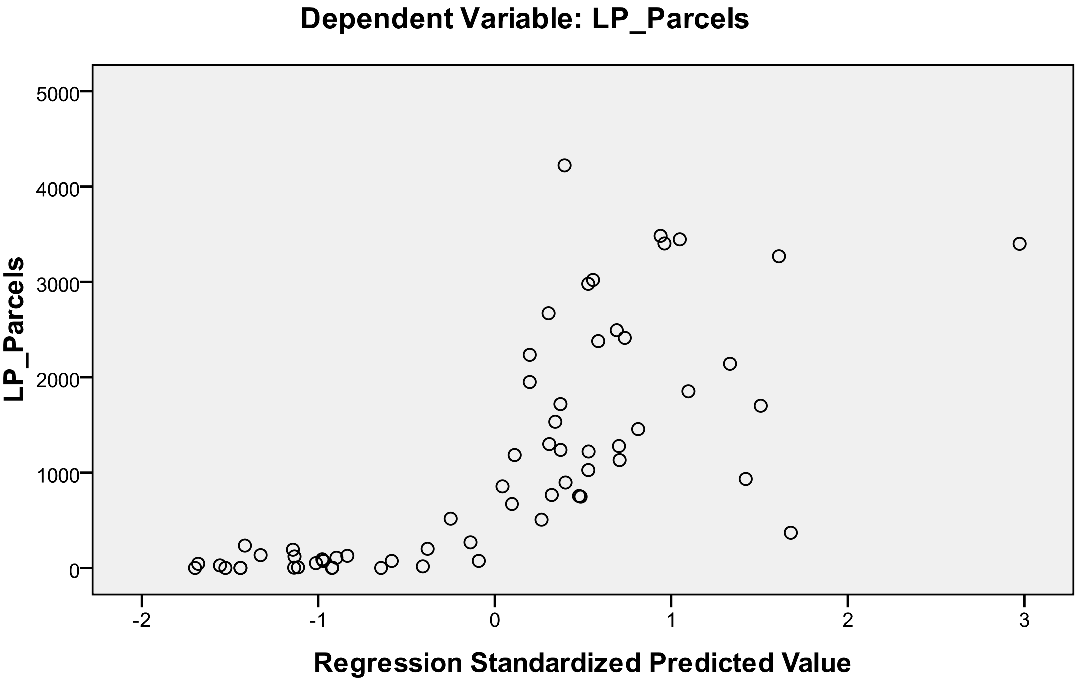

Dependent Variable: LP_Parcels
Mean =-8.74E-16
Std. Dev. =0.941
N =62
Frequency
20
15
10
5
0
-2
0
2
4
Regression Standardized Residual

Normal P-P Plot of Regression Standardized Residual

Dependent Variable: LP_Parcels



Scatterplot



Dependent Variable: LP_Parcels

Residential Parcel Development within Leapfrog Neighborhoods – Reduced Model

Descriptive Statistics

	Mean	Std. Deviation	N
LP_Parcels	1113.97	1176.546	62
X11_NB	2.0000	2.37473	62
X12_Age_exp_transformation	6.9679E11	4.28789E12	62
X13_Infill	7.6497E6	1.75906E7	62
X14	50579.2846	1.38640E5	62
X15	13631.0505	5904.92466	62
X16	6.1408	1.00468	62
X17	1.2583	.59996	62

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	X15	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	X14	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	X12_Age_exp_transformation	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: LP_Parcels

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.324[a]	.105	.090	1122.332	
2	.669[b]	.448	.429	888.858	
3	.710[c]	.504	.478	850.088	.586

a. Predictors: (Constant), X15

b. Predictors: (Constant), X15, X14

c. Predictors: (Constant), X15, X14, X12_Age_exp_transformation

d. Dependent Variable: LP_Parcels

ANOVA[d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8862143.206	1	8862143.206	7.036	.010[a]
	Residual	7.558E7	60	1259629.312		
	Total	8.444E7	61			
2	Regression	3.783E7	2	1.891E7	23.938	.000[b]
	Residual	4.661E7	59	790068.120		
	Total	8.444E7	61			
3	Regression	4.253E7	3	1.418E7	19.616	.000[c]
	Residual	4.191E7	58	722650.151		
	Total	8.444E7	61			

a. Predictors: (Constant), X15

b. Predictors: (Constant), X15, X14

c. Predictors: (Constant), X15, X14, X12_Age_exp_transformation

d. Dependent Variable: LP_Parcels

Coefficients[a]

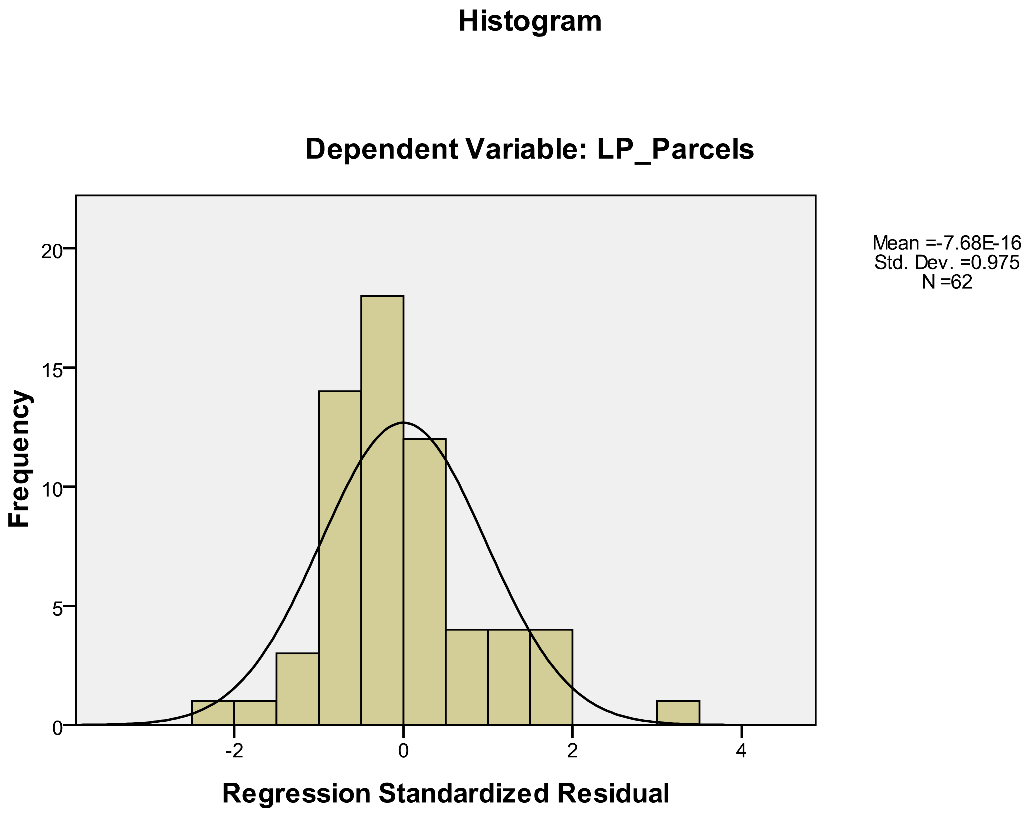
Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	234.096	361.047		.648	.519		
	X15	.065	.024	.324	2.652	.010	1.000	1.000
2	(Constant)	-656.763	321.574		-2.042	.046		
	X15	.153	.024	.768	6.327	.000	.635	1.575
	X14	-.006	.001	-.735	-6.055	.000	.635	1.575
3	(Constant)	-622.274	307.845		-2.021	.048		
	X15	.146	.023	.734	6.278	.000	.626	1.596
	X14	-.006	.001	-.704	-6.029	.000	.628	1.593
	X12_Age_exp	6.523E-11	.000	.238	2.550	.013	.985	1.015

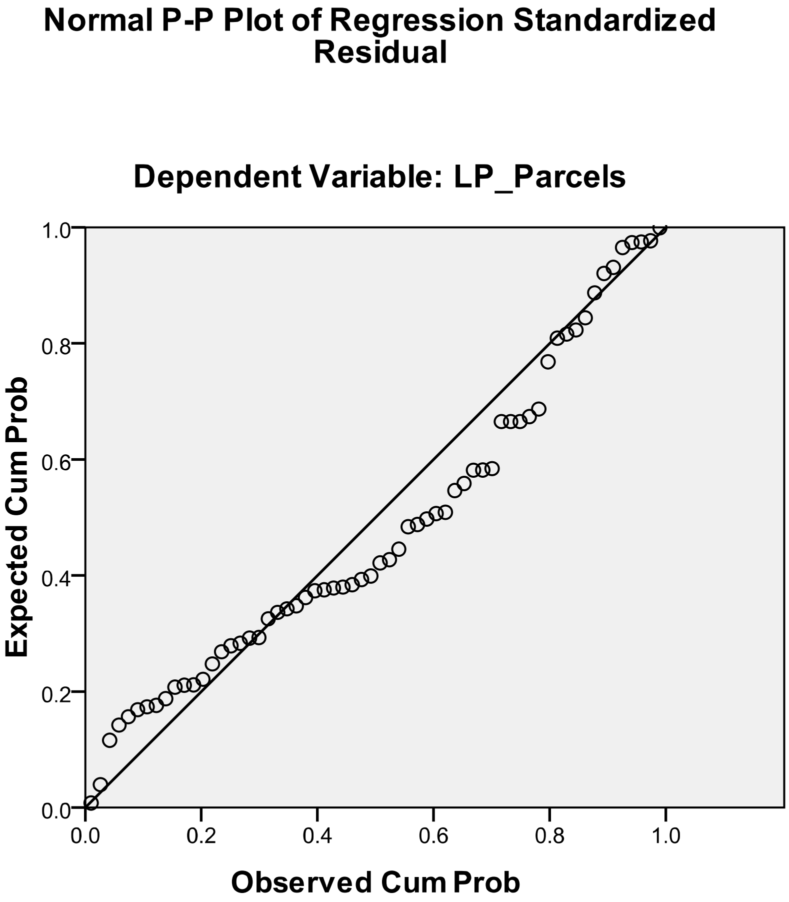
a. Dependent Variable: LP_Parcels

Residuals Statistics[a]

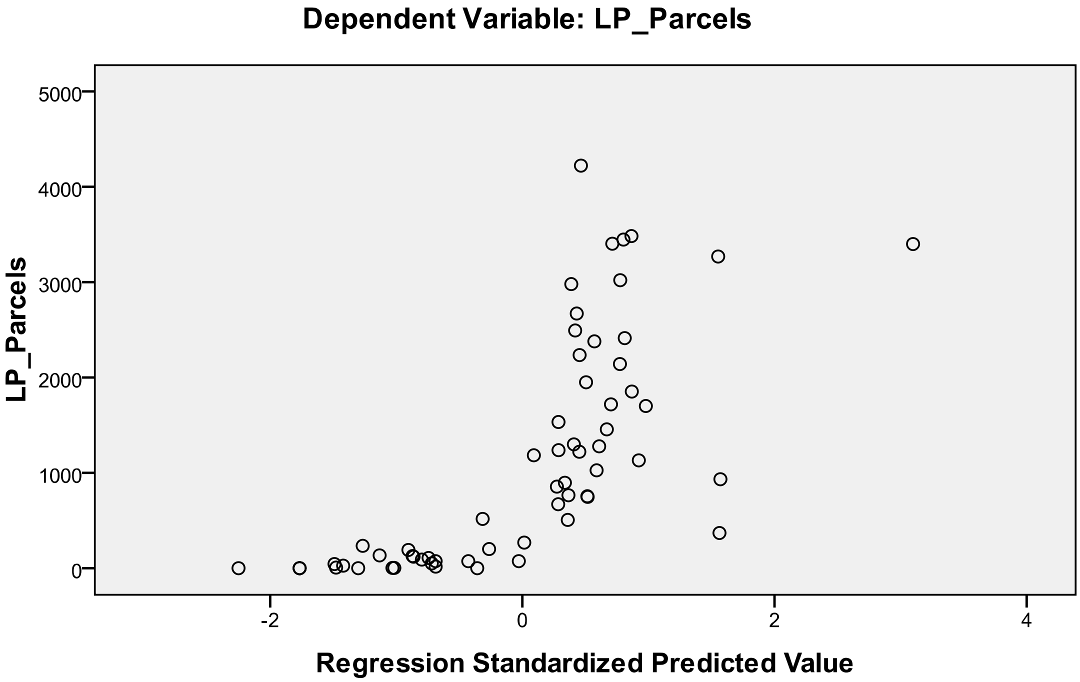
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-764.02	3701.20	1113.97	834.956	62
Residual	-2049.995	2720.736	.000	828.921	62
Std. Predicted Value	-2.249	3.099	.000	1.000	62
Std. Residual	-2.412	3.201	.000	.975	62

a. Dependent Variable: LP_Parcels


Histogram
Dependent Variable: LP_Parcels
Mean =-7.68E-16
Std. Dev. =0.975
N =62
Frequency
0
5
10
15
20
-2
0
2
4
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: LP_Parcels
Expected Cum Prob
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

Scatterplot



APPENDIX F

REGRESSION OUTPUT

RESIDENTIAL DEVELOPMENT WITHIN CONTAGION NEIGHBORHOODS

Residential Parcel Development within Contagion Neighborhoods -Full Model

Descriptive Statistics

	Mean	Std. Deviation	N
Parcels developed in Contagion	757.94	729.417	62
X11	2.24	2.720	62
X12	9.29	5.678	62
X13_Leapfrog	1.2871E7	1.53218E7	62
X14	14633.6851	11391.99669	62
X15	11716.6421	5619.39856	62
X16	5.7102	.45812	62
X17	1.2190	.41804	62

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	X17, X14, X13_Leapfrog, X16, X11, X12, X15[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.939[a]	.881	.866	267.051	1.658

a. Predictors: (Constant), X17, X14, X13_Leapfrog, X16, X11, X12, X15

b. Dependent Variable: Parcels developed in Contagion

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.860E7	7	4086280.244	57.298	.000[a]
	Residual	3851074.037	54	71316.186		
	Total	3.246E7	61			

a. Predictors: (Constant), X17, X14, X13_Leapfrog, X16, X11, X12, X15

b. Dependent Variable: Parcels developed in Contagion

Coefficients[a]								
		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	-1840.073	584.828		-3.146	.003		
	X11	11.514	16.209	.043	.710	.481	.601	1.663
	X12L	43.381	10.128	.338	4.283	.000	.353	2.829
	X13L	2.848E-5	.000	.598	8.119	.000	.405	2.471
	X14	-.001	.003	-.019	-.386	.701	.879	1.138
	X15	.028	.011	.219	2.686	.010	.331	3.025
	X16	314.337	101.247	.197	3.105	.003	.543	1.840
	X17	-252.098	108.600	-.144	-2.321	.024	.567	1.763

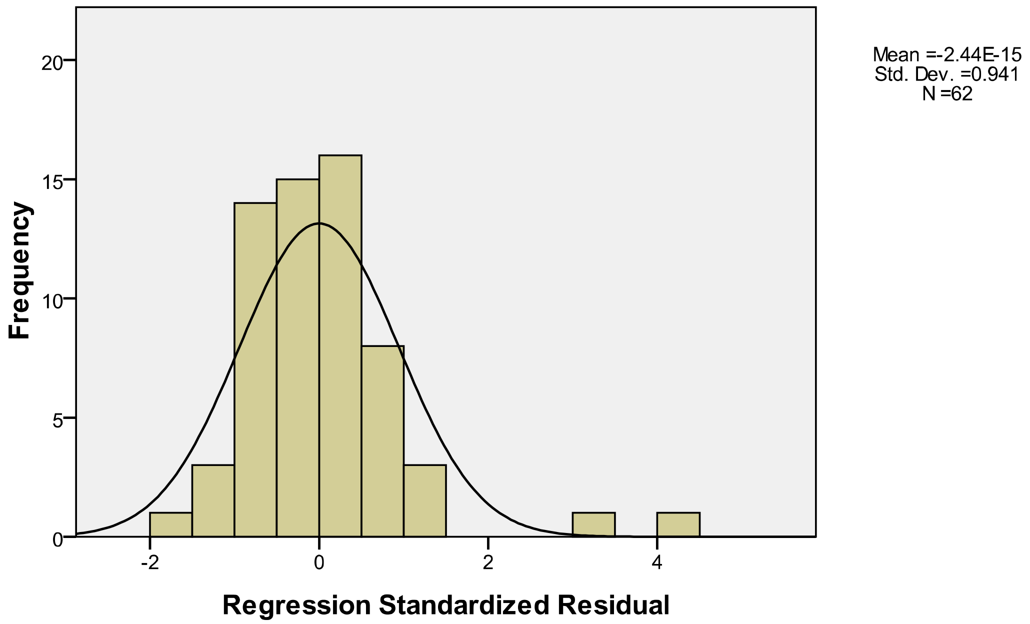
a. Dependent Variable: Parcels developed in Contagion

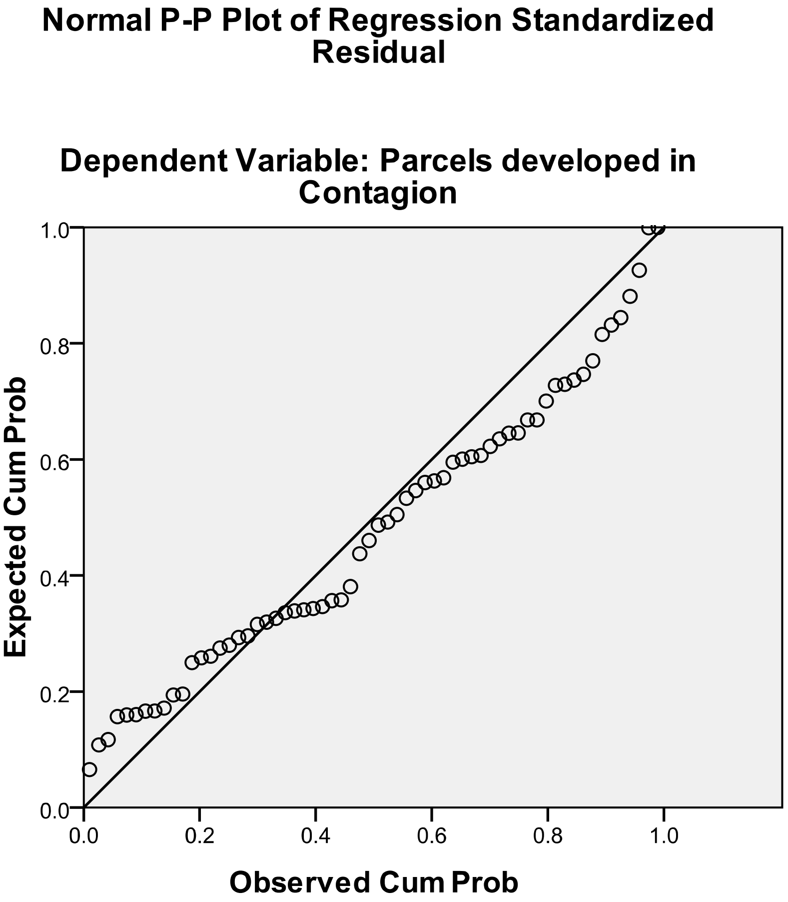
Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-314.12	2777.44	757.94	684.775	62
Residual	-402.964	1126.776	.000	251.262	62
Std. Predicted Value	-1.566	2.949	.000	1.000	62
Std. Residual	-1.509	4.219	.000	.941	62

a. Dependent Variable: Parcels developed in Contagion

Histogram

Dependent Variable: Parcels developed in Contagion



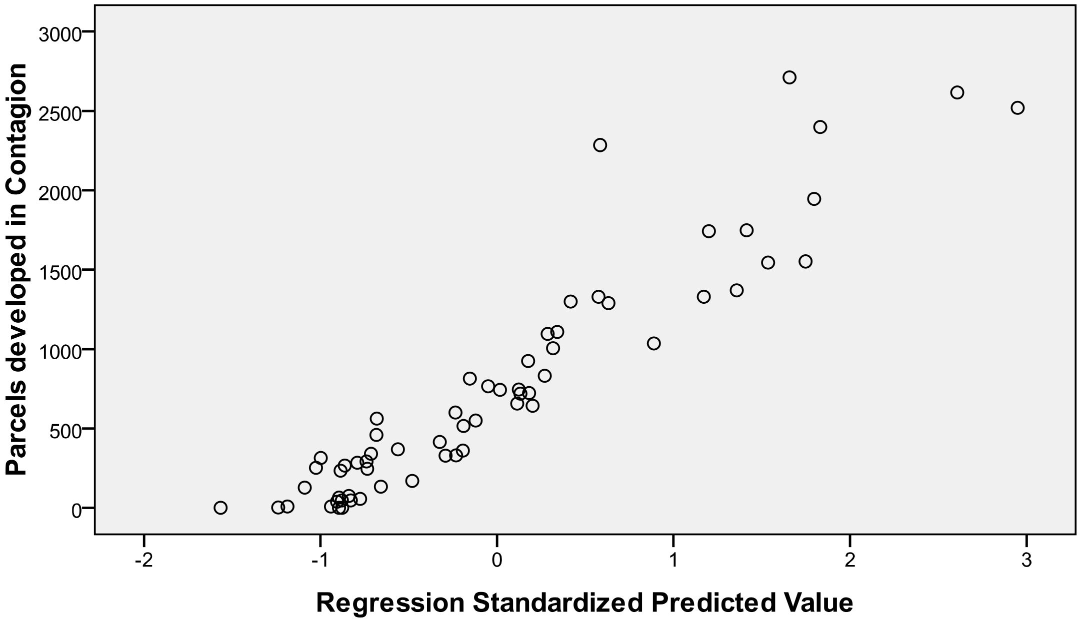


Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Parcels developed in Contagion

Scatterplot

Dependent Variable: Parcels developed in Contagion



Residential Parcel Development within Contagion Neighborhoods - Reduced Model

Descriptive Statistics

	Mean	Std. Deviation	N
Parcels developed in Contagion	757.94	729.417	62
X11	2.24	2.720	62
X12	9.29	5.678	62
X13_Leapfrog	1.2871E7	1.53218E7	62
X14	14633.6851	11391.99669	62
X15	11716.6421	5619.39856	62
X16	5.7102	.45812	62
X17	1.2190	.41804	62

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	X13_Leapfrog	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	X12	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Parcels developed in Contagion

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.883[a]	.779	.775	345.690	
2	.920[b]	.847	.842	290.171	1.829

a. Predictors: (Constant), X13_Leapfrog

b. Predictors: (Constant), X13_Leapfrog, X12

c. Dependent Variable: Parcels developed in Contagion

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.528E7	1	2.528E7	211.586	.000[a]
	Residual	7170101.691	60	119501.695		
	Total	3.246E7	61			
2	Regression	2.749E7	2	1.374E7	163.228	.000[b]
	Residual	4967746.868	59	84199.099		
	Total	3.246E7	61			

a. Predictors: (Constant), X13_Leapfrog

b. Predictors: (Constant), X13_Leapfrog, X12

c. Dependent Variable: Parcels developed in Contagion

Coefficients[a]

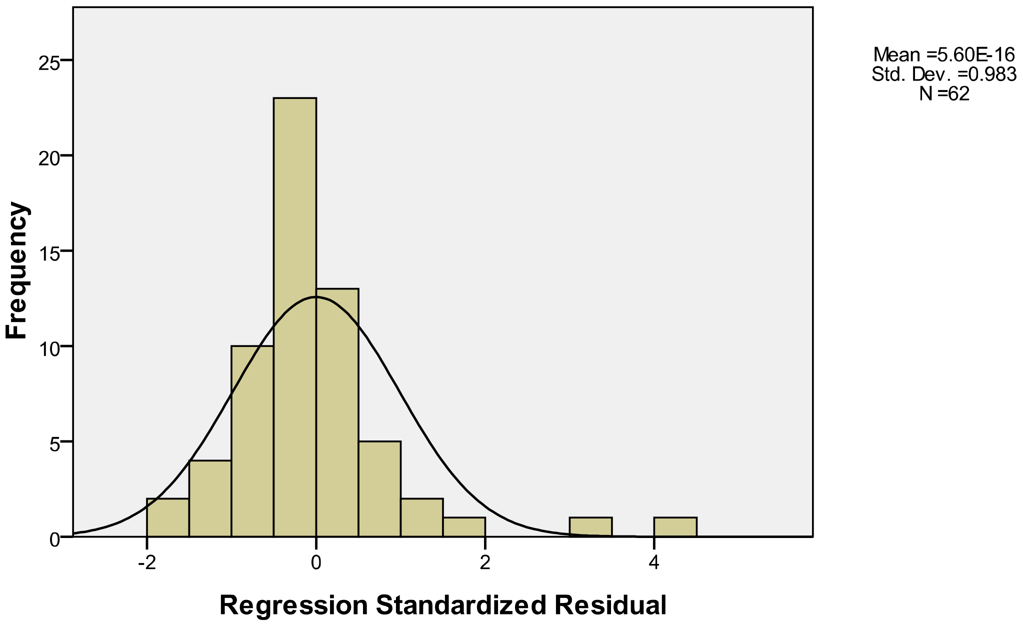
Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	217.092	57.532		3.773	.000		
	X13L	4.202E-5	.000	.883	14.546	.000	1.000	1.000
2	(Constant)	-54.752	71.815		-.762	.449		
	X13L	3.730E-5	.000	.783	14.375	.000	.873	1.145
	X12L	35.807	7.001	.279	5.114	.000	.873	1.145

a. Dependent Variable: Parcels developed in Contagion

Residuals Statistics[a]

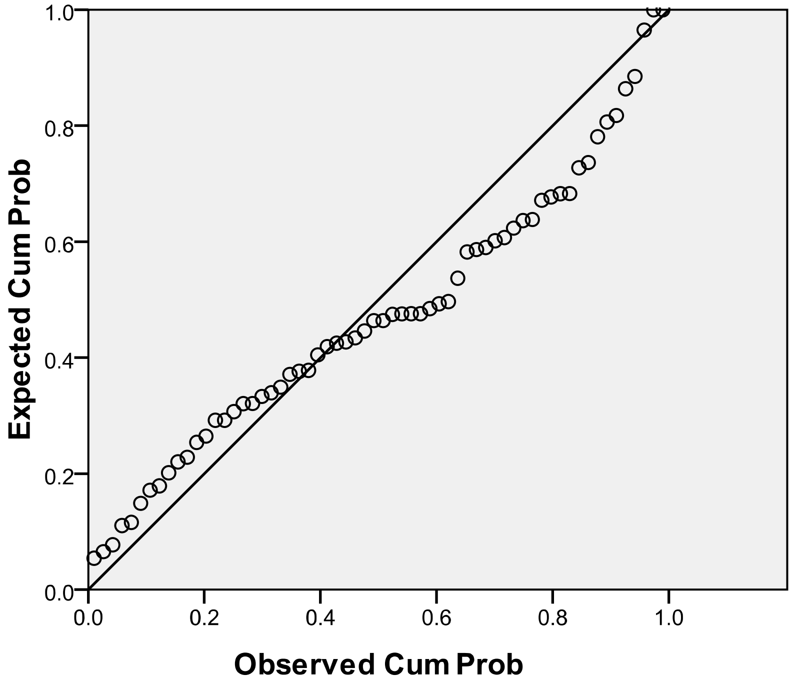
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	18.57	2839.68	757.94	671.276	62
Residual	-465.923	1284.406	.000	285.374	62
Std. Predicted Value	-1.101	3.101	.000	1.000	62
Std. Residual	-1.606	4.426	.000	.983	62

a. Dependent Variable: Parcels developed in Contagion



Histogram

Dependent Variable: Parcels developed in Contagion

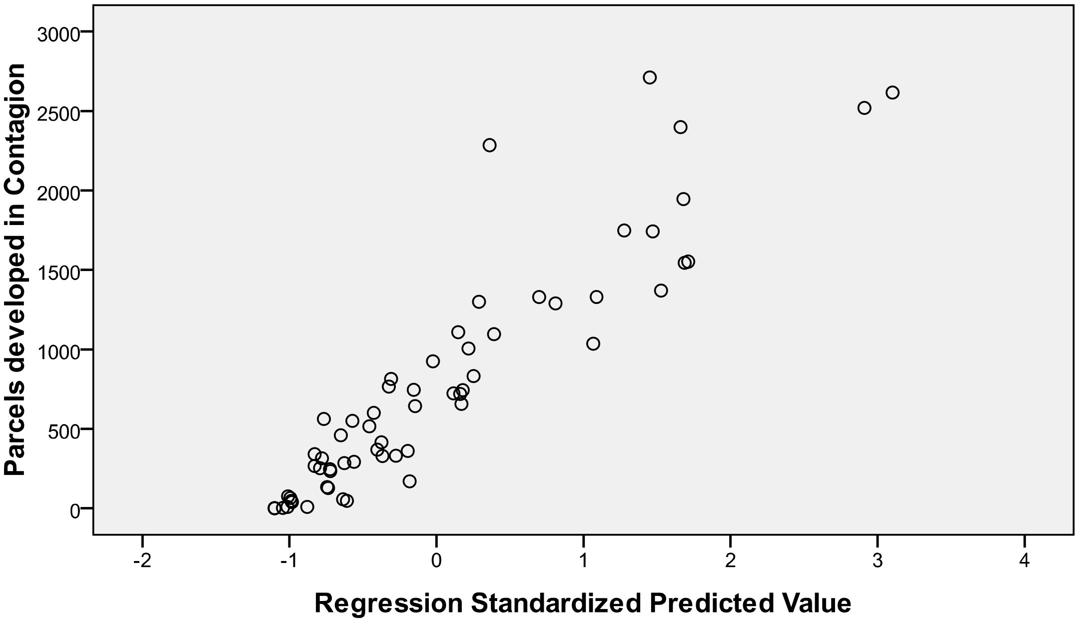


Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Parcels developed in Contagion

Scatterplot

Dependent Variable: Parcels developed in Contagion



APPENDIX G

REGRESSION OUTPUT

RESIDENTIAL DEVELOPMENT WITHIN INFILL NEIGHBORHOODS

Residential Parcel Development within Infill Neighborhoods -Full Model

Descriptive Statistics

	Mean	Std. Deviation	N
Parcels developed infill NB	290.15	285.846	62
X11	1.0968	1.37554	62
X12	1.8990	.82375	62
X13_contagion	9.0036E6	1.02000E7	62
X14	21494.3889	30231.67646	62
X15	14894.0292	7612.42519	62
X16	5.6755	.58018	62
X17	1.2001	.72243	62

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	X17, X15, X13_contagion, X16, X14, X11, X12[a]	.	Enter

a. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.672[a]	.452	.381	224.901	.935

a. Predictors: (Constant), X17, X15, X13_contagion, X16, X14, X11, X12

b. Dependent Variable: Parcels developed infill NB

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2252839.157	7	321834.165	6.363	.000[a]
	Residual	2731334.537	54	50580.269		
	Total	4984173.694	61			

a. Predictors: (Constant), X17, X15, X13_contagion, X16, X14, X11, X12

b. Dependent Variable: Parcels developed infill NB

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	-524.605	378.248		-1.387	.171		
	X11	53.214	25.586	.256	2.080	.042	.669	1.494
	X12	149.688	47.097	.431	3.178	.002	.551	1.815
	X13_contagion	1.133E-5	.000	.404	3.154	.003	.618	1.618
	X14	.000	.001	-.055	-.450	.655	.673	1.485
	X15	.002	.004	.048	.437	.664	.833	1.200
	X16	71.109	64.565	.144	1.101	.276	.591	1.692
	X17	-40.979	56.060	-.104	-.731	.468	.506	1.978

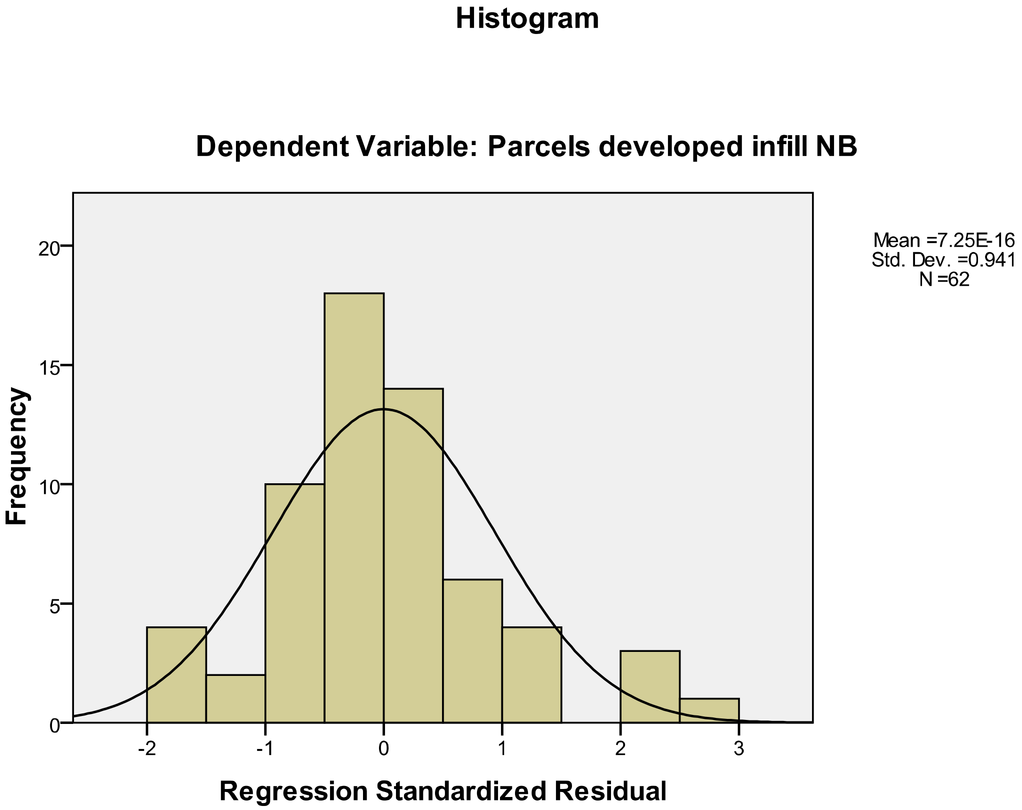
Coefficients[a]

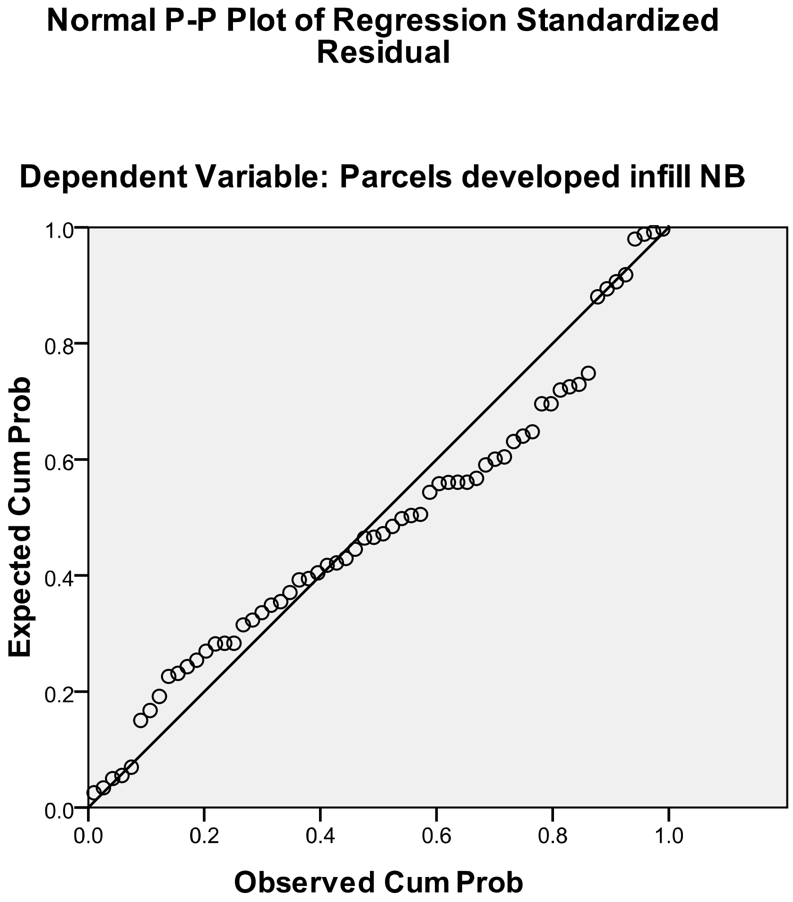
a. Dependent Variable: Parcels developed infill NB

Residuals Statistics[a]

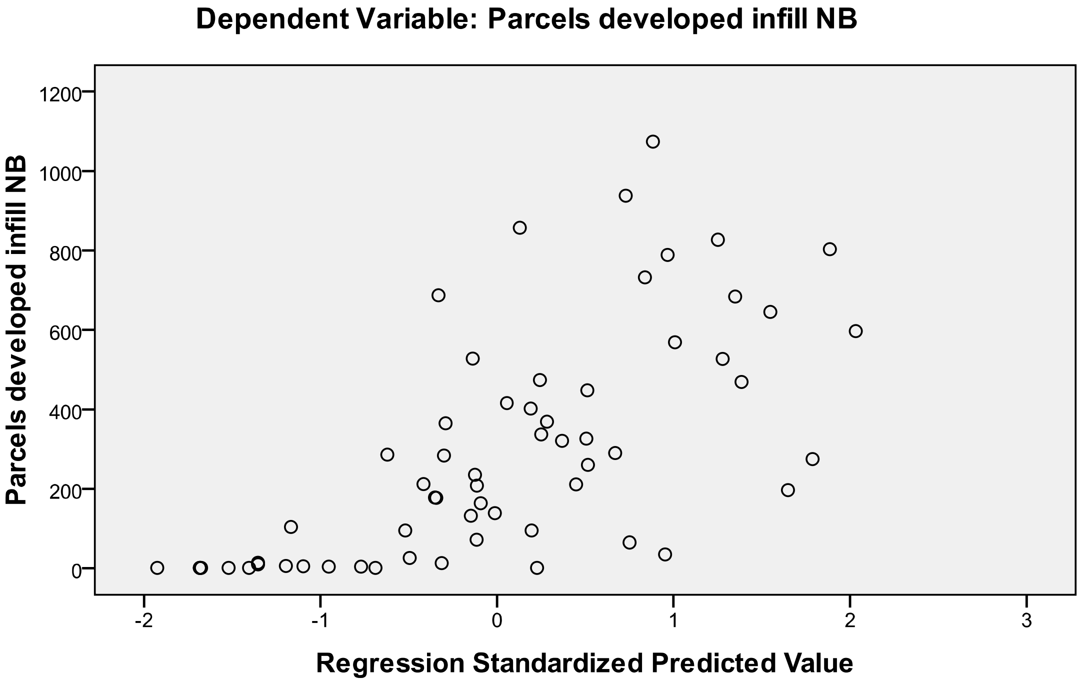
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-79.74	680.68	290.15	192.176	62
Residual	-438.153	614.039	.000	211.603	62
Std. Predicted Value	-1.925	2.032	.000	1.000	62
Std. Residual	-1.948	2.730	.000	.941	62

a. Dependent Variable: Parcels developed infill NB


Histogram
Dependent Variable: Parcels developed infill NB
Mean =7.25E-16
Std. Dev. =0.941
N =62
Frequency
0
5
10
15
20
-2
-1
0
1
2
3
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Parcels developed infill NB
Expected Cum Prob
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

Scatterplot



Residential Parcel Development within Infill Neighborhoods - Reduced Model

Descriptive Statistics

	Mean	Std. Deviation	N
Parcels developed infill NB	290.15	285.846	62
X11	1.0968	1.37554	62
X12	1.8990	.82375	62
X13_contagion	9.0036E6	1.02000E7	62
X14	21494.3889	30231.67646	62
X15	14894.0292	7612.42519	62
X16	5.6755	.58018	62
X17	1.2001	.72243	62

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	X13_contagion	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	X12	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	X11	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Parcels developed infill NB

Model Summary[d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.498[a]	.248	.235	249.980	
2	.603[b]	.364	.342	231.795	
3	.653[c]	.426	.396	222.074	.874

a. Predictors: (Constant), X13_contagion

b. Predictors: (Constant), X13_contagion, X12

c. Predictors: (Constant), X13_contagion, X12, X11

d. Dependent Variable: Parcels developed infill NB

ANOVA[d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1234775.511	1	1234775.511	19.760	.000[a]
	Residual	3749398.182	60	62489.970		
	Total	4984173.694	61			
2	Regression	1814180.032	2	907090.016	16.883	.000[b]
	Residual	3169993.662	59	53728.706		
	Total	4984173.694	61			
3	Regression	2123783.297	3	707927.766	14.355	.000[c]
	Residual	2860390.396	58	49317.076		
	Total	4984173.694	61			

a. Predictors: (Constant), X13_contagion

b. Predictors: (Constant), X13_contagion, X12

c. Predictors: (Constant), X13_contagion, X12, X11

d. Dependent Variable: Parcels developed infill NB

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	164.558	42.498		3.872	.000		
	X13_contagion	1.395E-5	.000	.498	4.445	.000	1.000	1.000
2	(Constant)	-43.646	74.650		-.585	.561		
	X13_contagion	1.080E-5	.000	.385	3.525	.001	.902	1.109
	X12	124.573	37.935	.359	3.284	.002	.902	1.109
3	(Constant)	-90.581	73.932		-1.225	.225		
	X13_contagion	1.028E-5	.000	.367	3.493	.001	.897	1.114
	X12	121.725	36.362	.351	3.348	.001	.901	1.110
	X11	52.004	20.755	.250	2.506	.015	.992	1.008

a. Dependent Variable: Parcels developed infill NB

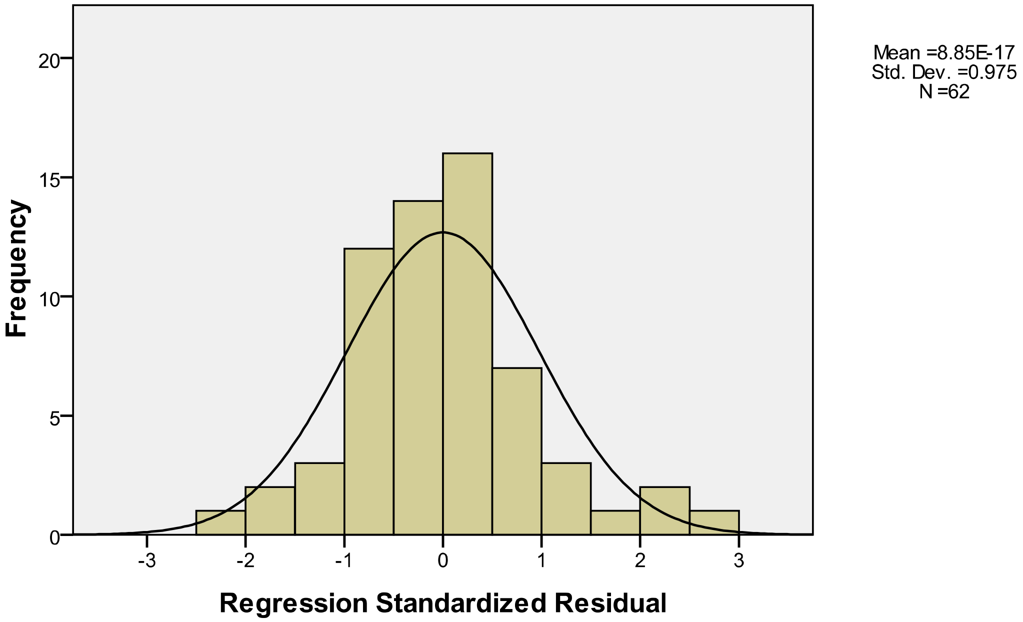
Residuals Statistics[a]

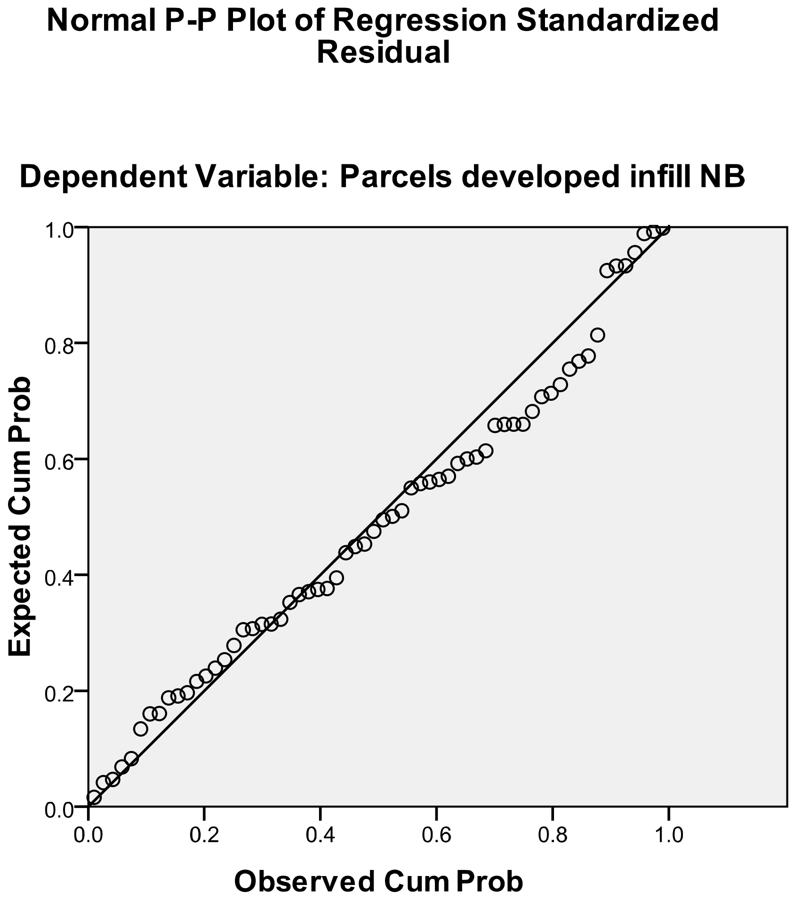
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-90.42	754.39	290.15	186.591	62
Residual	-475.629	646.655	.000	216.545	62
Std. Predicted Value	-2.040	2.488	.000	1.000	62
Std. Residual	-2.142	2.912	.000	.975	62

a. Dependent Variable: Parcels developed infill NB

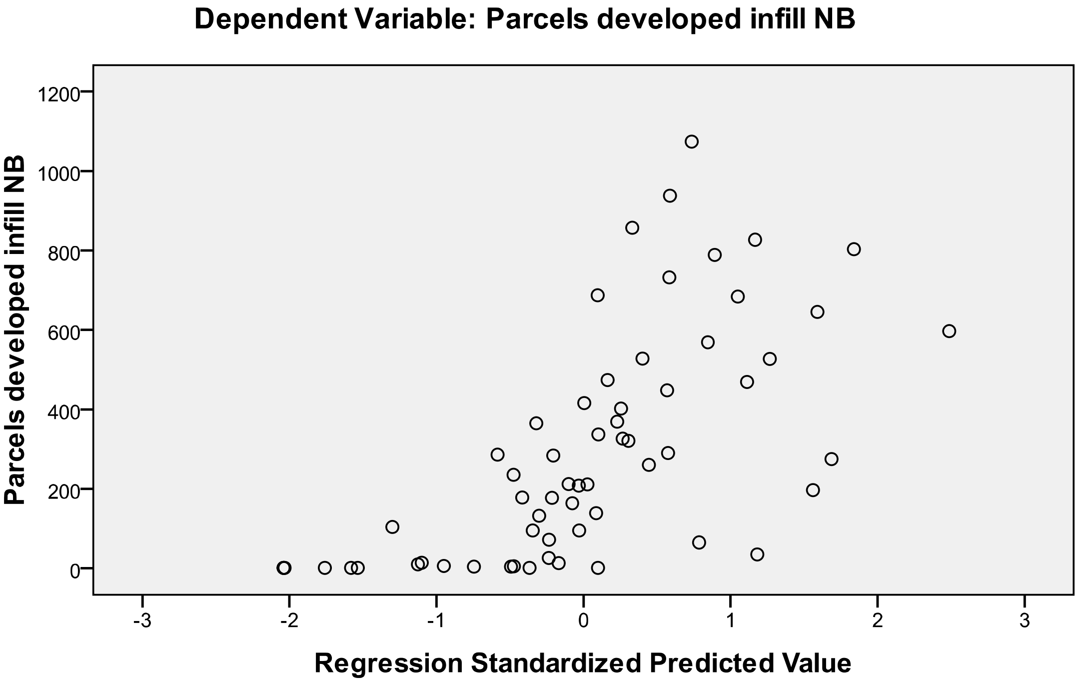
Histogram

Dependent Variable: Parcels developed infill NB




Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Parcels developed infill NB
Expected Cum Prob
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0

Scatterplot



APPENDIX H

REGRESSION OUTPUT

Residential Parcel Development and year –Leapfrog Neighborhood

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X11[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: LP_Parcels

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.783[a]	.613	.606	738.320

a. Predictors: (Constant), X11

b. Dependent Variable: LP_Parcels

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.173E7	1	5.173E7	94.902	.000[a]
	Residual	3.271E7	60	545116.989		
	Total	8.444E7	61			

a. Predictors: (Constant), X11

b. Dependent Variable: LP_Parcels

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	-99723.042	10351.405		-9.634	.000
	X11	51.044	5.240	.783	9.742	.000

a. Dependent Variable: LP_Parcels

Residual of year and Age –Leapfrog Neighborhood

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Age[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Unstandardized Residual

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.059[a]	.003	-.013	737.03247590

a. Predictors: (Constant), Age

b. Dependent Variable: Unstandardized Residual

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	114007.127	1	114007.127	.210	.649[a]
	Residual	3.259E7	60	543216.871		
	Total	3.271E7	61			

a. Predictors: (Constant), Age

b. Dependent Variable: Unstandardized Residual

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	70.999	181.053		.392	.696
	Age	-6.699	14.623	-.059	-.458	.649

a. Dependent Variable: Unstandardized Residual

Residential Parcel Development and year –Contagion Neighborhood

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X11[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Parcels developed in Contagion

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.745[a]	.556	.548	490.336

a. Predictors: (Constant), X11

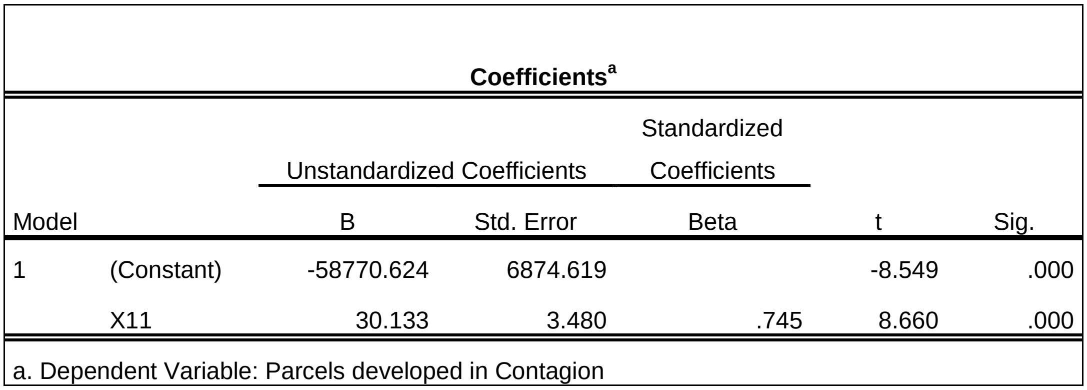
b. Dependent Variable: Parcels developed in Contagion

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.803E7	1	1.803E7	74.988	.000[a]
	Residual	1.443E7	60	240429.872		
	Total	3.246E7	61			

a. Predictors: (Constant), X11

b. Dependent Variable: Parcels developed in Contagion



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-58770.624	6874.619		-8.549	.000
	X11	30.133	3.480	.745	8.660	.000

a. Dependent Variable: Parcels developed in Contagion

Residual of year and Age –Contagion Neighborhood

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X12[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Unstandardized Residual

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.065[a]	.004	-.012	489.28427009

a. Predictors: (Constant), X12

b. Dependent Variable: Unstandardized Residual

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	61846.511	1	61846.511	.258	.613[a]
	Residual	1.436E7	60	239399.097		
	Total	1.443E7	61			

a. Predictors: (Constant), X12

b. Dependent Variable: Unstandardized Residual

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	52.092	119.854		.435	.665
	X12	-5.608	11.033	-.065	-.508	.613

a. Dependent Variable: Unstandardized Residual

Residential Parcel Development and year – Infill Neighborhood

Variables Entered/Removed[b]			
Model	Variables Entered	Variables Removed	Method
1	Year[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Parcels developed infill NB

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.780[a]	.609	.602	180.321

a. Predictors: (Constant), Year

b. Dependent Variable: Parcels developed infill NB

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3033230.768	1	3033230.768	93.285	.000[a]
	Residual	1950942.926	60	32515.715		
	Total	4984173.694	61			

a. Predictors: (Constant), Year

b. Dependent Variable: Parcels developed infill NB

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-24126.689	2528.140		-9.543	.000
	Year	12.360	1.280	.780	9.658	.000

a. Dependent Variable: Parcels developed infill NB

Residual of year and Age – Infill Neighborhood

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	X12[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Unstandardized Residual

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.063[a]	.004	-.013	179.96367519

a. Predictors: (Constant), X12

b. Dependent Variable: Unstandardized Residual

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7727.462	1	7727.462	.239	.627[a]
	Residual	1943215.463	60	32386.924		
	Total	1950942.926	61			

a. Predictors: (Constant), X12

b. Dependent Variable: Unstandardized Residual

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-1497.517	3065.846		-.488	.627
	X12	.761	1.558	.063	.488	.627

a. Dependent Variable: Unstandardized Residual

VITA

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- M.L.A., Graduate School of Environmental Studies, Seoul National University, Seoul, Korea. 2001.
- B.Agr., Department of Horticultural Science, College of Natural Science, Seoul Women's University, Seoul, Korea. 1997.

Experience

- Fall 2007 – Spring 2009: Instructor (computer section), Dept. of Landscape Architecture and Urban Planning, Texas A&M University.
- Summer 2008: Student Technician II, Economics, Trade, and Logistics Program, Texas Transportation Institute.
- Fall 2005 – Spring 2007: Teaching Assistant, Graduate Assistant, Dept. of Landscape Architecture and Urban Planning, Texas A&M University.
- Summer 2005: GIS Student Worker, Dept. of MAPS/GIS, Evans Library, Texas A&M University,
- Spring 2004 – Spring 2005: Teaching Assistant, Dept. of Landscape Architecture and Urban Planning, Texas A&M University.
- Mar. 2010 – Jul. 2003: Researcher, Department of Urban Environment, Seoul Development Institute.
- Spring 1999: Teaching Assistant, Dept. of Landscape Architecture, Seoul National University, Graduate School of Environmental Studies.