The Accessibility and Development Impacts of New Transit Infrastructure:
The Circle Line in Chicago

by

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Abstract

This thesis explores the impacts of new transit infrastructure projects on the land use transportation system. Land use and transportation systems are inherently interconnected and form an integrated system; and transport projects affect not just the transportation system, but also land use patterns. Current evaluation frameworks and models applied to new transport infrastructure projects usually focus on transportation system improvements, and so do not reflect the process of land use transportation interaction. To overcome this limitation, this thesis argues that the evaluation of transport projects should consider their accessibility and development impacts; and that this requires models which explicitly incorporate the interaction between land use and transportation.

The Circle Line in Chicago is a proposed circumferential rail transit line which will serve the urban core of the Chicago region, and is likely to significantly affect both land use and travel patterns. This thesis assesses how existing models can be used to quantify the accessibility and development impacts of this project; and how an existing evaluation framework, developed by the Federal Transit Administration, considers these impacts. In addition, this thesis develops a quasi-integrated land use transportation model for the Chicago region; and applies it to quantify the accessibility and development impacts of the Circle Line project. The frameworks and models developed for the Circle Line project provide an example of how to improve the current FTA evaluation methodology.

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The Accessibility and Development Impacts of New Transit Infrastructure: The Circle Line in Chicago

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1. Introduction

Over the past decade, there has been an increase in investment in transit infrastructure in the United States with a number of cities starting or extending transit lines. Transit infrastructure projects are seen as opportunities to provide an alternative to the automobile, reduce road congestion, automobile emissions, transit travel times, as well as increase transit ridership. Another significant impact of new transit infrastructure projects is to change land use patterns and to increase development intensity around transit. In other words, to affect the land use system by capitalizing on the transportation system improvements afforded by these projects. While the argument for leveraging the interaction between transport and land use is not new, this interaction is not formally incorporated into the evaluation frameworks currently used to assess new transit infrastructure projects. This thesis improves the current evaluation methodology, creates a framework to consider land use and transport interactions, and develops a model to quantify the impact of new transit infrastructure projects on land use patterns and on the larger integrated land use transportation system (LUT).

The concept of accessibility, defined as the degree to which the LUT allows people to fulfill their daily wants and needs in terms of access to opportunities and activities (like education, employment, shopping, etc.), is the key to understand, consider and quantify the impacts of transportation projects on the LUT, and vice versa. Accessibility is the benefit afforded by the integrated LUT. Accessibility also captures the potential impacts of transportation system improvements, land use and development changes, and the interplay between the two. However, accessibility, understood this way, is rarely explicitly used in the evaluation of new transit infrastructure projects. This thesis demonstrates techniques for incorporating accessibility impacts into transit evaluations, and shows the effect of doing so in an integrated LUT framework.

Recognizing the accessibility benefits and possible land development impacts of new transit infrastructure projects is an important step. Increasing and ultimately realizing these accessibility and development benefits, however, requires change in current land use policies (e.g. zoning regulations and urban design guidelines) to support development around transit. In many instances this does not happen, in part due to a lack of understanding regarding the influence of land use policies in supporting development around transit. This thesis shows a clear link between land use policies, development, and accessibility.
1.1. Research Objectives

The specific research objectives of this thesis are:

— Improving the evaluation framework for new transit infrastructure projects: New transit infrastructure projects in the United States are evaluated by the Federal Transit Administration using the FTA New Starts evaluation framework in order to make federal funding decisions. Currently, the number of projects applying for federal funding far exceeds the total amount of funding available, and so this evaluation framework serves a critical purpose to indentify the most deserving projects. The evaluation framework uses an accessibility measure to quantify benefits of new transit infrastructure projects. However, the framework and models used to calculate the accessibility measure force it to focus narrowly on transportation system improvements. Potential land use or development impacts are sometimes not considered, and rarely quantified. Consequently, this evaluation framework ignores potentially substantial benefits of new transit infrastructure projects and may undermine many deserving projects. This thesis improves the current evaluation criteria by developing frameworks and models that quantify accessibility, and development impacts of such projects.

— Incorporating potential development impacts in the calculation of accessibility: This thesis builds upon prior research, specifically Jeffrey Busby’s (MST 2004) thesis ‘Accessibility-based Transit Planning’. Busby estimates the impact of new transit infrastructure projects on accessibility using a gravity-based measure of accessibility. His model considers the effect of transportation system improvements on accessibility. However, his model does not account for development impacts due to changes in accessibility and subsequent accessibility impacts due to changes in development. This thesis builds upon Busby’s research by incorporating potential development impacts into the calculation of accessibility impacts.

— Increasing development intensity around new transit infrastructure: The intensity of development at a location depends upon a number of factors like accessibility, zoning regulations, urban design guidelines, socio-economic characteristics, location factors etc. Among these, zoning regulations and urban design guidelines are policy factors, insofar that public agencies like city planning departments have some explicit control over them. New transit infrastructure projects create the potential for increasing development intensity. However, this potential can only be realized if policy factors like zoning regulations and urban design guidelines allow and encourage development. This thesis provides a means to quantify the impact of certain public policy levers like zoning regulations and urban design guidelines on development. Ultimately, this thesis aims to understand how current policies can be
changed to increase development intensity and fully realize the potential of new transit infrastructure projects.

1.2. Research Questions

Specific research questions for this thesis are defined based on the objectives outlined above:

- What is accessibility? And what is the importance of accessibility in understanding, considering and quantifying the interaction between transport and land use?
- What are the potential accessibility and development impacts of new transit infrastructure projects?
- Do current evaluation frameworks for new transit infrastructure projects adequately consider accessibility and development impacts and benefits?
- Can the argument for investing in new transit infrastructure projects be strengthened by considering accessibility and development impacts and benefits?
- What are the current models for quantifying the accessibility and development impacts of new transit infrastructure projects?
- How can these models be improved?
- Can the accessibility and development impacts of new transit infrastructure be increased by changing current land use policies like zoning regulations and urban design guidelines?

1.3. Contribution to the Circle Line Project in Chicago

The Chicago Transit Authority (CTA) has proposed an ambitious new circumferential rail transit line called the Circle Line. This new line will link many of the existing radial rail transit lines and commuter rail lines, and so will facilitate connections throughout the transit system in the Chicago region. The Circle Line project also has the potential to influence land use patterns in its vicinity. The CTA is currently in the process of applying for federal funding for the Circle Line project through the Federal Transit Administration’s New Starts program where it will be evaluated using the FTA New Starts evaluation framework.

The Circle Line project thus presents an ideal context in which to address the research questions posed by this thesis. By doing so, this thesis contributes to the case being made for the Circle Line project by:
— Enumerating the potential impacts and benefits of new transit infrastructure projects like the Circle Line project, and then demonstrating the importance of considering accessibility, land use and development impacts and benefits in addition to transportation system improvements in their evaluation.

— Analyzing the accessibility measure and models used by the FTA New Starts evaluation framework; demonstrating its limitations as related to land use and development impacts; and presenting methods and models to improve the accessibility measure and model.

— Creating frameworks and developing models to consider and quantify the potential accessibility and development impacts of the Circle Line project.

— Applying these framework and models to quantify the potential accessibility and development impacts of the Circle Line project, and to demonstrate the effects on evaluation criteria.

— Proposing policy interventions like changing zoning regulations and urban design guidelines in order to increase development intensity around the Circle Line; and quantifying the accessibility and development impacts of these policy interventions.

While this thesis and research effort focuses on the Circle Line project in Chicago, the research approach is applicable to other proposed major new transit infrastructure projects in cities across the United States and other parts of the world.

1.4. Thesis Structure

This thesis has 9 chapters including this introductory chapter. The second chapter focuses on understanding the interaction between transport and land use, the role of accessibility in transport and land use interaction, and the various models currently used to forecast transportation and land use system changes as a result of infrastructure, policy, macroeconomic, or demographic changes.

The third chapter focuses on understanding the potential impact and benefits, especially accessibility and development impacts and benefits, of new transport infrastructure projects; and how these impacts are considered and quantified for new transit infrastructure projects in the FTA New Starts evaluation framework.

The fourth chapter presents the context in which this research is conducted: the Chicago region, its current regional transportation system, and the Chicago Transit Authority’s proposed Circle Line project. The likely accessibility and development impacts of the Circle Line project and current models to quantify these impacts are also assessed in this chapter.
The fifth chapter presents a quasi-integrated land use transportation modeling framework to consider and quantify the accessibility and development impacts of the Circle Line project. This model consists of two parts: an accessibility model to estimate the effect of transportation system improvements and development on accessibility, and a development intensity model to estimate the effect of changes in accessibility and public policies on land development.

The sixth chapter details the accessibility model as specified for the Chicago region application. The seventh chapter presents the specification and estimation of the development intensity model for the Chicago case.

The eighth chapter presents the application of the quasi-integrated land use transportation model to consider and quantify the accessibility and development impacts of the Circle Line project using a scenario analysis methodology.

The ninth and final chapter draws conclusions and presents avenues for future research.
2. Transport, Land Use and Accessibility

The interaction between land use and transportation has been the subject of much research over the past half century. Numerous researchers have shown that changes in the land use system affect travel patterns, and that changes in transportation affect the growth, distribution and location of uses, firms, households etc. in the land use system. New transport infrastructure projects in a region affect not just the transportation system, but also the land use system of the region. Consequently, new transport infrastructure projects must be evaluated based on their impacts on the integrated land use transportation (LUT) system.

This chapter considers the interaction between transport, land use, accessibility and development, and is organized in 4 main sections which provide reviews of: the interaction between transport and land use; the concept of accessibility; the concept of development; and transport and land use models.

2.1. Transport and Land Use Interaction

In general, travel is an intermediate good. Transportation system users travel to engage in some activity or to reach opportunities, e.g. jobs, markets, retail, entertainment etc. Rarely is travel an end in itself. Consequently, the demand for travel in the transportation system arises from the need of users to travel from a place (place of residence or work etc.) to a destination (e.g. downtown etc.) in order to engage in some activity or to access some opportunity (e.g. employment or shopping etc.) at the destination location. Quite simply, land use patterns such as the location of residences and firms affect travel patterns and so affect the transportation system.

The first theories into the interaction between land use and transport stem from the work of von Thünen. Working in the context of agricultural land uses, he suggested that farmers, in their location decisions for different agricultural uses, make a trade-off between transportation costs and land costs (rent). If transportation costs are proportional to distance travelled, then the amount of land rent that farmers can afford to pay decreases with increasing distances from the city (i.e. to the market for agricultural goods), and less valuable crops will tend to locate towards the periphery.

Alonso (Alonso, 1964) extended and adapted von Thünen's work into a theory of urban land uses, focusing on the trade-off that residents make with respect to commuting distance (to CBD) and land prices. He suggested that transportation costs affect land values, and that land values in turn affect urban land use patterns. He used the notion of the bid-rent function, a function of the highest amount that households and/or firms are willing to
bid in rent for a location, which declines as distance from the CBD increases. This theory suggests that if the CBD of a city is the location of all employment and is the only market for goods and services in the city, then as transportation costs increase with distance from the CBD, firms and households are willing to pay more in rent for locations closer to the CBD, and conversely firms and households pay lesser rents for locations farther away from the CBD. When the simplifying conditions of centralized employment and markets are lifted, this theory suggests that as firms value access to markets, employees etc. and households value access to jobs, goods and services etc., firms and households tradeoff between the transportation costs of this access and land rents.

The work of Alonso, and other researchers including Muth (Muth, 1969) and Mills (Mills, 1972) suggests that the value of access, or accessibility, at locations gets capitalized into the value of land, and as more intensive land uses will outbid less intensive land uses, then densities will be higher at locations with greater accessibility. Also, if firms value this access more than households do, then firms will locate themselves at places with greater accessibility than households. Consequently, these theories suggest that access to jobs, markets, etc. is a major factor influencing the location decisions of firms and households, and that changes in accessibility affects the location, and also the density of firms and households in a region. These theories provide a basis for understanding how the transportation system affects land use patterns.

The above discussion shows that the land use system affects the transportation system and vice versa. This cyclical process is illustrated graphically by Giuliano (Giuliano, 2004) in Figure 2-1. This figure suggests that transport system improvements (due to new or improved transport infrastructure or improved transport service) lead to an increase in accessibility at certain locations, which leads to a change in the value of land at those locations. This change in value at locations in turn leads to a change in the number and distribution of opportunities and activities and so to a change in land use patterns. Furthermore, changes in the number and distribution of opportunities and activities lead to changes in travel patterns thus affecting the transportation system, and the whole process repeats.
The interaction between land use and transportation is also affected by other factors. These include public policies such as those which may allow or disallow development; or affect travel patterns by, say, increasing the fuel tax; and exogenous events like, say, a major natural disaster, which may accelerate or decelerate land use change. Figure 2-2 illustrates the interaction of these factors and the role of individual preferences.

2.2. Accessibility

Accessibility is an important concept in the field of transportation and land use planning. However, as a concept, accessibility is “a misunderstood, poorly defined and poorly measured construct” (Geurs & van Wee, 2004). As a first step in understanding and quantifying the accessibility impacts of new transit infrastructure projects, this concept needs to be well defined, well understood, and well computed using appropriate measures.
2.2.1. Defining Accessibility

Accessibility has been variously defined as "the potential of opportunities for interaction" (Hansen, 1959), the "systematic relationship between the spatial distribution and intensity of development, and the quantity and quality of travel within a region" (Wachs & Kumagai, 1973), "the ease with which any land-use activity can be reached from a location using a particular transport system" (Dalvi & Martin, 1976), "the freedom of individuals to decide whether or not to participate in different activities" (Burns, 1979), "the benefits provided by a transportation/land-use system" (Ben-Akiva & Lerman, 1985), "the attractiveness of potential destinations and ease of reaching them" (Handy, 1993), the "extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations" (Geurs & van Wee, 2004), and "indicators for the impact of land-use and transport developments and policy plans on the functioning of the society in general" (Geurs & van Wee, 2004). These definitions highlight the concept of accessibility as a measure of the degree of access to opportunities or activities in the land use system as provided by the transportation system.

Accessibility, such defined, is the link between the land use and transportation systems (Figure 2-3).

Figure 2-3: Accessibility as the link between Transportation and Land Use

2.2.2. Components of Accessibility

This definitional framework of accessibility has been expanded by a number of researchers. Geurs and Ritsema van Eck (Geurs & Ritsema van Eck, 2001) and Geurs and van Wee (Geurs & van Wee, 2004) in their review of accessibility measures consider accessibility in terms of 4 components:

- **Land use component**: This component reflects the land use system in terms of the supply (number and quality) of opportunities (employees, households, jobs, shops, health facilities etc.) at destination locations, and the demand for opportunities at origin locations. This component also considers competition between the supply and demand for opportunities.

- **Transport component**: This component reflects the transportation system in terms of the generalized cost of travel (travel time, reliability, safety, convenience etc.) between origins and destination locations, and also reflects the disutility for an individual in travelling between locations due to the generalized cost imposed on the individual for doing so. This component also considers the supply, demand, and the competition between supply and demand for transportation.
— **Temporal component**: This component considers the time availability of opportunities e.g. the number and quality of opportunities available at different times of the day.

— **Individual component**: This component considers the availability of opportunities and transportation choices given an individual’s socio-economic characteristics (income, age, household situation etc.), abilities (education level etc.), and preferences.

These components are a reflection of the various factors affecting accessibility including land use and transportation.

**Figure 2-4: Components of Accessibility**

![Accessibility Diagram](image)

Source: (Geurs & van Wee, 2004)

Figure 2-4 shows the components of accessibility and gives an indication of the manner in which these components affect accessibility, and also each other. The supply and demand for opportunities in the land use systems drives the demand for travel in the transportation system (transport component). The competition for travel in turn may cause congestion and so place time restrictions (temporal component) and affect an
individual’s choices (individual component) (Geurs & van Wee, 2004). This figure also gives an indication of the effect of accessibility on its constituent components. Accessibility to opportunities affects the location decisions of households and firms (land use component), an individual’s economic and social opportunities (individual component), and the amount of time needed to access opportunities and to carry out activities (temporal component).

Seen through this framework, accessibility captures the interaction between land use and transportation, is affected by both land use and transportation, and in turn affects the LUT. Consequently, accessibility as a concept and as a metric can capture the impact of changes, like new transport infrastructure projects, on the LUT.

### 2.2.3. Factors Affecting Accessibility

The use of accessibility as a metric of impacts on the LUT requires a thorough understanding of the factors affecting accessibility.

A framework to consider accessibility changes has been used and applied by Geurs and Ritsema van Eck (Geurs & Ritsema van Eck, 2003) in a study of current and future job accessibility in the Netherlands. In this study, they theorize that accessibility changes occur due to changes in land use, transport and travel preferences. Assuming that travel preferences remain constant, they consider changes in accessibility over time to consist of 3 components (Figure 2-5):

- **Land use component:** Due to changes in the number and distribution of opportunities.

- **Travel time component:** Due to changes in travel times resulting from transport infrastructure projects (new and/or expansions) and increased congestion. Furthermore, they consider changes in the travel time component to have 2 components: an ‘infrastructure component’ due to changes in transportation supply (e.g. new projects which reduce travel times) and regulations (e.g. speed limits), and a ‘congestion component’ due to congestion and delays.

- **Combination component:** Due to the interaction between the land use and travel time components.
Zegras (Zegras, 2005) presents a basic framework for considering the factors affecting accessibility, and their direction of influence. This framework (Table 2-1) shows how changes in the transportation system and/or the land use system can affect accessibility. When applied to new transport infrastructure projects, this framework suggests that any improvements in travel times due to these projects, will serve to increase accessibility.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect on Accessibility (all else equal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Improved with more links, faster or cheaper service</td>
</tr>
<tr>
<td>Spatial distribution of</td>
<td>Improved if proximity of opportunities is increased</td>
</tr>
<tr>
<td>opportunities</td>
<td></td>
</tr>
<tr>
<td>Individual (personal/firm)</td>
<td>Improved with physical, mental, economic ability to take</td>
</tr>
<tr>
<td>characteristics</td>
<td>advantage of opportunities</td>
</tr>
<tr>
<td>Quality of opportunities</td>
<td>Improved with more, or better opportunities within same distance</td>
</tr>
</tbody>
</table>

Seen through these two frameworks it is clear that new transport infrastructure projects, which make travel faster or cheaper, or create more travel path choices, can positively impact the LUT by improving accessibility.

2.2.4. Process of Land Use, Transport and Accessibility Change

The process of transport and land use change, as facilitated by accessibility is described by Parsons Brinckerhoff Inc. (1999). They suggest that changes in transport will affect land use patterns only if transport changes have a substantial effect on accessibility. Where transport changes have a substantial effect on
accessibility, like in the case of major new transport infrastructure projects (e.g. a new transit line), locations in the immediate vicinity of the infrastructure will become more accessible causing a shift in travel patterns. As the number of trips to these locations increases, market pressures to intensify development at these locations will increase, leading to an increase in competition for these sites, and so to an increase in land value. However, increases in land values are influenced by public policies including zoning regulations and design guidelines that allow changes in land use patterns from the existing state. As such, the magnitude of changes in land use patterns at a location in a region is dependent upon the magnitude of accessibility change at that location, the accessibility at that location relative to the accessibility at surrounding locations, and the state of the real estate market in the region. Furthermore, changes in land use patterns at locations can be encouraged by development-supportive public policies such as density bonuses, reduced parking requirements, and/or lower impact fees.

Changes in land use patterns will change travel patterns and so affect accessibility. A major new development project (e.g. a multi-family residential development, or a new shopping center) at a location will cause a shift in travel patterns with users making trips to and from this location. These trips were either not made before or were made to and from different locations. The magnitude of change in users’ travel patterns is dependent upon the accessibility of the new development’s location, and the accessibility at that location relative to the accessibility at surrounding locations. Any change in travel patterns will cause a change in accessibility.

Consequently, it is clear that accessibility is a key factor in the process of land use and transportation system change, and is a key measure of the impacts of new transport infrastructure projects on the LUT.

2.2.5. Accessibility Measures

Given that accessibility is a measure of the benefits afforded by the LUT, and can capture the impacts of new transport infrastructure projects on the LUT, the accurate computation of accessibility becomes crucial.

There is no single measure of accessibility. The various measures of accessibility, and their different focuses, uses, advantages and disadvantages are detailed below (Geurs & Ritsema van Eck, 2003) (Geurs & van Wee, 2004):

1. **Infrastructure-based measures**: These measures focus on the transportation component of accessibility and analyze the service and performance level of transport infrastructure in terms such as ‘level of congestion’, ‘average travel speed’ etc. Computation of infrastructure-based measures requires data regarding congestion levels, roadway speeds etc. The advantage of infrastructure-based measures is that they are easily computed, and also easily communicated to and understood by (non-technical)
decision makers. Their major disadvantage is that they do not incorporate the land use, temporal and individual components of accessibility.

2. **Location-based measures**: These measures analyze the degree of accessibility at locations to spatially distributed opportunities in terms such as 'number of jobs within 30 minutes drive' etc. Location-based measures are very useful in understanding both regional and local accessibility. There are 3 kinds of location-based measures:

- **Distance measures**: These location-based measures consider the relative accessibility between any two locations in terms of travel times, distances or costs. Computation of distance measures requires data regarding the number of opportunities at locations and travel times (or distance or costs) between locations. Distance measures are relatively easily computed, and also easily communicated and understood. Their major shortcoming is that they do not explicitly incorporate the land use component of accessibility in terms of the spatial distribution of opportunities. They also do not incorporate the individual component of accessibility. Distance measures are shown mathematically below (Equation 2-1):

  **Equation 2-1: Distance Accessibility Measures**
  \[
  A_{ij} = C_{ij}
  \]
  Where:
  \[
  i = \text{origin location} \\
  j = \text{destination location} \\
  A_{ij} = \text{relative accessibility at location } i \text{ to location } j \\
  C_{ij} = \text{travel time (or distance or cost) from } i \text{ to } j
  \]

- **Isochronic measures**: Isochronic measures, the second type of location-based measures, are also known as contour measures and cumulative opportunity measures. These measures consider the number of opportunities that can be reached from a given origin location within a given travel time, distance or cost; or conversely, the average or total time, distance or cost required to reach a given number of opportunities. Computation of isochronic measures requires data regarding the number of opportunities at locations and travel times (or distance or costs) between locations. The advantage of isochronic measures is that they are easily computed using available land use and transportation system data, and also that they are easily communicated. Their disadvantage is that all opportunities within a given travel time, distance or cost are weighted equally, and so farther opportunities are considered the same as closer opportunities. In addition, they do not consider
competition effects, i.e. the demand for opportunities might be greater than their supply; and do not explicitly incorporate the individual component of accessibility. Isochronic measures are shown mathematically below (Equation 2-2):

**Equation 2-2: Isochronic Accessibility Measures**

\[ A_i = \sum_{j} B_j W_j \]

Where:
- \( i \) = origin location
- \( j \) = destination location
- \( A_i \) = accessibility at location \( i \)
- \( B_j \) = number of opportunities at location \( j \)
- \( W_j \) = equals 1 if \( C_{ij} < C^*_{ij} \), and 0 otherwise
- \( C_{ij} \) = travel time (or distance or cost) from \( i \) to \( j \)
- \( C^*_{ij} \) = given travel time (or distance or cost)

Source: (Busby, 2004)

- **Potential Accessibility Measures**: Potential accessibility measures, also known as gravity-based measures, are a third type of location-based measures. These measures overcome some of the disadvantages of isochronic measures by considering the fact that farther opportunities are less accessible than closer opportunities, and so should not be weighted equally. This differential weighting is done by incorporating a declining function of travel time, distance or cost. While these measures do not usually incorporate competition effects, such effects can be considered, such as with balancing factors from a double constrained spatial interaction model. Computation of potential accessibility measures requires data regarding the number of opportunities at locations, travel times (or distance or costs) between locations, and observed travel trip times (or distance or costs) of users (to compute the declining function of travel time). The advantage of potential accessibility measures is that they are easily computed using available land use and transportation system data. However, they have the disadvantage of not usually being easy to communicate and explain to (non-technical) decision makers. In addition, they do not explicitly incorporate the individual component of accessibility. Potential accessibility measures are shown mathematically below (Equation 2-3):
Equation 2-3: Potential Accessibility Measures

\[ A_i = \sum_j B_j f(C_{ij}) \]

Where:
- \( i \) = origin location
- \( j \) = destination location
- \( A_i \) = accessibility at location \( i \)
- \( B_j \) = number of opportunities at location \( j \)
- \( C_{ij} \) = travel time (or distance or cost) from \( i \) to \( j \)
- \( f(C_{ij}) \) = travel time (or distance or cost) impedance function

Source: (Busby, 2004) (Geurs & van Wee, 2004)

3. **Person-based measures:** These measures, analyze the degree of accessibility of individuals with certain monetary and temporal budgets to spatially distributed opportunities in terms such as ‘the number of jobs that an individual can participate in at a given time’ etc. While person-based measures are very useful in understanding individual-specific, disaggregate-level accessibility, their major disadvantages are that they are not easily computed using available land use and transportation system data due to the requirement of disaggregate survey data and time/cost budget data, and that they are not easily communicated to and understood by decision makers.

4. **Utility-based measures:** These measures, also known as logsum measures, analyze the economic benefits that individuals derive from access to spatially distributed opportunities using the land use transportation (LUT) system. Utility-based measures can be computed from logit discrete choice models, which are widely used in transportation system analysis. Logit models can be used to predict the choices that an individual will make among a set of choices, assuming that an individual associates a utility with each choice, and that the individual chooses the choice with the maximum utility. In this case “the utility of the choice situation to the individual” (Ben-Akiva & Lerman, 1985) can be used as a measure of accessibility. Expected maximum utility of an individual’s choice set, as calculated from the denominator of the multinomial logit model, also known as the logsum value, serves as the summary measure of accessibility. This measure is not directly comparable across individuals and must be converted into units of a variable in the utility function such as time or cost. These measures of accessibility can be derived from discrete choice models of mode choice, destination choice, path choice etc. However, the choice modeled affects the measure of accessibility derived. For example, the expected maximum utility from a mode choice model will represent only the benefits from this choice set (i.e. between modes) and not the complete benefits derived from a LUT. Accessibility measured
from travel (or transportation system) models will incorporate only transportation system choices. The nested logit choice framework (e.g. mode and destination choice) allows for extending the utility-based accessibility measure to include both the land use and transportation systems, and all the relevant choices faced by individuals and firms including mode, path, destination, location choice etc. are modeled therein. Computation of utility-based measures requires detailed disaggregate travel behavior survey data regarding the various alternatives available to individuals and the socio-economic characteristics of the individuals themselves. Utility-based measures can be extended to incorporate the land use, transportation, individual and temporal components of accessibility, and are very useful in understanding both regional and local accessibility, and in monetizing accessibility benefits. The disadvantages of utility-based measures are that they are data hungry requiring, for example, disaggregate travel behavior survey data (Busby, 2004), and that they are usually not easily communicated to and understood by (non-technical) decision makers. Utility-based accessibility measures are shown mathematically below (Equation 2-4):

**Equation 2-4: Utility-Based Accessibility Measures**

\[ A_n = E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln \sum_{i \in C_n} \exp(\mu V_{in}) \]

Where:
- \( i \) = alternative
- \( n \) = individual
- \( A_n \) = accessibility of individual \( n \)
- \( U_{in} \) = utility for individual \( n \) considering alternative \( i \)
- \( V_{in} \) = systematic component of utility \( U_{in} \) for individual \( n \) considering alternative \( i \)
- \( C_n \) = choice set
- \( \mu \) = scale parameter of the error associated with each alternative

Source: (Busby, 2004) (Geurs & van Wee, 2004)

5. **Activity-based measures:** These measures go beyond the focus on trip-making behavior of individuals, and instead consider the benefits associated with the activities that an individual participates in throughout the day (shopping, working etc.). These activities can be pursued, as individual trips, trip-chaining, by substituting telecommunications for transportation, etc. Consequently, these measures incorporate traditionally hard to model situations like working from home etc. Theoretically, such measures provide a more complete picture of accessibility. These measures are thus better than utility-based measures, but have some of the same disadvantages, including being data hungry.
Table 2-2 shows how the measures described above incorporate the 4 components of accessibility.

**Table 2-2: Accessibility Measures vis-à-vis Components of Accessibility**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Transport Component</th>
<th>Land use component</th>
<th>Temporal component</th>
<th>Individual component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure-based</td>
<td>Travelling speed; vehicle-hours lost in congestion</td>
<td>Amount and spatial distribution of the demand for and/or supply of opportunity</td>
<td>Peak-hour period; 24-hour period</td>
<td>Trip-base stratification, e.g., Home-to-work business</td>
</tr>
<tr>
<td>Location-based measures</td>
<td>Travel time and/or costs between locations of activities</td>
<td>Travel time and costs may differ, e.g., between hours of the day, between days of the week, or seasons</td>
<td>Stratification of the population (e.g., by income, educational level)</td>
<td></td>
</tr>
<tr>
<td>Person-based measures</td>
<td>Travel time between locations of activities</td>
<td>Amount and spatial distribution of supplied opportunities</td>
<td>Temporal constraints for activities and time-availability for activities</td>
<td>Accessibility is analyzed at individual level</td>
</tr>
<tr>
<td>Utility-based measures</td>
<td>Travel costs between locations of activities</td>
<td>Amount and spatial distribution of supplied opportunities</td>
<td>Travel time and costs may differ, e.g., between hours of the day, between days of the week, or seasons</td>
<td>Utility is derived at the individual or homogenous population group level</td>
</tr>
</tbody>
</table>

Source: (Geurs & van Wee, 2004)

Amongst these accessibility measures, the person-based, utility-derived, and the activity-based measures are the most theoretically sound as they incorporate all four components of accessibility. However, data and analytical requirements for these measures make them difficult to implement. Among the remaining measures of accessibility, potential accessibility (gravity-based) measures are the most theoretically sound.

These measures can be used to assess benefits afforded by the LUT and also the accessibility impacts of new transport infrastructure projects.
2.3. Development

Accessibility is affected by and in turn affects the number and distribution of opportunities available in the land use system. The concept of development and development intensity provides a means of considering and quantifying these opportunities.

2.3.1. Defining Development

Development, in the context of cities and regions, has been variously defined as the act, process, or result of “making some area of land...more profitable or productive or useful” (WordNet, Princeton University, 2007), “realizing the potentialities of a site, estate, property, or the like, by laying it out, building...., etc.” (Oxford English Dictionary, 2007), or “(converting) a tract of land to a new purpose or (making) it suitable for residential, industrial, business, etc., purposes” (Oxford English Dictionary, 2007). In other words, development can be defined as the act, process, or result of building on land, thereby increasing its value. Building on land increases the number of opportunities (jobs, households, shops etc.) available on that area of land.

Urban land use theories suggest that the value of access, or accessibility, at locations gets capitalized into the value of land. Seen in this light, development at a location reflects, in part, the value of accessibility at that location, and so changes in accessibility will cause changes in development¹.

¹ This development change can be either new development or redevelopment. Redevelopment will occur if the value of the new potential exceeds the existing value by a large amount.
2.3.2. Factors Affecting Development

The location decisions of households and firms, the main actors in the process of land use and transportation interaction, influence development. Based on a review of the literature regarding the process of development, Parsons Brinckerhoff Inc. (1999) have enumerated the factors affecting the location decisions of households and firms.

Table 2-3: Factors Influencing Location Decision of Households

<table>
<thead>
<tr>
<th>Relative Importance</th>
<th>Factor</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly Important</td>
<td>Housing costs</td>
<td>Most households must balance costs with the housing and community characteristics they desire.</td>
</tr>
<tr>
<td>Moderately Important</td>
<td>Access to jobs</td>
<td>Access to jobs is a significant determinant of residential location in large metropolitan areas, but may not matter in smaller urban areas where nearly every location has good automobile access to jobs.</td>
</tr>
<tr>
<td>Access to goods and services</td>
<td>Preferences may vary by household types. Singles like living near entertainment. Empty nesters near leisure and culture. Corporate executives want good access to airports.</td>
<td></td>
</tr>
<tr>
<td>School quality</td>
<td>Important to households with school age children.</td>
<td></td>
</tr>
<tr>
<td>Type of community residents</td>
<td>Although some people like diversity, most people want to live near people who are like them.</td>
<td></td>
</tr>
<tr>
<td>Somewhat Important</td>
<td>Amenities and quality of life</td>
<td>Households seek locations with views, attractive design, distance from industries and traffic, low crime rates, and other indicators of quality of life.</td>
</tr>
<tr>
<td>Quality of non-school public services</td>
<td>There is some evidence that households consider the quality of public services like police protection when selecting communities.</td>
<td></td>
</tr>
<tr>
<td>Property tax rates</td>
<td>The evidence is mixed on whether taxes matter in household location decisions.</td>
<td></td>
</tr>
</tbody>
</table>

Source: (Parsons Brinckerhoff Inc., 1999)

Table 2-3 shows the factors affecting the location decisions of households, and their relative importance. This table suggests that housing costs (land rents), as related to household income, are the most important factor in a household’s location decision, followed by access to jobs, and to goods and services.
Table 2-4: Factors Influencing Location Decision of Firms

<table>
<thead>
<tr>
<th>Relative Importance</th>
<th>Factor</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly Important</td>
<td>Costs and availability of space</td>
<td>Firms make trade-offs between the cost of space and other locational characteristics that they desire</td>
</tr>
<tr>
<td></td>
<td>Access to labor</td>
<td>Firms have different labor needs that influence where they locate. Some locate in the CBD to have the greatest access to a high skilled labor force. Some prefer suburban locations where there are stable clerical and support workers. Some locate near residential areas preferred by key technical and managerial staff.</td>
</tr>
<tr>
<td></td>
<td>Access to customers</td>
<td>Critical to retail and customer serving offices. Also important to many manufacturing firms.</td>
</tr>
<tr>
<td></td>
<td>Access to highways</td>
<td>All types of firms need access to dominant mode of transportation to attract workers and customers and to receive and send deliveries.</td>
</tr>
<tr>
<td>Moderately Important</td>
<td>Near like firms</td>
<td>Many firms agglomerate near similar types of firms in retail centers, office parks, industrial parks, and downtowns. This improves their access to workers, customers, and intermediate inputs, and facilitates an exchange of information.</td>
</tr>
<tr>
<td></td>
<td>Near suppliers, support services</td>
<td>This is most important for manufacturers and somewhat important for offices.</td>
</tr>
<tr>
<td>Somewhat Important</td>
<td>Amenities, quality of life, prestige</td>
<td>This is important for firms with many professional workers and technical workers.</td>
</tr>
<tr>
<td></td>
<td>Quality of public services</td>
<td>Public services are important for business activity and growth. Some manufacturers have specific requirements for large amounts of water and sewer capacity.</td>
</tr>
</tbody>
</table>

Source: (Parsons Brinckerhoff Inc., 1999)

Table 2-4 shows the factors affecting the location decisions of firms, and their relative importance. This table suggests that costs (land rent) and availability of space, access to labor (employees), access to customers, and access near highways are the most important factors in a firm’s location decision.
Beyond households and firms, developers play an important role in the development process. Developers are the agents of land use change - converting land from one use to another; increasing or decreasing the intensity of land use; and determining what to develop and where. Consequently, developers' decisions influence development patterns. Parsons Brinckerhoff Inc. (1999) have also enumerated the factors affecting developers' decisions.

Table 2-5: Factors Influencing Developer Decisions about What and Where to Develop

<table>
<thead>
<tr>
<th>Factor</th>
<th>How Factor Affects Developer's Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales and rental prices</td>
<td>Critical determinant of profitability. Most desirable locations command higher prices.</td>
</tr>
<tr>
<td>Accessibility and visibility</td>
<td>Necessary for retail and most office development. Access to highways important to manufacturing that relies on trucking. More accessible residential locations are more desirable than less accessible locations.</td>
</tr>
<tr>
<td>Site Characteristics</td>
<td>Can influence both prices and the cost of development.</td>
</tr>
<tr>
<td>Growth corridors (e.g. desirable community characteristics)</td>
<td>Development is more likely to occur where there is momentum, but as an area becomes built out or preferences change, these can shift. Developers who correctly anticipate shifts can make more money.</td>
</tr>
<tr>
<td>Competition in the market</td>
<td>Profit levels depend upon the competition from existing development and the products that other developers might build.</td>
</tr>
<tr>
<td>Land availability and costs</td>
<td>A major factor in deciding what and where it is profitable to build.</td>
</tr>
<tr>
<td>Zoning and other regulations</td>
<td>Impacts depend upon whether a community is market-oriented (i.e. adapts regulations to fit with developer proposals) or growth-management oriented (development must fit within plans).</td>
</tr>
<tr>
<td>Cost and difficulty of getting permits</td>
<td>Can add to the costs and risks of a project, influencing the type of projects proposed.</td>
</tr>
</tbody>
</table>

Source: (Parsons Brinckerhoff Inc., 1999)

Factors affecting developers' decisions - and thus the process of development - include: land rents, accessibility, site characteristics, zoning regulations, development incentives, etc. Land availability is a major factor affecting developers' decisions in the urban core of regions (see Table 2-5).
2.3.3. **Development Measures**

There is no single measure of development. Measures used include:

- Gross or net floor area (square meters or square feet) in total or segmented by use e.g. residential, commercial, retail etc.
- Number of residential dwelling units
- Number of persons, households, workers etc.
- Number of firms, shops etc.
- Number of jobs, employees etc.
- Planning applications in total or segmented by use e.g. residential, commercial etc., and considered in terms of the number of applications received, and/or the proposed gross or net floor areas, number of residential dwelling units, firms etc.

Among these measures, gross or net floor area and number of dwelling units provide some indication of the physical shape of cities, while the number of household and firms relate to the main ‘actors’ in the process of land use and transportation interaction.

Development at any location within a region can be computed in terms of the number of opportunities (households and jobs) available within that location. To compare development across locations, a development intensity measure (density), in terms of the number of opportunities (households, jobs etc.) available per acre (or hectare, etc.) within a location, is used.

2.4. **Transport and Land Use Models**

Models can be used to understand and represent the land use and transportation systems, and the interaction between transport and land use. These models can also be used for land use and transportation planning purposes and to assess and forecast the impacts of potential changes - e.g. new transport infrastructure projects or policy changes etc., - on land use and transportation systems.

These models fall into 3 distinct categories: travel demand forecasting models, land use forecasting methods and models, and integrated land use transportation models.
2.4.1. Travel Demand Forecasting Models

Travel demand forecasting models are used to predict the effect of transportation system changes on travel patterns in terms of traffic or ridership by mode either for a particular link, route or for the entire transportation network. These are the most commonly used models in transportation planning.

Travel demand forecasting models simulate the supply and demand for transportation in a region (MWCOG, 2007). The supply of transportation is represented by the location, connections, and capacity of the road and highway network, and the transit (bus, rail, commuter rail, ferry etc.) network. The demand for transportation is calculated using a series of mathematical models. The most commonly used method for deriving the demand for transportation is the ‘4 step approach’: trip generation, trip distribution, mode split, and trip assignment. The first 3 steps of this approach estimate the demand from travel while the fourth step equilibrates demand and supply. This approach can be described as:

- **Trip Generation:** The number of person trips produced by and attracted to each zone is estimated, based on the number of households, jobs, etc. in the zone, and using trip generation and attraction factors.

- **Trip Distribution:** The number of trips starting (origin) and ending (destination) in each zone is estimated, based on the number of trips produced and attracted in each zone, generally using a gravity model.

- **Mode Choice:** The mode of travel for the number of trips between origin and destination zones is estimated, generally using utility-based discrete choice models that consider various factors like cost, time, reliability, automobile ownership etc.

- **Trip Assignment:** The trips are assigned to available roadway and transit networks on feasible paths (of the estimated mode) based on calculated time/cost of travel, etc., in an iterative process until a state of equilibrium is reached.

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2 For a more detailed description see (MWCOG, 2007)
3 Prior to application of this approach the model study area is divided into zones.
Figure 2-6 shows the 4-step travel demand forecasting model.

**Figure 2-6: 4-Step Travel Demand Forecasting Model**

![Diagram of the 4-step travel demand forecasting model]

Source: (MWCOG, 2007)

Examples of travel demand forecasting models available as operational software packages include QRSII, CUBE VOYAGER, EMME/2, and TRANSCAD.

The 4 step approach is trip-based, in that it focuses on individual trips or a sequence of trips, and not on the fact that a person's travel patterns are part of a sequence of activities - e.g. shopping, picking kids from schools, etc. - where choices are made keeping in mind the entire sequence of activities. The 'state of the art' in travel demand models are activity-based models, which consider the entire sequence of activities that a person can engage in.

Travel demand forecasting models generally do not explicitly consider land use effects, and depend upon land use methods and models to make demographic and socio-economic projections. In the typical travel demand forecasting practice, land uses are treated exogenously. That is, land use scenarios feed into the 4-step process.
2.4.2. Land Use Forecasting Methods and Models

Land use forecasting methods and models are used to forecast future demographic and socio-economic patterns, and are commonly used in land use planning, and as inputs into the transportation planning process. Currently used methods and models to forecast land use changes are (Parsons Brinckerhoff Inc., 1999):

- Comprehensive plans and other land use regulations: In this method, forecasts of future demographic and socio-economic patterns are based on current comprehensive plans, zoning and other land use regulations. Transport and land use interactions are considered only in terms of the effect of major transport infrastructure projects, or major policy changes (e.g. tolls) on current plans and regulations. These methods focus on the supply side of land use changes - i.e. the allowable amount of development - and tend to ignore the demand for development, and the interaction between supply and demand.

- Use of experts: These methods rely on the knowledge and skill of ‘experts’ to analyze the situation and then to make forecasts of future demographic and socio-economic patterns. The most prominent example is the Delphi method, a systematic way to utilize expert opinion in an iterative process. In this method, experts provide judgments about future events or processes, like the effect of transportation investments on development, by responding to questionnaires; a moderator then summarizes the results of the questionnaires and submits the summary back to the experts for reconsideration; and then this process is repeated a number of times so that experts share their thinking and opinions to finally reach consensus or to clarify differences of opinion. Other similar methods include the use of committee or panel meetings and the use of interviews, surveys and expert analysis. These methods are currently widely used in making land use forecasts by incorporating advice from political leaders, land use planners, transportation planners, the development and real estate community, local residents etc. This method has the advantage of promoting consensus among various stakeholders, and using a holistic approach where various points of view are considered. However, this method is heavily dependent on the knowledge level and skill of ‘experts’, and can suffer if experts are chosen in a biased manner (i.e. not all experts or stakeholders are considered), or if there is outside political pressure in favor of certain outcomes.

- Allocation rules: This method involves the allocation of population and employment growth to zones based on certain rules. Examples include: the constant share rule, which allocates population and employment growth in zones in proportion to the amount of vacant land zoned for population and employment purposes respectively; the share of growth rule, which allocates population and
employment growth in zones in proportion to the amount of a region’s growth occurring in that zone over a certain time frame; the shift-share rule, which allocates employment growth in zones by considering differences between fast and slow growing parts of the regional economy, and shifts in the competitive advantage for certain parts of the region over other parts; and gravity models, which allocate population and employment growth in zones in proportion to the attractiveness (as measured by a gravity model) of that zone. These methods suffer from the fact that they extrapolate past trends to make future projections and so are less useful for long time frames. They also do not consider the potential redistribution of current employment and population patterns. Only the gravity model method implicitly considers transport and land use interactions.

— **Statistical methods:** Statistical methods to forecast future demographic and socio-economic patterns include multiple linear regression models and discrete choice (or multinomial logit) models. Multiple linear regression models can be designed to estimate the effect of various influencing factors like the amount of vacant land, zoning, accessibility etc. on variables like the amount of residential development, commercial development etc. Discrete choice models can be designed to estimate the choices of firms and individuals, including where to locate, considering various factors like characteristics of the firms and households (e.g. household income, household size, number of employees etc.), and characteristics of the choice (accessibility, cost, amount of space etc.). These techniques provide a robust, objective and quantitative method of forecasting population and employment growth and distribution, and for considering and quantifying the transport and land use interaction. However, these models require considerable amount of data and expertise, and suffer where appropriate data is not available or used, or where appropriate estimation techniques are not used.

— **Regional economic models:** Regional economic models simulate the economy of a region and can be used to estimate the impacts of major economic, infrastructure and policy changes on the regional economy and also to provide employment and population forecasts for regions or parts of regions. Regional economic models include input-output models, econometric models and combination models. Input-output models simulate economic transactions between firms, households and governments and can be used to estimate the impacts of new transport infrastructure projects on the regional economy, and so on firms and households in the region. Econometric models are statistical and mathematical models that model the decision-making processes of firms, households and governments, and can be used to forecast employment and population changes. Combination models incorporate both input-output and econometric models to create dynamic regional economic models, which can be used to
forecast population and employment growth and distribution, based on an historical analysis of the regional economy. Regional economic models usually do not consider areas smaller than the counties and so can only be used to make aggregate forecasts. These models require considerable amount of data and expertise.

These methods and models can be used individually or in some combination. For example, regional economic models can be used to forecast future regional population and employment growth, and allocation rules, qualitative methods or statistical methods can be used to distribute regional population and employment growth amongst the various zones in the region. Some of these methods and models can also be used to analyze and quantify the effect of transport infrastructure projects, and other transportation system changes, on land use patterns.

Most regional land use planning agencies use one or a combination of the methods and models described above.

2.4.3. Integrated Land Use Transportation Models

Travel demand forecasting models provide forecasts of future travel patterns, based on projections of future demographic and socio-economic patterns derived from land use methods and models; and land use methods and models provide forecasts of future land use patterns, considering future economic and transportation system changes. Consequently, travel demand forecasting and land use forecasting methods and models can be used in combination to analyze the interaction between transport and land use, and to analyze the effect of transportation and land use system changes on the integrated LUT. However, in this approach there is no formal feedback loop between transportation and land use, and so the interaction between transport and land use can only be analyzed through the creation of alternate scenarios (Miller, Kriger, & Hunt, 1999). This involves using an iterative process where the outputs of one run of the travel demand forecasting model are used to revise the land use forecasts, and then these revised land use forecasts are used as inputs into the next run of the travel demand forecasting model, and so on.

An alternative approach involves the formal integration of land use and transportation models. This can occur via the explicit link of a land use model capable of incorporating transportation system changes and a transportation model; or via a fully integrated modeling package. Integrated models internally combine travel demand forecasting functions and land use forecasting functions, and internally model the effects of the land use system on transportation patterns and the effects of the transportation system on land use patterns.
some form or another, these models account for the mutual dependency between land uses and travel. Few regions in the United States use integrated land use transportation models (Miller, Kriger, & Hunt, 1999).

An ideal land use interaction model would consist of at least four major components (or sub-models) and account for the four major drivers of change (either exogenously or endogenously) (Miller, Kriger, & Hunt, 1999) (see Figure 2-7).

**Figure 2-7: Ideal Integrated Land Use Transportation Model**

![Diagram of Ideal Integrated Land Use Transportation Model]

- Components:
  - Land development: This component models the land development process, from vacant land to redevelopment over time.
  - Location choice: This component models the location choices of households (residential development), firms (commercial development) and workers (jobs).
  - Activity/Travel: This component models travel patterns, ideally using an activity-based approach to travel demand forecasting.
  - Automobile Ownership: This component models automobile ownership levels which are a major factor influencing household travel patterns.

- Major drivers:
  - Demographics: This includes demographic evolution and change in terms of population size, education level, age distribution, sex distribution etc.
  - Regional economics: This includes regional economic evolution and change in terms of the size of the economy, distribution by economic sector etc.
- Government policies: This includes policies like zoning, taxation, interest rates etc.
- Transportation system: This includes the transportation network (supply) in terms of roads, highways, transit infrastructure and routes etc.

In addition, the ideal integrated land use transport model should incorporate market mechanisms; should be applicable to short range as well as long range decision making and forecasting purposes; and should be operational at a high level of disaggregation (Miller, Kriger, & Hunt, 1999).

A number of operational integrated land use transportation models exist. The models range in their approach, underlying modeling mechanisms, and even data requirements. In the U.S. context, commercial models that have been used by agencies include: DRAM/EMPAL, MEPLAN, TRANUS, NYMTCLUM and UrbanSim etc. Some of these models are described below (Parsons Brinckerhoff Inc., 1999):

- **DRAM/EMPAL**: DRAM/EMPAL consists of a disaggregated residential allocation models (DRAM), and an employment allocation model (EMPAL), and links to traditional 4-step travel demand models. This model is able to internally analyze the interaction between transport and land use (Parsons Brinckerhoff Inc., 1999). DRAM can be used to forecast the number of households by income quartile in each zone, while EMPAL can be used to forecast the number of jobs in 5 industry categories, while the travel demand model can be used to forecast travel patterns. Both DRAM and EMPAL are spatial interaction models derived from the original Lowry model (which uses a gravity model to allocate workers to residential locations).

- **MEPLAN and TRANUS**: MEPLAN and TRANUS are closely related. These models represent the interaction between the location of activities, land use, and the transportation system in a comprehensive framework. The models consider location and travel choice decisions in an internally consistent manner, using input-output models to represent the interaction between firms, households and governments (Parsons Brinckerhoff Inc., 1999). These models can be used to forecast land and floor space consumption by land use category, changes in supply and demand by economic sector, growth and distribution of population and employment, trip generation and distribution of goods and people by mode and trip purpose, and traffic flows between zones. These models use the concepts of markets - for space, transport, labor etc.

- **UrbanSim**: UrbanSim incorporates the interaction between land use, transportation, and public policy, and as such can be used for integrated land use transportation planning, and for analysis of urban development. This model simulates decision-making processes, including the travel and location choices of households and firms, and the development choices of developers; accounts for land,
buildings, and occupants; simulates the development process over time; simulates the land market using the mechanism of prices; incorporates the effect of public policies by modeling market responses; and addresses both new development and redevelopment at the parcel-level. UrbanSim uses discrete choice models for the all decision-making processes, and is designed for a high degree of spatial and activity aggregation. The model requires a number of exogenous inputs: baseline land use, population and employment; transport and land use plans; regional economic forecasts; development policies; and environmental and density constraints. The model forecasts acreage by land use; housing units by housing type; square feet of non-residential space by type; property values; businesses and employment by sector; households by type; and accessibility measures to employment by type and by population.

While all of these models integrate land use and transportation modeling functions, they still have a number of shortcomings when compared to the ideal integrated land use transportation model. These include: a high degree of spatial aggregation and so an inability to create fine grained disaggregate forecasts; a lack of endogenous demographic processes; a lack of endogenous automobile ownership processes; and incorporation of a trip-based 4-step travel demand forecasting process instead of an activity-based model (Miller, Kriger, & Hunt, 1999).

2.5. Conclusions

The interaction between transport and land use is cyclical, in that the land use system affects travel patterns, and the transportation system affects land use patterns. In addition, individual preferences, external events and public policies affect the process of transport and land use interaction. Accessibility is a key concept in the interaction between transport and land use. Accessibility can be used as a metric to measure the benefits afforded by the integrated land use transportation system (LUT), and to measure the impact of new transport infrastructure projects on the LUT.

Robust models of land use transport interaction are required to consider and quantify the impact of new transport infrastructure projects on the LUT. Most regions use travel demand forecasting models and some land use forecasting methods or models. In theory, integrated land use transport models, which combine travel demand and land use forecasting functions, provide a better representation of the interaction between transport and land use, and better consideration and quantification of the impacts of new transport infrastructure projects on the LUT. Few regions in the United States currently use such integrated land use transport models.
3. Evaluation of New Transit Infrastructure Projects

There is a finite and ever more constrained amount of resources available to fund transport infrastructure projects, and especially to fund transit infrastructure projects. Simultaneously, there are numerous transport infrastructure projects vying for funding. In this climate, policy makers in federal, state and local governments and agencies need robust evaluation techniques to conduct transport infrastructure project appraisals that enable them to make sound investment decisions that allocate their resources in the most efficient way.

This chapter considers the evaluation of new transport infrastructure projects, and is organized in 3 sections: a description of a comprehensive evaluation framework for new transport infrastructure projects, and its application to a proposed new transit infrastructure project; a description and assessment of the FTA New Starts Evaluation Framework which is applied to most new transit infrastructure projects in the United States; and conclusions.

3.1. Evaluation Frameworks

Evaluation can be termed as the process of “determining the desirability of different courses of action and of presenting this information to decision makers in a comprehensive and useful form” (Meyer & Miller, 2000). Evaluation provides information to decision makers regarding the impacts of projects or project alternatives, and so informs the decision-making process. Evaluation of new transport infrastructure projects involves defining the impacts of the project (or project alternative) in terms of its benefits and costs, determining how these benefits and costs are to be measured and then measuring them, and comparing these benefits and costs across project alternatives and to relative standards and guidelines.

3.1.1. Potential Impacts, Benefits and Costs of New Transport Infrastructure Projects

New transport infrastructure projects can potentially have a number of impacts and benefits. These include:

- **Reduced Travel Times**: New transport infrastructure projects can reduce travel times for users of the transportation system to some (or all) zones in a region from some (or all) zones in a region, and especially to and from zones in the immediate vicinity of the infrastructure. Travel time savings are generally considered to be the most significant potential benefit of new transport infrastructure projects.
— **Reduced Vehicle Operating Costs:** New transport infrastructure projects can reduce vehicle operating costs by improving vehicle operating conditions.

— **Improved Safety:** New transport infrastructure projects can improve safety conditions in terms of reduced fatalities and injuries, reduced property damage, and reduced disruptions in traffic flow (and so reduced travel times) due to accidents.

— **Improved Reliability:** New transport infrastructure projects can improve travel time reliability (and so reduce travel time variance), thereby reducing the amount of time users need to budget for ensuring their on-time arrival at destination.

— **Improved Quality of Transport Service:** New transport infrastructure projects can improve the quality of transport service in terms of convenience, cleanliness, access to information, comfort etc.

— **Accessibility:** As shown in the previous chapter, new transport infrastructure projects can improve accessibility, in terms of access to jobs and goods and services by households, and access to employees and customers by firms (businesses, industries, retail establishments etc.). These accessibility improvements can arise in two ways: first, new transport infrastructure projects can in the short run reduce the travel time and/or cost required to access activities or opportunities; and second, new transport infrastructure projects can in the long run affect the land use system, and so can affect the growth and/or a redistribution of population, employment, shopping etc. into certain zones, thereby changing the number of activities or opportunities available.

— **Efficiency and Productivity:** New transport infrastructure projects can improve economic efficiency and growth by improving capital and labor productivity. These benefits are detailed below:

  - Travel times savings, accessibility improvements and reliability improvements due to new transport infrastructure projects can allow firms to reorganize industrial/commercial production and distribution practices e.g. to move to a just-in-time production process (Mohring & Williamson, 1996), and so institute more efficient practices.

  - Travel time savings and accessibility improvements can also allow firms to take advantage of increasing economies of scale effects (OECD Road Transport Research Programme, 2002), and of strengthening agglomeration effects (Gibbons & Machin, 2003) (Gibbons & Machin, 2004) (UK Department for Transport, 2006) (Graham, 2006) (Cross London Rail Links, 2005). The benefits of agglomeration are: a larger, more specialized labor market, providing employers with more choice of skills and more competition for jobs; more competing and complementary businesses and institutions, providing additional pressure for innovation and efficiency, and enabling greater
specialization among support services; a larger, more specialized client market; and greater potential for contact and knowledge sharing, both informally via social interaction and more formally via conferences.

- Accessibility improvements can allow access to a greater number of jobs by workers, access to more productive jobs that pay higher wages, reduced job-search costs, greater worker efficiency by reducing commuting effort, and lower durations of unemployment all of which lead to increased labor efficiency and productivity (Gibbons & Machin, 2003) (Gibbons & Machin, 2004) (UK Department for Transport, 2006).

- Development: New transport infrastructure projects can promote commercial, industrial, retail or residential development either in already built areas or in newly accessible un-built areas. Increased accessibility provided by a new transport infrastructure project at a zone gets capitalized into the value of land, which in turn leads to pressures for increasing the intensity of development at that zone. Firms can take advantage of travel time savings and increased access to workers and to customers by growing and by increasing commercial development intensity (Gibbons & Machin, 2003). Similarly, developers can take advantage of travel time savings and increased access to employment and to goods and services by increasing residential development intensity. Increased development is related to accessibility improvements (increasing development intensity increases the number of available activities or opportunities), and to efficiency and productivity improvements (increasing development intensity increases economy of scale and agglomeration effects).

- Employment: New transport infrastructure projects, and specifically their construction, operation and maintenance can increase regional employment. Generally, project-related jobs are considered to be both a benefit of the project as well as a cost incurred by the project. However, in certain special situations when job creation largely affects long-term unemployed workers, project-related jobs can be considered as benefits.


- Environment: New transport infrastructure projects can have substantial impacts on the environment, including impacts on climate change, use of natural resources (fossil fuels etc.), bio-diversity, air

Historically, the evaluation of new transport infrastructure projects have focused narrowly on impacts and benefits relating to users of the transportation system particularly reduced travel times and vehicle operating costs, and improved safety, etc. (Meyer & Miller, 2000). However, as shown in the above list, new transport infrastructure projects also have impacts and benefits on the wider socio-economic and natural systems like efficiency and productivity improvements, increased development, reduced (or increased) social exclusion, and impacts on the environment. Incorporating these effects in project evaluations becomes more complicated due to challenges in estimating and valuing impacts as well as challenges relating to isolating effects and possible double-counting.

Costs of new transport infrastructure projects include the financial costs and opportunity costs of the project, and the costs imposed by the project on users of the transportation system and on socio-economic and natural systems. Usually, evaluation frameworks differentiate between the two: costs of the projects and costs imposed by the project. Financial costs and opportunity costs are considered to be the ‘costs’ of the project, while the costs imposed on users of the transportation system and on the socio-economic and natural system are considered as ‘negative benefits’.

3.1.2. Quantification of Benefits and Costs

Evaluation of new transport infrastructure projects should ideally focus on the amount of net social or economic welfare provided by a project (or project alternative). Net social or economic welfare is a measure of the net gain (or loss) to society as a whole. Quantification of net social or economic welfare is usually done using the concept of ‘willingness to pay’ - the amount of money each individual or firm is willing to pay for the change (improvement) in his, her, or its circumstance. For example, the willingness to pay for a minute saved of commuting time, for cleaner air, or for more efficient industrial practices etc. Net social or economic welfare can be considered as the sum of the willingness to pay for all individuals and firms, and society in general for all improvements resulting from the new transport infrastructure project. The willingness to pay for consumers can be calculated as the change in consumer surplus due to an improvement, while the willingness to pay for producers can be calculated as the change in producer surplus due to an improvement.

Usually, all the benefits and costs of projects are quantified, using the concept of change in consumer/producer surplus, and then monetized, using conversion factors like the social value of time, the social value of safety.
improvements etc. A number of issues must be addressed in the quantification and monetization of benefits and costs. These include:

- **Transfers**: Benefits (or costs) are net economic or social gains (or losses). Transfers, on the other hand, involve a redistribution of economic activity - gain to one group and cost to another, and so produce zero net gains. Care must be taken to differentiate between benefits (or costs) and transfers. Transfers should not be considered as benefits (or costs). Examples of transfers include wages, which are a transfer of money from one group (employers) to another (employees).

- **Double counting**: Care must be taken to not double count benefits (or costs). For example, accessibility improvements occur, in part, due to travel time savings, and so the travel time savings portion of accessibility improvements should not be double counted.

- **Long time periods**: New transport infrastructure projects have a long useful lifetime stretching into decades and sometimes centuries, and will create impacts over a long time period. Care must be taken to consider all benefits (and costs) over the lifetime of the project, and to value benefits and costs based on when they occur. Discounting calculates the present value of future benefits.

- **Intangible benefits**: Not all the benefits (or costs) of a project are tangible - easily quantified or given a monetary value. For example, the loss of natural views, or the aesthetic of a bridge, etc. However, these intangible benefits should not be left out of the evaluation process due to the difficulty of quantifying and monetizing them. At the very least, these benefits should be included in qualitative terms.

- **Distributional effects**: Projects affect different groups differently, with some 'winners' and some 'losers'. Care must be taken to consider the distributional impacts of the project - gains to some groups versus losses to other group - in addition to the net gains and losses. Projects should be potential pareto improvements i.e. projects where the gains for the winners are large enough that in principle they can compensate the losers for their loses. In addition, care must be taken that negative impacts (costs) should not be more than the limits specified by regulations, such as environmental justice provisions.

- **Conversion factors**: The computation of benefits (and costs) is quite sensitive to the conversion factors chosen, such as the social value of time. Care must be taken that these factors are computed in a rigorous and theoretically sound manner.

- **Models**: Care must be taken to ensure that appropriate, rigorous and theoretically sound models are used to quantify benefits (and costs). When necessary, an integrated land use transportation model,
which considers all relevant aspect of the interaction between land use, transportation and socio-economic systems, should be used. Such a model should be able to predict the effect of transportation system improvements, like a new transport infrastructure project, in terms of its travel time, accessibility, development, productivity and efficiency benefits, etc.

3.1.3. Determining Effectiveness

A number of methods can be used to determine the net social or economic benefit of new transport infrastructure projects and so to determine the effectiveness of these projects over time. These include:

- **Present worth method**: Benefits and costs for each project (or project alternative) are discounted to their equivalent present values, and then compared with each other to determine effectiveness.

- **Annual worth method**: Benefits and costs for each project (or project alternative) are discounted to their equivalent annual values, and then compared with each other to determine effectiveness.

- **Benefit-cost method**: Benefits and costs for each project (or project alternative) are separated, cash flows are discounted to their equivalent present (or annual) values, these are used to compute a benefit-cost ratio, and then the benefit-cost ratio of projects (or project alternatives) are compared to determine effectiveness.

- **Return-on-investment method**: Return on investment, which is the interest rate that balances present and future cash flows, is calculated and then compared to a minimum rate of return for the project specified before the evaluation to determine effectiveness.

These three steps in project evaluation (definition of benefits and costs, quantification of benefits and costs, and determination of the effectiveness of a project) together create a comprehensive evaluation framework that informs the decision making process. An example of the application of such an evaluation framework to a new transit infrastructure project, Crossrail in London, is described below.
3.1.4. Case Study: Crossrail in London

A comprehensive evaluation framework, such as the one described above, has been applied to the Crossrail project in London. This evaluation has been detailed in a report titled *An Economic Appraisal of Crossrail*, an ex-ante appraisal of the Crossrail project (Cross London Rail Links, 2005). 4

The Crossrail project aims to connect the western and eastern sides of the Greater London region and provide access to Heathrow Airport, the West End, the City of London (London’s CBD), the Isle of Dogs including Canary Wharf, and Stratford (the site of the 2012 Olympics), by means of a mass transit rail link that crosses under the center of London (Figure 3-1) (Transport for London, 2006).

Figure 3-1: Crossrail Regional Route Map

![Crossrail Regional Route Map](Image)

The project sponsors, Transport for London (London’s Transportation Department) and the UK Department for Transport, currently in the process of applying to the British Government for funding, have prepared an economic appraisal of the project. They believe that the Crossrail project has benefits beyond the traditionally considered user benefits, and so their “economic appraisal includes both conventional transport benefits and also an evaluation of the wider economic impacts of the scheme” (Cross London Rail Links, 2005). Both sets

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4 The report *An Economic Appraisal of Crossrail* (Cross London Rail Links, 2005) is the primary source for all material in this section unless otherwise noted.
of benefits have been computed and then compared to the costs of the project to get benefit-cost ratios for the project.

The project lifetime has been considered to be 60 years from a service starting year of 2013. Benefits and costs have been discounted to present values for the year 2002 using a discount rate of 3.5% for the first 30 years of the project and 3% thereafter. Population and employment growth for the entire Greater London region has been derived from the ‘London Plan’, a vision plan. A travel demand forecasting model has been used to quantify transportation system improvements.

Employment forecasts for the areas affected by Crossrail have not been developed using an integrated land use transportation model. However, some of the methods\(^5\) used to estimate future employment in the areas affected by Crossrail, explicitly consider the interaction between land use and transportation (Cross London Rail Links, 2005). These include:

- **The Laser model:** This model incorporates the interaction between land use, density and accessibility; and predicts changes in employment due to changes in accessibility as a result of Crossrail.

- **The Centre for Economics and Business Research (cebr) approach:** This approach models the relationship between the population and jobs and accessibility as measured by an isochronic measure; and predicts changes in employment due to changes in accessibility as a result of Crossrail.

The costs of the Crossrail project have been computed in terms of capital costs, maintenance costs and operating costs, to arrive at total costs of £13,902 million in present value. The revenues of the project have been computed in terms of Crossrail gross rail revenue, less transfers from other rail (transfers to other existing and proposed rail transit projects), to arrive at net revenues of £6,149 million in present value. The net cost of the project have been computed in terms of total costs, less net revenues, with adjustments made for indirect tax revenues to arrive at net costs of £8,960 million in present value (Table 3-1).

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\(^5\) 6 different methods were used to estimate future employment
Table 3-1: Crossrail Costs

<table>
<thead>
<tr>
<th>Present Value</th>
<th>£ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>10,626</td>
</tr>
<tr>
<td>Maintenance Costs</td>
<td>1,606</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>1,670</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td><strong>13,902</strong></td>
</tr>
<tr>
<td>Crossrail Gross Rail Revenues</td>
<td>13,575</td>
</tr>
<tr>
<td>Less Transfers From Other Rail</td>
<td>(7,426)</td>
</tr>
<tr>
<td><strong>Net Revenues</strong></td>
<td><strong>6,149</strong></td>
</tr>
<tr>
<td>Total Costs</td>
<td>13,902</td>
</tr>
<tr>
<td>Less Net Revenues</td>
<td>(6,149)</td>
</tr>
<tr>
<td>Plus indirect tax reductions</td>
<td>1,207</td>
</tr>
<tr>
<td><strong>Net Costs</strong></td>
<td><strong>8,960</strong></td>
</tr>
</tbody>
</table>

Source: (Cross London Rail Links, 2005)

The user benefits of the Crossrail project, have been computed in terms of time savings (by public transport and roads), vehicle operating cost savings and reduction in accidents on highway, improved comfort (i.e. reduction in crowding), ambience and/or quality, and benefits to mobility impaired passengers. Benefits to users taking business trips and to users taking leisure or long-distance trips have been considered separately. Net benefits (less of disbenefits accruing during construction of the project) have been computed as £16,093 million in present value (Table 3-2)

Table 3-2: Crossrail User Benefits

<table>
<thead>
<tr>
<th>Present Value</th>
<th>£ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leisure/Long-distance trips</td>
<td></td>
</tr>
<tr>
<td>Time Savings</td>
<td>7,985</td>
</tr>
<tr>
<td>Ambience/Crowding</td>
<td>2,889</td>
</tr>
<tr>
<td>Other</td>
<td>355</td>
</tr>
<tr>
<td>Business trips</td>
<td></td>
</tr>
<tr>
<td>Time Savings</td>
<td>4,847</td>
</tr>
<tr>
<td>Other</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total User Benefits</strong></td>
<td><strong>16,093</strong></td>
</tr>
</tbody>
</table>

Source: (Cross London Rail Links, 2005)

Considering only conventional transport benefits, the Crossrail project has a benefit-cost ratio of 1.80:1 (£16,093m/£8,960m) i.e. for every £1.00 of costs, benefits worth £1.80 will be generated by the project (Table 3-4).

As the Crossrail project connects and serves the business clusters of the West End, the City of London and the Isle of Dogs in Central London, the project sponsors believe and show that “significant wider economic benefits
above and beyond those accruing to transport users (through time savings and ambience/crowding benefits) will arise, as a result of growth in those areas, facilitated by Crossrail” (Cross London Rail Links, 2005). Furthermore “the values placed on time savings and ambience/crowding benefits reflect the values that the travelers themselves place on those benefits. The assessment of the wider economic benefits identifies areas where the overall benefits extend beyond the direct benefits to users, encompassing external effects on productivity and output.” (Cross London Rail Links, 2005).

The sponsors of the Crossrail project argue that growth in the business clusters of the West End, the City of London and the Isle of Dogs, is important because of the higher productivity of Central London employment in comparison to employment in the rest of the Greater London region. This higher productivity is primarily due to the benefits of agglomerations. These benefits are a result of the higher efficiency of each job within these areas, as result of being in a very high employment density area.

Transportation system improvements due to Crossrail have been estimated to add between 5,000 and 13,000 jobs in Central London by the year 2016, and between 23,000 and 40,000 jobs by the year 2026. All further calculations have been made based on a scenario with 5,000 additional central London jobs by 2016 and 33,000 by 2026.

The wider benefits of the Crossrail project have been computed in terms of:

- **Move to more productive jobs:** This is a result of jobs moving to Central London, with its higher productivity, as a result of Crossrail, from Outer London. Productivity differences between Central London and Outer London jobs have been calculated as about £10,000 to £12,000 per person per annum, which discounted over 60 years gives £10,772 million in benefits. After adjusting for double counting, this gives net benefits of £3,232 million in present value.

- **Agglomeration benefits:** This is a result of the increased productivity of all existing Central London jobs due to the marginal increase in employment density as a result of Crossrail. Additional agglomeration benefits to existing Central London jobs have been estimated to be £100 per job per annum, which give net benefits of £3,094 million in present value.

- **Increased labor force participation:** This is a result of more people working (expanding workforce) due to better access to jobs as a result of Crossrail, and is estimated to amount to £349 million in net benefits in present value.

---

6 For information please see **Crossrail: Socio-Economic Technical Report** (Cross London Rail Links, 2005)
— *Imperfect competition:* These are benefits not captured in the standard appraisal, such as user benefits as a result of Crossrail, due to the violation of the assumption of perfect competition. Based on UK Department for Transport guidance, this is estimated to amount to £486 million in net benefits in present value.

This evaluation approach produces total wider benefits of £7,161 million in present value (Table 3-3).

**Table 3-3: Crossrail Wider Benefits**

<table>
<thead>
<tr>
<th>Present Value</th>
<th>£ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move to More Productive Jobs</td>
<td>3,232</td>
</tr>
<tr>
<td>Agglomeration Benefits</td>
<td>3,094</td>
</tr>
<tr>
<td>Labor Force Participation</td>
<td>349</td>
</tr>
<tr>
<td>Imperfect competition</td>
<td>486</td>
</tr>
<tr>
<td><strong>Total Wider Benefits</strong></td>
<td><strong>7,161</strong></td>
</tr>
</tbody>
</table>

Source: (Cross London Rail Links, 2005)

Considering these wider benefits in addition to conventional transport benefits, the Crossrail project has a benefit-cost ratio of 2.60:1 (£23,254m/£8,960m) i.e. for every £1.00 of costs, benefits worth £2.60 will be generated by the project (Table 3-4). This ratio falls into the category of ‘high value for money’ as defined by the UK Government.

**Table 3-4: Crossrail Benefit-Cost Ratios**

<table>
<thead>
<tr>
<th>Present Value</th>
<th>£ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Costs</td>
<td>8,960</td>
</tr>
<tr>
<td>Total User Benefits</td>
<td>16,093</td>
</tr>
<tr>
<td>Total Wider Benefits</td>
<td>7,161</td>
</tr>
<tr>
<td>Total User + Wider Benefits</td>
<td>23,254</td>
</tr>
<tr>
<td>Benefit-Cost Ratio without Wider Benefits</td>
<td>1.80</td>
</tr>
<tr>
<td>Benefit-Cost Ratio with Wider Benefits</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Source: (Cross London Rail Links, 2005)

The Crossrail project appraisal provides an example of a comprehensive evaluation framework applied for a proposed new transit infrastructure project.
3.2. The Current FTA New Starts Evaluation Framework

The Federal Transit Administration (FTA) supports locally planned and operated public mass transit systems throughout the United States including heavy rail, light rail, commuter rail, and bus rapid transit systems (Federal Transit Administration, 2006). The FTA also administers the US federal government’s primary financial funding assistance for major transit capital projects through its discretionary New Starts program (Federal Transit Administration, 2006). The New Starts program is part of the Capital Investment Grant Program provisions of 49 USC 5309 (Section 5309), most recently reauthorized by the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) in August 2005. It is also known as the Section 5309 New Starts program.

Most of the planning done for new transit infrastructure projects in the United States, including for the Circle Line in Chicago, adheres to the planning guidance set forth in the New Starts program, and aims to meet the evaluation framework therein. This is mainly due to the fact that most new transit infrastructure projects apply (or aim to apply) to the New Starts program for federal monies as a primary source of funding.

3.2.1. New Starts Process

Figure 3-2 shows the current FTA New Starts process.

Figure 3-2: FTA New Starts Process

Source: (Hussey & Rossi, 2006)
This process involves the following steps:

- **Systems planning:** This involves an identification of current regional travel patterns and problems in order of priority.

- **Alternatives analysis:** This involves the definition of a base case\(^7\), and alternative solutions (new transit infrastructure projects) to address the identified transportation problems. These project alternatives are analyzed in terms of their impacts, benefits and costs and then compared to the base case, using the FTA New Starts evaluation framework.

- **Selection of a locally preferred alternative:** Based on the evaluation, a locally preferred alternative is identified.

- **FTA decision regarding preliminary engineering:** At this point, based on the evaluation, the FTA makes a decision regarding whether or not to fund the preliminary engineering work for the locally preferred project alternative.

- **Preliminary engineering:** This involves the completion of preliminary engineering, the environmental impact statement, and the financial plan for the project.

- **FTA decision regarding final design:** At this point, based on the work already done and continuous project management oversight, the FTA makes a decision regarding whether or not to fund the final design work for the locally preferred project alternative.

- **Final Design:** This involves completion of the final engineering design for the project, and the start of the process of right-of-way acquisition, before-condition data collection etc.

- **Full funding grant agreement:** This leads to the signing of the full funding grant agreement in which the FTA guarantees funds for the project.

- **Construction:** This involves construction of the project. At all times project management oversight is carried out by the FTA.

---

\(^7\) A base case does not involve ‘doing nothing or a continuation of ‘current trends’, but rather involves improved systems management and operations together with modest investments, but without major new transit infrastructure projects. Such a base case levels the playing field between current conditions and future proposals, fills investment gaps between doing nothing and high cost alternatives, and provides incentive for incremental development.

3. Evaluation of New Transit Infrastructure Projects
The number of projects applying for New Starts funding far exceeds the amount of funds available, and so the FTA has developed an evaluation framework to identify projects that make the most efficient use of resources. The FTA's evaluation of new transit infrastructure projects includes a review of each project against the New Starts evaluation criteria.

### 3.2.2. Evaluation Criteria

The current (financial year 2007) evaluation criteria used within the FTA New Starts Evaluation Framework fall into two categories: project justification criteria and local financial commitment criteria.

New transit infrastructure projects submitted for New Starts funding to the FTA must demonstrate that they are justified, based on a review against the following project justification criteria (Federal Transit Administration, 2006):

- **Mobility Improvements**: The project must provide mobility improvements in terms of:
  - Normalized travel time savings, as measured by transportation system user benefits per project passenger mile
  - Number of current low-income households which would be served by the proposed project
  - Number of current jobs served by the proposed project
- **Environmental Benefits**: The project must provide environmental benefits in terms of:
  - Change in regional pollutant emissions
  - Change in regional energy consumption
  - EPA air quality designation
- **Operating Efficiencies**: The project must provide operating efficiencies in terms of:
  - System operating cost per passenger mile
- **Cost Effectiveness**: The project must be cost effective in terms of:
  - Incremental cost per hour of transportation system user benefits
- **Transportation Supportive Land Use Policies and Future Patterns**: The area around the project must have (or must be proposed to have) transit supportive land use in terms of:
  - Existing land use including the location and density of population and employment, and the presence of pedestrian friendly and accessible (ADA requirements) station areas
  - Transit supportive plans and policies including growth management, transit supportive corridor policies, and supportive zoning regulations near transit stations, and tools to implement land use policies
- Performance and impacts of policies including performance of land use policies, and potential impact of transit projects on regional land use in terms of new development in station areas

- **Other Factors:** Other factors may also be considered including:
  - Environmental justice considerations and equity issues
  - Opportunities for increased access to employment for low-income persons, and welfare to work initiatives
  - Livable communities initiatives and local economic development initiatives
  - Consideration of innovative financing, procurement, and construction techniques, including design-build turnkey applications
  - The cost effectiveness of the project based on alternative land use forecasts which consider the economic development impacts (benefits), in addition to the transportation system user benefits, of the proposed transit capital investment
  - Any other factor which the project sponsor believes articulates the benefits of the proposed major transit capital investment but which is not captured within the other project justification criteria

- **Economic Development Impacts:** In addition to the 6 criteria listed above, there is an on-going but as yet incomplete process of creating an additional criterion that considers the economic development impacts of New Starts projects.

New transit infrastructure projects submitted for New Starts funding to the FTA must demonstrate a level of local financial commitment including evidence of stable and dependable funds for construction, operation and maintenance of the project, based on a review against the following local financial commitment criteria (Federal Transit Administration, 2006):

- The proposed share of total project costs from sources other than the Section 5309 New Starts program, including Federal formula and flexible funds, the local match required by Federal law, and any additional capital funding

- The strength of the proposed capital financing plan in terms of:
  - Current capital condition
  - Completeness of plan
  - Commitment of capital funds
  - Capital funding capacity
  - Reasonable capital planning assumptions and cost estimates.
— The ability of the sponsoring agency to fund operation and maintenance of the entire system as planned once the project is built in terms of
  — Current operating financial condition
  — Completeness of operating plan
  — Commitment of operations and maintenance (O&M) funds
  — Operations and maintenance funding capacity
  — Operations planning assumptions and cost estimates

3.2.3. Computation of Transportation System User Benefits and Other Measures

One of the most important inputs for the evaluation criteria, and specifically for the criteria of mobility improvements and cost effectiveness is the transportation system user benefits measure. According to FTA, transportation system “user benefits are the changes in mobility for individual travelers that are caused by a project or policy change, measured in hours of travel time, and summed over all travelers” (Federal Transit Administration, 2004).

Transportation system user benefits accounts for 50% of the mobility improvements rating, with the other 50% being a combination of the number of low-income households served and the number of jobs served (Federal Transit Administration, 2006). Transportation system user benefits are also the major input in the rating for cost effectiveness.

Transportation system user benefits are computed using the process detailed below (Hussey & Rossi, 2006):

— A local mode choice logit model is used, where the variables included are in-vehicle time, wait time, walk access time, auto access time, fare, parking cost, number of transfer, income, auto ownership, and the quality of the pedestrian environment.

— From the local mode choice logit model, the logsum variable - log of the denominator of the logit function - is computed. This logsum variable “Represents the composite utility of all alternatives, including all variables. Increase in the utility of any alternative results in an increase in the logsum value” (Hussey & Rossi, 2006).

— The logsum variable is then expressed in units of time using the coefficient of in-vehicle time, to get user benefits.
Equation 3-1 shows the basic procedure for calculating the logsum value from the logit model.

**Equation 3-1: Transportation System User Benefits**

Utility, \( U_1 = B_0 + B_{11}X_1 + B_{21}X_2 + \cdots + B_{n1}X_n \)

Probability, \( P_1 = \frac{\exp(U_1)}{\sum_j \exp(U_j)} \)

Logsum = \( \ln \sum_j \exp(U_j) \)

User benefits = \( \frac{\ln \sum_j \exp(U_j)}{\text{Coefficient of invehicle time}} \)

Source: (Hussey & Rossi, 2006)

In order to compute user benefits defined above, FTA has developed a program (software) known as the SUMMIT program (Hussey & Rossi, 2006). This program has two major components: software code added to the software script of a mode choice model to save logsum values, and a post processor to save and report user benefits results. The program can generate a variety of reports, maps, and graphics showing the magnitude of user benefits and their location and distribution. Also, this program can be used as a diagnostic in order to identify previously unknown problems with models, problems with highway time savings, inconsistencies with other models, and problems in definitions of the alternatives.

Using the local mode choice models in conjunction with the SUMMIT program, user benefits are calculated system wide and then expressed in time equivalent units (hours). This thus provides a multimodal measure of traveler utility, which in fact is a utility-based accessibility measure computed from a mode choice model, for all users of the transportation system.

The methods used to calculate other measures needed for the evaluation are (Hussey & Rossi, 2006):

- **Mobility improvements:** Transportation system user benefits are calculated as shown above. The number of low income households served is calculated using GIS analysis of Census data for a one-half mile radius around stations. The number of jobs near stations is calculated using GIS analysis of best available local data sources.

- **Operating efficiencies:** Change in systemwide operating cost per passenger mile is calculated using forecasts of annual passenger miles and operating costs.

- **Cost effectiveness:** Incremental cost per transportation system user benefits is calculated using results of the SUMMIT software and annual systemwide capital and operating costs. Incremental cost per
incremental rider is calculated by dividing change in annual capital/operating costs by change in annual linked trips.

— *Environmental benefits:* Change in pollutant and precursor emissions and greenhouse gas emissions is calculated using annual regional VMT by vehicle classification, and local emissions factors derived from the Environmental Protection Agency (EPA) MOBILE emissions model. Change in regional energy consumption in the forecast year is calculated in BTUs, using regional VMT. Current regional air quality designation by EPA is also used.

### 3.2.4. Evaluation Process

The current (financial year 2007) evaluation process used within the FTA New Starts evaluation framework is shown in the figure below (Figure 2-3):

**Figure 3-3: FTA New Starts Evaluation and Rating Framework**

- **Summary project justification rating:** Each project is assigned ratings of high, medium-high, medium, medium-low or low or numeric ratings from 1 to 5 (low to high) for each of the five main project justification criteria (besides other factors).
- Ratings for mobility improvements and transit supportive land use criteria are assigned in comparison to other projects.
Ratings for cost effectiveness are assigned according to specific dollar breakpoints.

Ratings for operating efficiencies and environmental benefits are assigned according to decision rules.

Using some of the above project justification criteria ratings, each project is assigned a summary project justification rating of high, medium-high, medium, medium-low or low based. The ratings for cost effectiveness and transit supportive land use criteria have a weight of 50% each in the summary project justification rating for the project, with ratings for mobility improvements acting as a tie-breaker (in case the summary project justification rating for the project falls between two ratings, e.g. between a medium and medium-high rating). Ratings for operating efficiencies and environmental benefits are not considered in the summary project justification rating. Other factors, not otherwise captured in evaluation criteria, may be used to improve the summary project justification rating for the project, but by no more than one step e.g. medium to medium-high.

**Summary financial rating:** Each project is assigned numerical ratings from 1 to 5 (low to high) for each of the 3 local financial commitment criteria. Based on these a summary financial rating of high, medium-high, medium, medium-low or low is assigned. The rating for non Section 5309 funding share has a weight of 20%, the rating for strength and reliability of the capital plan has a weight of 50%, and the rating for strength and reliability of the operating plan has a weight of 30% in the summary financial rating.

**Overall project rating:** Based on the project justification and financial ratings, the FTA assigns each project an overall project rating of high, medium, or low (in following years the FTA will use ratings of high, medium-high, medium, medium-low or low). The decision rule used to reach the overall project rating is detailed below (Table 3-5).

<table>
<thead>
<tr>
<th>Summary Ratings</th>
<th>Overall Ratings (FY 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least medium-high for finance and project justification</td>
<td>High</td>
</tr>
<tr>
<td>At least medium for finance and project justification</td>
<td>Medium</td>
</tr>
<tr>
<td>Not rated at least medium for finance and project justification</td>
<td>Low</td>
</tr>
</tbody>
</table>

Source: (Federal Transit Administration, 2006)

This overall rating is used by the FTA to make decisions regarding whether or not to fund a project, and to determine the level of funding to be provided.
However, it is important to understand that the project justification, financial, and overall ratings are measures of very different things, and have very different uses. The project justification rating is a measure of a project’s benefits and cost effectiveness, the financial rating is a measure of the level of financial assistance requested by a project’s sponsoring agency and the strength of its financial plan, and the overall rating is a measure of FTA’s willingness to fund a project. Consequently, the summary project justification rating can be said to be an indication of the relative merits and demerits of the project itself, the summary financial rating can be said to be an indication of the relative merits and demerits of the project’s sponsoring agency, and the overall rating can be said to be an indication of FTA’s willingness to fund a project based on relative merits and demerits of the project and its sponsoring agency.

3.2.5. Assessment of the Current FTA New Starts Evaluation Framework

In some respects, the FTA New Starts evaluation framework compares favorably with the comprehensive evaluation framework described in the preceding section:

- **Considers some socio-economic and environmental effects:** The FTA New Starts evaluation framework does not focus solely on user benefits, but also considers the impacts and benefits of new transit infrastructure projects on the wider socio-economic and natural system including on the environment, on employment, and on development and land use patterns. Existing land use patterns are considered in terms of the location and density of population and employment, while future impact on development and land use patterns are considered in terms of the presence of transit supportive land use policies, and their performance. Economic development benefits and issues are also somewhat considered.

- **Considers distributional effects:** The FTA New Starts evaluation framework considers the distributional effect of new transit infrastructure including impacts on environmental justice and equity issues, and on employment for low-income persons.

However, the FTA New Starts evaluation framework still has a number of shortcomings, including:

- **Accessibility benefits are narrowly calculated:** Accessibility has been shown to be a measure of the benefits afforded by the LUT, including availability and attributes of travel options as well as the ultimate destinations (opportunities). This makes the calculation of accessibility benefits crucial to the evaluation of new transit infrastructure projects. In the FTA New Starts evaluation framework accessibility benefits are calculated as a utility-based measure using a discrete choice model. Specifically, a mode choice model is used to predict changes in the attractiveness of various modes of
travel due to transportation system changes. The accessibility benefits derived from this model represent only changes in the choice set regarding various modes of travel due to a new transport infrastructure project. This model does not consider changes in other choices (and choice sets) like the location decisions of households and jobs, development choices of developers, and the destination and path choices of users etc., due to new transit infrastructure projects. Consequently, the accessibility benefits calculated using the method and models outlined in the New Starts evaluation framework provide a narrow measure of accessibility, and accessibility benefits. Furthermore, these accessibility benefits represent only benefits due to transportation system changes with no integrated consideration given to accessibility changes due to changes in land use patterns including the growth and/or redistribution of opportunities and activities (development changes). As stated earlier, comprehensive calculation of the accessibility benefits of new transit infrastructure projects requires consideration of the changes in destination opportunities, including how these might change in time (due to the project). This implies that an integrated assessment of land use transportation interaction is necessary.

- **Does not consider quantified development benefits**: Development impacts and benefits are considered in the transportation supportive land use policies and future patterns criterion. However, these development benefits are considered only in terms of qualitative measures like the presence of transportation supportive land use policies etc., and generally not quantified i.e. no quantitative forecast of future development in terms of the number of households and jobs is required. Quantification of development benefits would allow the FTA to judge the relative development impacts of transit infrastructure projects, and also allow calculation of accessibility changes and benefits that might accrue as a result of growth and/or redistribution of opportunities and activities.

- **Does not consider efficiency and productivity benefits**: There is no consideration given to benefits accruing from efficiency and productivity improvements, especially in terms of economies of scale effects and agglomeration benefits, as a result of transit infrastructure projects. While these benefits are relatively difficult to estimate, the Crossrail project demonstrates a possible approach.

- **Does not consider economic development benefits**: As shown above, the FTA New Starts evaluation framework does not comprehensively account for the economic development benefits generated by projects (which include development benefits as well as efficiency and productivity benefits). Furthermore, the derivation of the project justification rating does not incorporate economic development benefits, but instead focuses almost exclusively on the cost-effectiveness and land use criteria. This has been identified by the United States General Accounting Office (GAO) as one of the
major flaws of the current FTA methodology, and one of the places where the current methodology does not comply with the SAFETEA-LU legislation (General Accounting Office, 2007).

The above list of issues highlights the fact that while the FTA New Starts evaluation framework is quite comprehensive in scope, it still has a number of shortcomings, especially where the complete quantification and consideration of benefits is concerned.

3.3. Conclusions

New transport infrastructure projects must be evaluated using comprehensive evaluation frameworks, which define all the impacts (benefits and costs) of a project; completely and accurately quantify all defined benefits and costs; and then determine the effectiveness of the project using robust methods against some predetermined criteria. Such evaluation frameworks help inform the decision making process as it relates to whether or not to build (or fund) new transport infrastructure projects. Currently, the FTA New Starts evaluation framework is used to appraise new transit infrastructure projects in the United States, and to make federal funding decision regarding the same. While this framework provides a comprehensive evaluation scope, it still suffers from a number of shortcomings. First, the model used to quantify accessibility benefits provides a narrow measure of accessibility, which does not explicitly consider changes in land use patterns due to the project. Second, the framework does not require development benefits to be quantified. Finally, this framework does not comprehensively consider economic development benefits.

The following chapters demonstrate an effort to calculate extended accessibility benefits, and development impacts, using a quasi-integrated land use transportation model, as developed for and applied to a specific new transit infrastructure project in Chicago, Illinois.
4. Research Context: The Circle Line in Chicago

This research effort focuses on the accessibility and development impacts of new transit infrastructure projects, and addresses a number of research questions, including how current evaluation frameworks consider these impacts; how to calculate development changes, and then incorporate these changes into the calculation of accessibility impacts; and how development-supportive public policies influence the intensity of development. The Chicago region, the current regional transportation system, and the Chicago Transit Authority’s proposed new Circle Line project, provide an ideal context in which to address these questions.

This chapter presents this context in 5 main sections, which describe: the Chicago region; the regional transportation system; current regional transportation and land use planning methods and models; the proposed Circle Line project; and its evaluation using the FTA New Starts evaluation framework.

4.1. Chicago Region

Chicago is one of the largest cities (by population) in the United States. It is located in the Midwestern region of the United States, on the southwestern banks of Lake Michigan, and in the northeastern part of the State of Illinois (Figure 4-1). The Chicago region is centered on the city of Chicago, and specifically on Chicago’s CBD: the ‘Loop’.

Figure 4-1: Chicago Region

Source: City of Chicago’s GIS files
Table 4-1 shows demographic statistics for the Chicago region. The entire region has a population of about 8.1 million, and has about 2.9 million households and about 3.8 million jobs. Population density for the entire region is quite low - about 3.8 persons per acre.

Table 4-1: Demographic Statistics for the Chicago Region

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area in acres</td>
<td>2,403,392</td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>6,129,121</td>
<td>3.38</td>
</tr>
<tr>
<td>Number of Households</td>
<td>2,921,904</td>
<td>1.22</td>
</tr>
<tr>
<td>Number of Jobs</td>
<td>3,862,381</td>
<td>1.61</td>
</tr>
<tr>
<td>Number of Workers</td>
<td>3,744,249</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Source: 2000 Census Transportation Planning Package Part 1 & Part 2

Table 4-2 shows the mode share for journey-to-work trips in the Chicago region. This table suggests that the entire Chicago region is very automobile dependent. Automobile travel (drive alone and carpool) accounts for about 80% of journey-to-work trips, while transit mode share is only about 12%.

Table 4-2: Mode Share for Journey-to-Work trips in the Chicago Region

<table>
<thead>
<tr>
<th>Mode share for journey-to-work</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive alone</td>
<td>69.13%</td>
</tr>
<tr>
<td>Carpool</td>
<td>11.04%</td>
</tr>
<tr>
<td>Bus or trolley bus</td>
<td>5.04%</td>
</tr>
<tr>
<td>Streetcar, trolley car, subway, or elevated</td>
<td>3.73%</td>
</tr>
<tr>
<td>Railroad or ferryboat</td>
<td>3.56%</td>
</tr>
<tr>
<td>Bicycle or walked</td>
<td>3.52%</td>
</tr>
<tr>
<td>Taxicab, motorcycle or other means</td>
<td>1.06%</td>
</tr>
<tr>
<td>Worked at home</td>
<td>2.92%</td>
</tr>
</tbody>
</table>

Source: 2000 Census Transportation Planning Package Part 1
4.2. Regional Transportation System

Figure 4-2 shows the regional road and highway system in the Chicago region. Overall the Chicago region has a well developed vehicular transportation system, with a number of highways radiating outwards from the Loop, connected by a circumferential 'beltway'. A grid-based local street pattern dominates most of the region, and especially the city of Chicago.

*Figure 4-2: Regional Road and Highways*

Source: Caliper Transportation Data CD

The road transportation system is currently at or near capacity, with a high level of congestion on almost all highways and arterials in the peak periods and sometimes throughout the day. The Texas Transportation Institute currently ranks Chicago as the third most congested city in the United States (Texas Transportation Institute, 2005). The most congested parts of the road system are in or near the Loop.
Chicago also has a well developed public transportation system. The Regional Transportation Authority (RTA) has financial oversight over, and is the regional planning body for, the 3 transit agencies that provide transit service in the Chicago region: the Chicago Transit Authority (CTA), Metra, and Pace. The RTA service area is comprised of the 6 county area of Cook, DuPage, Kane, Lake, McHenry and Will counties in northeastern Illinois (Figure 4-3).

**Figure 4-3: RTA 6-County Area**

![Map of RTA 6-County Area](image)

Source: City of Chicago GIS files

As can be seen in Table 4-3, the CTA rail and bus systems account for more than 75% of total transit ridership in the Chicago region.

**Table 4-3: Transit Ridership in the Chicago Region**

<table>
<thead>
<tr>
<th>Transit Service</th>
<th>Annual Unlinked Passenger Trips (in millions)</th>
<th>Percentage</th>
<th>Average Weekday Ridership By Route</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA Rail</td>
<td>154.90</td>
<td>26.98%</td>
<td>486,607</td>
<td>26.91%</td>
</tr>
<tr>
<td>CTA Bus</td>
<td>305.60</td>
<td>53.22%</td>
<td>929,961</td>
<td>51.43%</td>
</tr>
<tr>
<td>Metra Commuter Rail</td>
<td>76.90</td>
<td>13.39%</td>
<td>280,459</td>
<td>15.51%</td>
</tr>
<tr>
<td>Pace Suburban Bus</td>
<td>36.80</td>
<td>6.41%</td>
<td>111,167</td>
<td>6.15%</td>
</tr>
<tr>
<td>Total RTA</td>
<td>574.20</td>
<td></td>
<td>1,808,194</td>
<td></td>
</tr>
</tbody>
</table>

Source: (RTAMS, 2007)
4.2.1. Chicago Transit Authority

The CTA operates the nation's second largest transit system, which serves the city of Chicago and about 40 surrounding suburbs. The CTA system is comprised of rail and bus transit lines. Overall, the CTA system carries on-average nearly 1.5 million rides every weekday and about 460 million rides every year (RTAMS, 2007).

The CTA rail transit system consists of 8 rail transit lines: the Blue, Red, Green, Orange, Brown, Purple, and Yellow Lines, and the recently added (summer 2006) Pink Line. Five of these lines (Green, Orange, Brown, Purple, and Pink lines) converge in an elevated rail loop that defines Chicago’s CBD, hence the name ‘Loop’. Two lines (Blue and Red lines) pass north-south through the Loop in subways. The CTA rail transit system carries on-average nearly 0.5 million rides every weekday, and about 150 million rides every year (RTAMS, 2007). The CTA rail system is currently at or near capacity with a high level of crowding during the peak periods. The rail transit system is most congested in the Loop.

The CTA bus transit system consists of 154 bus routes. These routes include north-south, east-west and radial routes, many of which serve the Loop. The CTA bus system carries on-average nearly 1 million rides every weekday and about 300 million rides every year (RTAMS, 2007). Figure 4-4 shows the CTA rail and bus system.

Figure 4-4: CTA Rail and Bus System

Source: CTA GIS files
4.2.2. Metra and Pace

Metra operates one of the nation’s largest commuter rail systems, which on-average carries about 280,000 rides every weekday and about 77 million rides every year. The Metra commuter rail transit system consists of 11 lines, all of which terminate in the Loop, at 4 stations: LaSalle Street Station, Union Station, Ogilvie Transportation Center, and Randolph Street Station (Millennium Station).

Pace operates a suburban bus system, which on-average carries about 111,000 rides every weekday and about 37 million rides every year. The Pace suburban bus system consists of about 240 lines. Figure 4-5 shows the Metra commuter rail system and Pace suburban bus system.

Figure 4-5: Metra Commuter Rail System and Pace Suburban Bus System

Source: City of Chicago GIS files
4.3. Regional Land Use and Transportation Planning and Models

Regional land use and transportation planning in the Chicago region comes under the purview of the Chicago Metropolitan Agency for Planning (CMAP). CMAP was recently created by merging two agencies: the Chicago Area Transportation Study (CATS) and the Northeastern Illinois Planning Commission (NIPC). CATS is the designated Metropolitan Planning Organization (MPO) for the northeastern Illinois region, and as such is responsible for regional transportation planning in the Chicago region. NIPC has a mandate to be the regional growth management and comprehensive land-use planning agency for northeastern Illinois. The merger of NIPC and CATS has combined the previously separate responsibilities of regional transportation planning and regional land use planning. Consequently, CMAP is now responsible for integrated regional land use and transportation planning in the Chicago region.

Local land use planning in the Chicago region is carried out by the various municipalities, and specifically by their planning departments. In the city of Chicago, the city’s Department of Planning and Development has responsibilities for conducting land use planning, while the Department of Zoning has responsibilities for enforcing Chicago’s zoning ordinance.

CMAP has a number of operational land use and transportation models which can be used to analyze current and future land use and transportation patterns in the region. These models can also be used to understand and quantify the impacts of infrastructure or policy changes on land use and transportation systems.

Travel demand forecasting is done by the formerly CATS part of CMAP using a road, transit and highway network model, and a four-step demand model run on EMME/2 software. Socio-economic forecasts used in this model are generated by the formerly NIPC part of the CMAP. Employment and population forecasts for the year 2030 have been developed by NIPC. The process to develop these 2030 land use forecasts is described below (CMAP (NIPC), 2006):

- **Generation of region wide forecasts:** This step involved the generation of region wide forecasts for population, households and employment. The employment forecast was derived using a Regional Econometric Input-Output Model (REIM) developed by the Regional Economics Application Laboratory. This Laboratory is a joint effort between the University of Illinois at Urbana-Champaign and the Chicago metropolitan area.

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8 The region here is defined as the six county area of Cook, Lake, McHenry, DuPage, Kane, and Will counties. This coincides with the RTA service area.
Federal Reserve Bank. Population and household forecasts were generated with migration assumptions derived from the employment forecast.

— Compilation of expected local land use patterns: This step involved the compilation of expected land use patterns through meeting with local governments. This process uses an interactive mapping tool called ‘Paint the Town’ based on INDEX, a suite of GIS tools developed, marketed, and supported by Criterion, a urban planning consulting firm (CMAP (NIPC), 2006). This tool allows participants “to ‘paint’ (with a stylus on a computer screen) areas of expected new growth or redevelopment, specify the type and density of land use, and calculate the resulting change in population and employment – all in a single work session” (CMAP (NIPC), 2006). NIPC staff attempted to meet all 272 municipalities in the region to determine the amount of growth in terms of changes to municipal boundaries by 2030 (to account for new greenfield growth), and expected land development and redevelopment within each jurisdiction (to account for infill growth). 211 municipalities, representing 94% of the region’s population, eventually participated in the process. For the remaining 61 municipalities and for unincorporated areas, preliminary forecast totals were developed from prior forecasts and predicted boundaries (adjusted for land sought by adjacent participating municipalities). Using this process forecasts for population, households and employment at the local (municipality) level were generated. These forecasts represented the amount of population and employment growth requested by individual municipalities (CMAP (NIPC), 2006).

— Final adjustments: This final step involved the adjustment of local forecasts with each other, and then the adjustment of the local forecasts with region wide forecasts. Adjustment of local forecasts primarily involved the reconciliation of predicted municipal boundaries. In cases where a lot of overlap occurred, the overlapped areas were divided among the overlapping municipalities with each assigned a share. In cases where minor overlaps occurred, the overlapped area was designated to remain unincorporated. Adjustment of local forecasts with region wide forecasts involved the reconciliation of forecasted population and employment figures. Reconciliation of forecasted population figures was relatively simple as the sum of all local forecasts closely matched the regional forecasts, i.e. that the local municipalities had requested almost the same amount of population growth as was forecasted to occur region wide (CMAP (NIPC), 2006). Reconciliation of forecasted employment figures, on the other hand, was complicated by the fact that the sum of all local forecasts was almost double of the regional forecasts, i.e. that the local municipalities had requested almost double the amount of employment

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9 Denotes previously undeveloped land
growth than was predicted to occur region wide (CMAP (NIPC), 2006). Adjustment to the employment forecasts were determined by the application of employment allocation shares from input-output model runs used in the development of prior employment forecasts. This process thus works “to project the total number of residents and jobs for the region, indicating a distribution of these people and activities that is the most likely to occur given market forces and expected implementation of public policy” (CMAP (NIPC), 2006).

The land use forecasting process described above shows that while regional population and employment forecasts are based on quantitative input-output based models, local forecasts are primarily the result of a visioning process which combines land use forecasting methods like comprehensive plans and other land use regulations, qualitative methods and allocation rules. These local forecasts are thus primarily the result of a regional political consensus on where total regional jobs and housing (estimated using input-output based models) are likely to locate, and not based on a quantitative land use model. In addition, while the travel demand forecasting model can be used in conjunction with the land use forecasts in order to quantify the impacts of infrastructure, policy, or land use pattern changes on the transportation system, the reverse is not true, i.e. the effects of infrastructure, policy or travel pattern changes on the land use system cannot be quantified. These deficiencies are primarily the result of the fact that the Chicago region currently does not utilize an operationally integrated land use transportation modeling approach, which can be used to quantify the interacting effects of changes in both land use and travel patterns.

In addition to the models used by CMAP, some other land use and transportation models have been developed by the CTA-MIT research partnership, for internal use. The most relevant such model is a regional transit accessibility model developed by Jeffrey Busby, a former MIT student (2004) who is currently working at the CTA, as part of his masters’ thesis Accessibility-based Transit Planning (Busby, 2004). This model uses a gravity-based approach in which accessibility to jobs and to households at locations is computed by considering travel times between zones, a travel time impedance function, and the number of jobs and/or households at zones. This model can be used to quantify the effect of changes in travel times due to infrastructure or policy changes (calculated using a transit network model) on accessibility, and also the effect

10 The fact that double the numbers of jobs were requested by municipalities, than were forecasted by the regional economic model, is probably an indication of one of the flaws of the methodology used – that it is a political process, which is subject to the strong proclivity for political negotiations. Employment growth presents an additional source of revenue, and so is more ‘wanted’ than new residential growth.

11 This accessibility model is described in more detail in chapter 6
of changes in the number and distribution of jobs and households due to infrastructure or policy changes (calculated using a land use model) on accessibility.

A transit network model has already been developed and incorporated into this accessibility model. Land use effects remain exogenous to this model. Consequently, the accessibility model presently only quantifies the effect of changes in travel times on accessibility. The lack of a land use model precludes the quantification of changes in land use patterns due to changes in accessibility, and so does not allow consideration of the cyclical nature of land use and transportation change.

4.4. Circle Line Project

The Circle Line in Chicago is an ambitious major new rail transit infrastructure project proposed by the Chicago Transit Authority (CTA). The 8 existing CTA rail transit lines are all radial - they start or are centered in the Loop and radiate outwards. The Circle Line would be the first circumferential rapid-transit line in Chicago, which will essentially “Loop the Loop” (Chicago Transit Authority, 2006).

4.4.1. Purpose and Need

A large majority of the CTA’s rail users travel towards the Loop during the AM Peak period and outwards from the loop in the PM Peak period. For these users the radial focus of the CTA rail system is appropriate. However, a substantial number of users also access other destinations besides the Loop including the Illinois Medical District and the University of Illinois at Chicago, which are both major employment centers located to the west of the Loop. The current CTA rail transit system forces users to travel through the Loop to get to most other destinations including to neighborhoods, regional jobs centers, and civic and educational institutions (Chicago Transit Authority, 2006).

Table 4-4: CTA Customer Primary Trip Transfer Behavior

<table>
<thead>
<tr>
<th>Trip Type</th>
<th>% of Users Transferring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus/Rail Transfer to Rail/Bus</td>
<td>34%</td>
</tr>
<tr>
<td>Rail Transfer to Rail</td>
<td>6%</td>
</tr>
<tr>
<td>Bus Transfer to Bus</td>
<td>11%</td>
</tr>
<tr>
<td>Rail No Transfer</td>
<td>19%</td>
</tr>
<tr>
<td>Bus No Transfer</td>
<td>25%</td>
</tr>
<tr>
<td>Transfer from Another System (Metra/Pace)</td>
<td>4%</td>
</tr>
</tbody>
</table>

Source: (Northwest Research Group, 2004)
In addition, a large percentage of CTA’s users make at least one transfer (55%), with more than 40% of rail trips involving a transfer (Table 4-4). A number of users also interchange between the suburban (Metra) and urban (CTA) rail systems with many of these trips ending in the Illinois Medical District and the University of Illinois at Chicago (Chicago Transit Authority, 2006). Most of these users are also forced to pass through the Loop, as the Loop is the one location where the different CTA rail lines and Metra lines interface with each other.

Finally, trains usually run at or near full capacity in the Loop. This adversely affects users of the CTA rail transit system and especially users boarding or alighting at the Loop, including users whose trip starts or ends in the Loop, and users transferring between rail transit lines in the Loop.

**Figure 4-6: Circle Line Conceptual Train Routing Map - Ashland Alignment**

![Circle Line Conceptual Train Routing Map](image)

Source: (Chicago Transit Authority, 2002)

In short, the Loop is a bottleneck in the regional rail transit system. The proposed Circle Line would help relieve this bottleneck and change the predominantly radial emphasis of the current CTA rail system by circumferentially linking existing CTA rail transit lines and Metra suburban commuter rail lines, while still serving the Loop (Figure 4-6). It would also link population centers, and job centers outside the Loop. By making these connections and linkages, the Circle Line will allow users, especially those making crosstown trips or trips to non-Loop destinations, to have more convenient transfers between transit lines and to take alternate routes bypassing the urban core (Chicago Transit Authority, 2006). The Circle Line would also relieve crowding in
trains, and especially in the Loop, by reducing the number of users who need to transfer to other rail transit lines in the Loop.

The Circle Line will also give easier rail transit access to about 194,000 persons, 91,000 households and 550,000 jobs that are within a quarter mile buffer of the Circle Line.

4.4.2. Original Concept

The Circle Line was originally conceptualized as a transit line which would use heavy-rail-transit technology, with a partly elevated and partly-underground profile, following an alignment along Ashland Avenue (Chicago Transit Authority, 2006) (see Figure 4-6). As such, the Circle Line would use mostly preexisting underground or elevated rail tracks, and would entail the construction of only 6.6 miles of new track (out of a route length of 13.3 miles) along the Ashland street corridor (Chicago Transit Authority, 2006). The existing underground sections of the Circle Line would include the Red Line tunnel in the Loop, which would be shared with the Red Line and a proposed new service: the airport connector between O’Hare and Midway airports, which would link the Blue Line to the Orange Line via the Red Line tunnel. The existing elevated sections of the Circle Line would include the Orange Line and Pink Line tracks.

In this concept, the Circle Line would: connect most CTA rail transit lines and Metra lines; pass through and connect the dense residential neighborhoods of Pilsen, Heart of Chicago, University Village, Near West Side, West Town, East Ukrainian Village, Wicker Park, and Bucktown; pass through and connect the dense employment centers of the Illinois Medical District, the University of Illinois at Chicago, and the Loop; and pass through and connect some sparsely developed, primarily industrial, and sometimes abandoned areas along the north and south branches of the Chicago River. However, no final decision has been taken by the CTA regarding technologies, profiles, or alignments.

4.4.3. Phasing

The Circle Line project is envisioned to be implemented in 3 phases over a 10 to 15 year period (Chicago Transit Authority, 2006) (see Figure 4-7):

- **Phase I - Paulina Connector Restoration**: This phase consists of rebuilding a 3/4 mile section of track, which allows modification of existing rail transit routes and an increase in service frequencies. Specifically this phase involves the modification of Blue Line services in which one of the two branches of the Blue Line is separated out as the new Pink Line. This modification allows service frequencies to
be increased on the remaining branch of the Blue Line and on the new Pink Line. This phase was
implemented in the summer of 2006.

— **Phase II - Cermak-Archer Connector:** This phase would involve construction of 1.5 miles of new tracks
to connect the Pink Line to the Orange Line, which would allow easy transfers between the Pink, Green,
Orange and Blue Lines of the CTA, and some Metra Lines.

— **Phase III - North-Ashland Subway:** This phase would involve construction of 3.35 miles of new tracks
to connect the Pink Line to the Red Line and so complete the ‘loop’ of the Circle Line project. This
would allow easy transfers between the Pink, Green, Orange, Blue, Brown, Red and Circle Lines of the
CTA, and some Metra Lines.

**Figure 4-7: Circle Line Conceptual Track and Station Construction Phasing Plan**

Source: (chicago_l.org, 2002)

### 4.4.4. Frequency Restrictions

The proposed alignment of the Circle Line, and especially the fact that it would share tracks with other existing
rail lines, places a number of restrictions on its operation. The primary restriction is on the maximum frequency
of the Circle Line, due to capacity restrictions in the Red Line tunnel. The Red Line tunnel can allow a maximum
frequency of about 30 trains per hour (2 minute frequencies), which is an optimistic projection. The Red Line
currently runs at frequencies of 12 to 20 trains per hour, while the airport connector is proposed to run every 15 minutes (4 trains per hour). Given these conditions, the CTA projects that the Circle Line can at most reach a frequency of about 12 trains per hour (5 minute headways), which is possible but not likely. A more realistic projection for Circle Line headways is about 4 to 6 trains per hour (10 to 15 minute headways).

4.4.5. Potential Benefits

The major potential benefits of the Circle Line project are:

- **Travel time savings**: As proposed, the Circle Line in Chicago will allow users to have more convenient transfers between rail transit lines and to take alternate routes bypassing the urban core where there is concern regarding train capacity during peak hours (Chicago Transit Authority, 2006). The Circle Line will also provide easy (or easier) rail transit access to some users who live or work in the immediate vicinity of Circle Line stations. Consequently, the Circle Line will reduce travel times in terms of in-vehicle travel times, and walk times to some zones in the Chicago region from some zones in the Chicago region, and especially to and from zones in the immediate vicinity of Circle Line stations. Additionally, any increase in service frequency from current levels will reduce wait times. In some cases the Circle Line will help reduce the number of transfers required to travel between zones in the Chicago region.

- **Accessibility benefits**: By reducing travel times, the Circle Line will increase access to activities and opportunities in the region, and thus lead to accessibility improvements (benefits) in the Chicago region. The accessibility benefits of the Circle Line project are likely to be large in comparison to other new transit infrastructure projects, especially those located in suburban areas. This is due to the fact that the greatest reductions in travel times due to the Circle Line will occur in the immediate vicinity of Circle Line stations, which for the most part, are located in dense urban areas with a large number of opportunities (household and jobs), as opposed to being located in low-density suburban areas. In dense zones, even a small reduction in travel times will allow access to a large number of additional opportunities.

- **Development benefits**: The Circle Line in Chicago will potentially have significant development impacts and benefits. As discussed in preceding chapters, accessibility improvements in a zone get capitalized into the value of land, which increases the pressure to intensify the intensity of development at that zone. Also accessibility improvements affect the location decisions of firms and households. The Circle Line, like the Crossrail project in London, serves some dense employment centers like the Illinois
Medical District, the University of Illinois at Chicago, and the Loop, and also some dense residential neighborhoods. In these areas, increased accessibility due to the Circle Line will potentially promote commercial and residential development in terms of higher densities. Additionally, the Circle Line serves some sparsely developed, primarily industrial, and sometimes abandoned areas along the north and south branches of the Chicago River. In these areas, increased accessibility due to the Circle Line will potentially promote regeneration and development.

Beyond travel time savings, and accessibility and development benefits, the Circle Line project might also generate some environmental benefits like reduced automobile emissions as a result of people switching from automobiles to transit. The Circle Line might also generate some efficiency and productivity benefits.

4.5. Evaluating the Circle Line in Chicago

The Chicago Transit Authority is in the process of applying for federal funding for the Circle Line through the Federal Transit Administration’s New Starts program.

4.5.1. Current Status

Currently, the Circle Line project is in the ‘Alternatives Analysis Study’ part of the New Starts process. The universe of alternatives with which this process was started has currently been screened down to four: 2 bus-rapid-transit (BRT), at-grade alternatives that use Ashland and the Ashland-Ogden alignments, and 2 heavy-rail-transit (HRT), partly underground, partly elevated alternatives that use Ashland and the Ashland-Ogden alignments (Chicago Transit Authority, 2006). One ‘locally preferred alternative’ will be selected from these four alternatives.

4.5.2. Concerns

Seeing that the accessibility and development benefits of the Circle Line are potentially very large, the limitations of the FTA New Starts evaluation framework, especially the narrow measure of accessibility, and the non-consideration of quantified development benefits, significantly affect the case for federal funding being made by the CTA for this project.

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12 This depends on the latent demand for automobile use.
In addition, as shown earlier, comprehensive quantification of the accessibility and development impacts of new transit infrastructure projects, like the Circle Line, requires an integrated consideration of land use and transport interactions\textsuperscript{13}. This is not possible using currently available land use and transportation models in Chicago.

4.5.3. Role of this Thesis

As discussed in the previous chapter, the FTA New Starts evaluation framework has a number of shortcomings, as it applies to the quantification of accessibility and development impacts and benefits. These shortcomings can be addressed by improving the current FTA methodology for considering the interaction between land use and transportation, and the effect of new transit infrastructure projects on the integrated land use transportation system (LUT). The Circle Line presents an opportunity to apply such an improved methodology to a project currently applying for federal funding through the FTA New Starts program.

To improve the current FTA New Starts methodology as it applies to the Circle Line in Chicago, a quasi-integrated land use transportation model for the Chicago region has been developed as part of this research effort. This model considers the effects of both land use and transportation changes on the LUT in the Chicago region, and as such can be used to quantify the accessibility and development impacts of the Circle Line in Chicago. This model also incorporates the effect of land use policy changes like zoning regulations etc. on accessibility and development.

Such a model will benefit the CTA in a number of ways. Primarily, it will allow the CTA to quantifiably demonstrate Circle Line benefits beyond those considered within the current FTA New Starts evaluation framework. At the minimum, the quantification of accessibility and development impacts and benefits of the Circle Line, would allow the CTA to make a quantitative argument, that complements the qualitative argument, that the Circle Line project deserves high ratings in the FTA New Starts evaluation criterion of ‘transportation supportive land use policies and future patterns’, which accounts for 50% of the summary project justification rating. Finally, incorporation of land use policy effects will allows the CTA and the city of Chicago’s Department of Planning and Development to understand and judge the effectiveness of various ‘transportation supportive land use policies’, and then to quantify their potential impacts. This again would allow the CTA to build a strong qualitative case for the ‘transportation supportive land use policies and future patterns’ criterion of the FTA New Starts evaluation framework.

\textsuperscript{13} Which is also applicable to other new transport infrastructure projects besides transit projects
4.6. Conclusions

The Chicago region, the regional transportation system, and CTA's proposed Circle Line project provide the context for this research project. While the Chicago region is very automobile-oriented, it does have a well-developed transit system. The CTA rail and bus system, which carries more than 75% of all transit rides in the region, is the core of the regional transit system. Both the road and CTA rail systems are currently at or near capacity during the peak periods.

The configuration of the CTA rail system - a radial network centered on the Loop - and the lack of excess capacity have created a major bottleneck for rail transit service in the Loop. The Circle Line, an ambitious new circumferential rail transit line proposed by the CTA, aims to address this problem.

The Circle Line project is likely to generate substantial accessibility and development impacts, in addition to transportation system benefits. The FTA New Starts evaluation framework, which will be used to appraise this project, does not comprehensively consider these impacts. This potentially weakens the case for the Circle Line project.

This thesis improves the current FTA New Starts methodology for quantifying accessibility and development impacts of new transit infrastructure projects, within an integrated framework of land use and transportation interaction, using the case of the Circle Line project as an example. This is achieved by developing a quasi-integrated land use transportation model for the Chicago region. Current transport and land use models in Chicago cannot be used, as they do not explicitly consider the effect of transportation infrastructure projects on land use patterns.
5. Quasi-Integrated Land Use Transportation Model

This research effort develops a quasi-integrated land use transportation model for the Chicago region. This model incorporates the cyclical process of land use and transportation changes, and so is able to model, at least partly, some of the complexities of the integrated LUT.

This chapter focuses on the quasi-integrated land use transportation model, and is organized in 4 main sections: a definition and calculation of some of the key concept and measures used in the model; a description of the proposed framework that forms the basis for the model; a description of the components of this model; and a discussion regarding its shortcomings.

5.1. Concepts: Accessibility and Development

The quasi-integrated land use transportation model is developed around two concepts: accessibility and development.

5.1.1. Accessibility

Due to data and resource availability, I utilize a potential accessibility (gravity-based) measure for the proposed model. Computation of such a measure requires data regarding the number of opportunities at locations, travel times\(^{14}\) between locations, and observed travel trip times of users (to compute the travel time impedance function). This data is available for the Chicago region using previously developed network models and the 2000 Census Transportation Planning Package (CTPP).

This accessibility measure, however, still has some shortcomings. For example, competition effects cannot be easily captured. Furthermore, they do not explicitly incorporate the individual and temporal component of accessibility. Finally, the challenge of communication to decision-makers remains. The final output of the potential accessibility measure shown in Equation 2-3 is a large number that shows the number of (travel time) adjusted opportunities, also termed as equivalent opportunities\(^{15}\) (e.g. equivalent households, or jobs),

\[\text{Equation 2-3}\]

\(^{14}\) Distance or generalized costs can also be used
\(^{15}\) An opportunity which is a factor of 0.5 away (as calculated by the impedance function) is counted as half an equivalent opportunity, and so on.
accessible at any given origin location in a region. However, this (large) number's significance is not readily understood - it is not readily comparable across origin locations, and is not related or comparable to the total number of opportunities available in a region.

To overcome this disadvantage, in this thesis the potential accessibility measure i.e. equivalent opportunities accessible at any given origin location in a region, is divided by the total number of opportunities available in a region\(^{16}\) (all locations), and expressed as an index between 0 and 1 (Equation 5-1), to provide an alternate measure of accessibility.

**Equation 5-1: Potential Accessibility and Potential Accessibility Index Measures**

\[
A_i = \sum_j B_j f(C_{ij})
\]

\[
A_R = \sum_{i \in R} \sum_j B_j f(C_{ij})
\]

\[
A_{II} = \frac{\sum_{j \in R} B_j f(C_{ij})}{\sum_{j \in R} B_j}
\]

\[
A_{IR} = \frac{\sum_{i \in R} \sum_j B_j f(C_{ij})}{\sum_{j \in R} B_j}
\]

Where:

- \( R = \text{set of locations within a region} \)
- \( i = \text{origin location} \)
- \( j = \text{destination location} \)
- \( A_i = \text{accessibility at location } i \)
- \( A_R = \text{regional accessibility} \)
- \( A_{II} = \text{accessibility index at location } i \)
- \( A_{IR} = \text{regional accessibility index} \)
- \( B_j = \text{number of opportunities at location } j \)
- \( C_{ij} = \text{travel time from } i \text{ to } j \)
- \( f(C_{ij}) = \text{travel time impedance function} \)

This potential accessibility index measure helps relate the potential accessibility measure at any origin location in a region to the total number of opportunities available in a region, and so is more easily understood and compared. For example, a potential accessibility index measure of 1 indicates that from that origin location, all

\[^{16}\text{This process only involves a monotonic transformation, and so does not change the underlying value of the potential accessibility measure.}\]
opportunities within the region are accessible within minimum (zero) travel time, distance or cost bounds; a measure of 0 indicates that from that origin location, no opportunities are accessible within maximum travel time (say 3 hours), distance or cost bounds; while a measure of 0.5 indicates that roughly half of the opportunities in the region are accessible from that location after accounting for the time, distance, or cost required to access them. This index is comparable across origin locations, and across different modes at the same origin location. This potential accessibility index measure can also be extended to include a measure for regional accessibility by summing the accessibility at origin locations within a region, over all locations in the region.

Due to the availability of a complete dataset (2000 Census Transportation Planning Package (CTPP) data, and existing transportation system model data), concerns regarding the ease of communicability, and to avoid computation of a value-of-time metric, this thesis considers travel times between locations, rather than distances or costs, in the computation of accessibility. This approach has some shortcomings including the fact that other aspects of travel costs like those imposed by lack of reliability, or discomfort etc. cannot be included in travel time.

5.1.2. Development

This thesis focuses on residential and commercial development. As mentioned in Chapter 2, no single measure of development exists. The various measures of development currently used include gross or net floor area, number of residential dwelling units, persons, households, workers, residential planning applications etc. for residential development; and gross or net floor area, number of firms, jobs, employees, commercial planning applications submitted etc. for commercial development. Most research on the interaction between land use and transportation focuses on the decisions of firms and households, including location choices and travel choices etc. Thus firms and households are the ideal measure of commercial and residential development respectively, where clarity of causes of change and implications of choices is concerned. Household data is available from CTPP data, and so the number, distribution, and density of households in locations are used as proxy measures for residential development. However, such data is not available for firms. Instead, jobs data, which give an indication of the size and location of firms, and can be derived from CTPP data, are used. Thus the number, distribution, and density of jobs are used as proxy measures for commercial development.
Development at a location is computed in terms of the number of households and jobs available at that location; and development intensity is computed in terms of the density of households and jobs at locations (Equation 5-2).

**Equation 5-2: Development Measures**

\[ DI_k = \frac{B_k}{Z_k} \]
\[ DI_R = \frac{\sum_{k \in R} B_k}{\sum_{k \in R} Z_k} \]

Where:
- \( R \) = set of locations within a region
- \( k \) = location
- \( B_k \) = number of opportunities (development) at location \( k \)
- \( Z_k \) = area of location \( k \)
- \( DI_k \) = development intensity at location \( k \)
- \( DI_R \) = regional development intensity

**5.2. Framework**

Accessibility, as defined and computed above, has two primary components\(^{17}\): the transportation component in terms of travel times between locations and a declining function of travel times, and the land-use component in terms of opportunities (households and jobs) available at each location (Geurs & Ritsema van Eck, 2003).

Changes in either the transportation or land-use component will change accessibility.

New transport infrastructure projects can immediately change the transportation component by reducing travel times between locations. For a location in the region, any reduction in travel times will increase the number of equivalent opportunities accessible from that location, thus increasing local accessibility at that location in the short run. For the region as a whole, increasing local accessibility at locations (in the region) in the short run will add up to also increase regional accessibility in the short run (Figure 5-1).

\(^{17}\) The individual and temporal components of accessibility are assumed to remain constant.
Over a period of time, new transport infrastructure projects can not only change the transportation component but also change the land use component of accessibility. For a location in the region, increases in local accessibility will make that location more attractive to households and firms making location decisions, and so can create the potential for increasing development at that location. Any change in development is dependent upon the presence of public policies like zoning regulations and design guidelines which encourage rather than discourage development. Any change in development at a location will not be immediate but will rather take place over a period of time (in the long run). Also, any increase in development at a location will lead to an increase in the number of opportunities (households and jobs) at that location. Increase in the number of opportunities at a location may be the result of a redistribution of opportunities within the region, of growth in the total number of opportunities in the region, or both. In any case, any increase in development will change the number and/or distribution of opportunities within the region, and so will change both local accessibility and regional accessibility in the long run.

If increases in the number of opportunities at locations in the region are primarily the result of regional growth, then the overall number of opportunities in the region will increase, and changes in local accessibility and regional accessibility will probably be positive. If increases in the number of opportunities at locations in the region are primarily the result of redistribution, then changes in local accessibility due to long run changes in development will be positive in some locations and negative in some locations. When the effects of travel time and long run development changes are taken together, and consideration is given to the fact that increases in development are most likely to occur at the most accessible locations, changes in local accessibility are likely to be positive for most, if not all, locations. Change in regional accessibility is also likely to be positive.
The process of accessibility and development change is cyclical, where accessibility changes will affect development, and development changes will affect accessibility.

Figure 5-2 shows the framework that is the basis for the quasi-integrated transportation land use model developed in this thesis. This framework can be used to consider and quantify both the short run and long run accessibility impacts and long run development impacts of new transport infrastructure projects.

As discussed in Chapter 3, the accessibility benefits measured in the current FTA New Starts evaluation framework represent only benefits due to immediate transportation system changes (travel time etc.), while no consideration is given to accessibility changes due to development over time. Consequently, the FTA New Starts evaluation framework focuses on short run changes in accessibility, and does not explicitly require the calculation of long run accessibility changes and long run development changes. Thus the proposed framework
provides an extension to the current methodology of the FTA New Starts evaluation framework as it applies to the consideration and quantification of accessibility and development impacts and benefits.

5.3. Components

Based on the framework described above, the quasi-integrated land use transportation model contains two major components. The first component is an accessibility model(s), based on the potential accessibility measures detailed above. This model, detailed in the next chapter, considers the effect of changes in travel times, and the number and distribution of households and jobs on accessibility. The second component is a development intensity model(s), which predicts the effect of changes in accessibility, development-supportive public policies including zoning regulations and urban design guidelines, socio-economic characteristics, and location factors on development. This development intensity model is detailed in Chapter 7.

The two components of this model are integrated conceptually in a unifying framework, but are not fully integrated operationally. Instead these components are separate parts which work together and share inputs and outputs. Hence the prefix 'quasi' in the quasi-integrated land use transportation model.

5.4. Shortcomings

The quasi-integrated land use transportation model developed has a number of shortcomings, including the data used, namely CTPP data. This data only provides information for journey-to-work trips, and leaves out many other trip purposes, including shopping, recreations, education, etc. Furthermore, CTPP data provides a very incomplete coverage of 'opportunities', e.g. job trip ends, with little or no information regarding the quality of opportunities available. Another major shortcoming is the lack of a regional economic/demographic model which can be used to provide regional population and employment forecasts. Such a model can be used to predict whether a region is growing, and if so, the magnitude of regional growth. This can give an indication of whether the increase in the number of opportunities at a location due to increases in local accessibility is likely the result of redistribution or growth. Finally, this model does not explicitly model land markets including prices, land and space availability, vacancy rates, etc. Future improvements could address these shortcomings.
5.5. Conclusions

This chapter presented the concepts, framework and components behind a quasi-integrated land use transportation model for the Chicago region developed as part of this research effort. This model explicitly considers the process of land use and transportation interaction, and models the effect of transportation system improvements and policy changes on the integrated LUT. The quasi-integrated land use transportation model focuses on the link between accessibility and development, and consequently, has two major components: an accessibility model and a development intensity model. Such a model can be used to study the interaction between land use and transport in the Chicago region, and to quantify the accessibility and development impacts of the Circle Line project.

The next two chapters describe the two components of the quasi-integrated land use transportation model for the Chicago region.
6. Accessibility Models

The accessibility model developed for the Chicago region considers all modes of travel including automobile, transit, walk etc. This is achieved by developing separate accessibility models for the different modes of travel.

This chapter focuses on accessibility models for the Chicago region, to be used in the quasi-integrated land use transportation model, and is organized in 3 main sections which provide descriptions of: a transit accessibility model that builds upon the model developed by Busby; a walk accessibility model; and an automobile accessibility model built upon a CATS network model.

6.1. Transit Accessibility Model

As mentioned in Chapter 4, Busby (2004) has developed a transit accessibility model for the Chicago region, incorporating the current regional transit system. This transit accessibility model consists of a transit network model in TransCAD incorporating the CTA and METRA rail transit networks, plus the CTA bus network. This network model was used to produce a skim matrix with all the transit travel time segments between zones. Accessibility at zones was then computed using a gravity-based approach with the following inputs: a travel time impedance function based on 1990 CTPP data, the number of opportunities (persons and jobs) at zones also derived from 1990 CTPP data, and the travel time matrix. The components of this accessibility model, and some improvements made to it as part of this research effort are described below.

6.1.1. CTA Transit Network Model

The CTA transit network model has been developed as part of multiyear CTA-MIT research effort, primarily by Prof. Mikel Murga at MIT, and two MIT students, Jeffrey Busby and Ajay Martin. It was started as a way of understanding and representing the CTA transit system, and has been developed and improved incrementally as development time has been committed, as data have become available, and as it has been applied (Busby, 2004).
The model covers an area of 25 miles beyond the Loop, including the CTA service network which extends about 15 miles beyond the Loop, expressways, major arterials, and the Metra commuter rail system (Busby, 2004). This model consists of\(^\text{18}\) (Busby, 2004):

- **Transportation Analysis Zones (TAZs):** The model area was partitioned using TAZs (4002 in total) which have been defined by CMAP(CATS). According to the Census Bureau “a traffic analysis zone (TAZ) is a special area delineated by state and/or local transportation officials for tabulating traffic-related data—especially journey-to-work and place-of-work statistics” (U.S. Census Bureau, 2007). TAZs are defined with an aim “to create homogeneous areas of socioeconomic characteristics and tripmaking tendencies of the population” and that “the zones in the TAZ system constitute the objects, or geographical individuals, that are the basic units for observation and measurement of spatial phenomena” (O’Neill & Hess, 1999). For planning purposes the Census Bureau releases aggregated socio-economic and transportation data at the TAZ level with each decennial Census in the CTPP.

- **Street and Rail Infrastructure Layer:** The transportation network including walk access to transit, drive access to transit, streets for buses, and tracks for railways in the CTA transit network model was modeled as interconnected nodes and links in a single infrastructure layer. The links represented include:
  - **Centroid Connector Links:** Centroid connector links connect the TAZ centroid to the transportation network, and are not physical links but rather a representation of the access path from the former to the latter. Four centroid connector links per centroid were generated automatically in TransCAD. These links were used only at the start or end of a modeled trip, with the remaining part of the trip on the physical transportation network i.e. road and/or rail. Travel times along centroid connector links were computed using average speeds of 3 mph for walk access and 20 mph for drive access.
  - **Road Infrastructure Links:** Road infrastructure links are a representation of actual streets, arterials and highways. These links were sourced from the Caliper Transportation Data CD, which itself was sourced from the Census Bureau’s Tiger Files. For computational simplicity, only local streets within a quarter mile of CTA bus stops and rail stations together with arterials and highways were used to describe walk access to transit. Travel times for buses along road infrastructure links were computed using AM Peak period free flow speeds derived from the street functional classification provided in the dataset.

\(^{18}\) For a detailed description of the transit network model please see Busby (2004).
— **Rail Infrastructure Links**: Rail infrastructure links are a representation of the CTA and Metra rail track geometry. These links were sourced from shapefiles in the CTA’s GIS (Geographic Information System) database. AM Peak period travel times along rail infrastructure links were computed using station-to-station running times from HASTUS scheduling software minus 40 seconds of dwell time.

— **Pedestrian Access Links**: Pedestrian access links connect the stations to the street network, and also include transfer paths between platforms. Travel times along pedestrian access links were sourced from CTA field measurement data where available. Otherwise pedestrian access links were given a travel time of one minute, considering the time to validate the fare media. Average speeds were not applied to the geometrical length, due to the issue of changing levels (going up/down using stairs, escalators or elevators) while accessing stations or transferring.

— **Transit route layer**: The transit route system including bus, rail, and commuter rail routes was modeled in a single transit route layer. Attributes for each route include route name and ID, headway (for AM Peak, PM Peak, Midday, and Owl (late night) periods), dwell time, fare, maximum and minimum wait time, and layover time at terminal points. The route system defines the infrastructure links (roads or rail) used by each route in either direction, and takes the travel time from the underlying infrastructure links. Stops or stations are defined for each route in either direction at their physical location. Other relevant variables therein include weights for different components of travel time i.e. access, wait, in-vehicle travel times etc., and transfer penalties.

The CTA transit network was modeled as existing in 2004, and also with the Circle Line project.

TransCAD allows the computation of different components of travel time like in-vehicle, waiting, transfer, and walk access and egress times separately, which can then be added to compute total travel times. These times can refer to actual clock times or perceived times, which are calculated by weighting clock times using weighting factors for each time component. TransCAD allows the computation of travel times between locations using 4 different methods: the ‘shortest path’ method, the ‘method of optimal strategies’, the ‘pathfinder’ method, and the ‘stochastic user equilibrium algorithm’ method. The shortest path method was used in the computation of travel times. This method assumes that all users traveling between zones choose the path with the lowest generalized travel cost. The shortest path method is faster to compute, and also easier to use (as it generates only one value of travel time) in comparison to the other three methods. The shortest path method also has one major shortcoming in that this method does not take into account the advantage of having multiple feasible paths between locations as offered by a dense network, and so it sometimes leads to unrealistic traffic
assignments. For example, it will assign all users between locations to the path with the shortest travel time, and none to an alternate path which takes just seconds longer. Other methods overcome this shortcoming, but were found to be difficult to use, and prone to computational errors.

Travel times between TAZs were computed with the existing CTA transit network and also with the different phases on the proposed Circle Line. A weighted travel time, rather than clock time, measure was used as "users perceive the different travel time components of a transit trip differently" (Busby, 2004). The weights were derived using coefficients from a CATS mode choice model estimated from a 1990 personal home travel survey, which were then adjusted for different modes according to FTA guidance for New Starts travel demand forecasting and roughly calibrated in an iterative process (Busby, 2004). Table 6-1 shows the final weights used.

Table 6-1: Weights for Components of Travel Time in Existing CTA Transit Network Model

<table>
<thead>
<tr>
<th></th>
<th>In-Vehicle Time</th>
<th>Waiting Time</th>
<th>Transfer Time</th>
<th>Walk Access/Egress Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA Rail</td>
<td>1.00</td>
<td>2.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
<tr>
<td>CTA Bus</td>
<td>1.50</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>METRA Commuter Rail</td>
<td>1.00</td>
<td>2.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Source: (Busby, 2004)

6.1.2. Gravity-based approach

A gravity-based approach was used compute accessibility. This has the following form (Equation 6-1):

Equation 6-1: Gravity-Based Approach in Existing CTA Transit Network Model

\[ A_i = \sum_j B_j f(C_{ij}) \]

Where:

- \( i \) = origin TAZ
- \( j \) = destination TAZ
- \( A_i \) = accessibility at TAZ \( i \)
- \( B_j \) = number of opportunities at TAZ \( j \)
- \( C_{ij} \) = travel time from TAZ \( i \) to \( j \)
- \( f(C_{ij}) \) = impedance function

Source: (Busby, 2004)
Components of travel times (wait time, in-vehicle time, access/egress time, transfer time) for the AM Peak period were computed from the transit network model using the shortest path method, then weighted using the weights shown above, and then summed to give total perceived travel times between zones. The number of opportunities at TAZs, in terms of numbers of persons and jobs, were derived from the 1990 CTPP data.

The major remaining and critical element of the gravity-based approach is the impedance function. This function was used "to describe the relative disutility of longer trips. The implicit assumption in this model is that potential destinations in close proximity are more valuable to a traveler than destinations further away, all other things being equal." (Busby, 2004). This function should be calibrated to replicate observed trip travel times, which should be sourced from surveys. In the case of commuting trips in the Chicago region, CTPP data (based on decennial census data) is the only source.

A frequency distribution of observed trip travel times usually follows a gamma function - which is not continuously declining but rather has a peak - and so implies that closer destinations are not always more valuable than farther ones. The reason for this is that there is a spatial mismatch between household and jobs locations. However, if the focus is narrowly on accessibility, then a continuously declining function, which always shows that closer opportunities are more valuable than farther opportunities, is required.

**Figure 6-1: Impedance Function in Existing CTA Transit Network Model**

Numerous functional forms were tested including a decreasing exponential function, and a decreasing exponential function with cut off at the maximum point. The functional form that was finally selected was a
cumulative travel time distribution curve, because it “satisfies the requirement of a continuously decreasing function and is grounded in actual travel behavior. Furthermore, it can be calibrated to a value of 1 for zero travel times and asymptotically approaches zero at very long travel times” (Busby, 2004). The impedance function was thus fitted to a cumulative distribution of travel times between locations, using journey-to-work data sourced from the 1990 CTPP data (Figure 6-1).

In order to eliminate bias due to the inclusion of suburban auto-oriented trips from the analysis of the CTA service area, only bus and rail transit trips whose origin was a TAZ in the model and whose destination was a TAZ within a two-mile radius of the center of the Loop were used (Busby, 2004). Exclusion of auto trips did not have any effect on the shape of the transit time distribution, while exclusion of transit trips not bound for two-mile radius of the center of the Loop had only a slight effect of the travel time distribution (it slightly narrowed the distribution by eliminating some longer cross-town transit trips) due to the fact that most transit trips have their destination in and around the loop. Trips on commuter rail were also not included in this estimation, as the travel time distribution of commuter rail trips was markedly different from that of bus or rail trips\(^{19}\), and as this model was primarily intended to analyze the Chicago region as defined by a 25 mile radius from the Loop where bus and rail, and not commuter rail, provide primary transit services. Exclusion of Metra commuter rail trips narrowed the transit travel time distribution, as commuter rail trips are generally longer than CTA bus or rail trips.

Equation 6-2 shows the final mathematical form of the impedance function.

**Equation 6-2: Impedance Function in Existing CTA Transit Accessibility Model**

\[
 f(C_{ij}) = \frac{1.08438}{(1 + 0.08438 \times e^{0.076223 \times C_{ij}})}
\]

Where:
- \( i = \text{origin TAZ} \)
- \( j = \text{destination TAZ} \)
- \( C_{ij} = \text{travel time from TAZ} \ i \ \text{to} \ j \)
- \( f(C_{ij}) = \text{impedance function} \)

Source: (Busby, 2004)

---

\(^{19}\) Trips on commuter rail have significantly longer travel times, primarily because commuter rail serves suburban and ex-urban locations
6.1.3. Results

Using this transit accessibility model, Busby was able to compute and compare regional accessibility and local accessibility at the TAZ level before and after the proposed Circle Line. His results show that regional accessibility will increase by 2.06% after implementation of the Circle Line. Of this, 1.54% increase in regional accessibility will occur after implementation of Phase 1 of the Circle Line which includes the Pink Line project, together with a modification of existing rail transit routes and an increase in service frequencies, but no new infrastructure development. Phase 1 of the Circle Line has largely been completed as of early 2007. Consequently, this analysis suggests that the majority of the accessibility impacts of the Circle Line project may already have accrued. His results also show that some TAZs in the immediate vicinity of the Circle Line will experience substantial accessibility improvements upon implementation. He identifies these zones as potential locations for increased development.

6.1.4. Shortcomings

The CTA transit accessibility model developed by Busby has a number of shortcomings:

- **Does not consider all components of accessibility:** This model calculates a gravity-based measure of accessibility, and so suffers from the shortcomings inherent in this measure including the fact that it does not consider the temporal or individual (except for the inclusion of perceived rather than clock travel times) components of accessibility. Also this model does not consider competition effects.

- **Does not use recent data:** The data used in this accessibility model is from the 1990 census which was 14 years old at that time. Land use and travel patterns in Chicago have changed significantly since 1990, and so may not be relevant for conducting analyses in the present day.

- **Uses only journey-to-work data:** This model uses only journey-to-work data from the 1990 CTPP to estimate the impedance function. Consequently, this model is only appropriate for analyzing the accessibility of households to jobs, and vice-versa.

- **Does not use all TAZs:** TAZs within the defined region i.e. 25 miles beyond the Loop, but across the state border in Indiana were not used in the model. This shortcoming may lead to some inaccuracies in the computation of accessibility.

- **Uses shortest path method available to compute travel times:** This accessibility model uses the shortest path method in TransCAD, which does not take advantage of the multiple feasible paths between locations offered by the dense CTA transit network, to compute travel times.
— *Uses weighted travel times:* This accessibility model uses perceived/weighted travel times as an input in the gravity-based approach to compute accessibility. This is appropriate as it allows some consideration of the individual component of accessibility (e.g. personal preferences in terms of the fact that waiting time is perceived to be more onerous than in-vehicle time). However, the observed trip travel times from the CTPP data used in the estimation of the impedance function, which is an integral part of the gravity-based approach, are clock times and not perceived or weighted times. Consequently, while the weight factors serve to incorporate the different perceptions of the trip time components to choose the shortest path, the reported times from that critical path, are taken as unweighted. This discrepancy\(^{20}\) may lead to inaccuracies in the computation of accessibility.

— *Does not consider the development impacts of the Circle Line:* This accessibility model considers and quantifies the short run accessibility impacts of the Circle Line due to the immediate change in travel times between TAZs as a result of the Circle Line. However, this model is not combined with a land use model which can generate population and employment forecasts based on the changes in accessibility. Consequently, the calculated accessibility measure does not include long run changes in accessibility due to the likely increases in development, and so this model likely underestimates the potential local and regional transit accessibility impacts of the Circle Line project.

Some of these shortcomings can be easily overcome. For example, this model can be updated to use more recent data now available from the 2000 census. Also, travel times can be computed using the pathfinder method for computing travel times in TransCAD, which takes advantage of the multiple feasible paths between locations offered by the CTA transit network. Finally, the development intensity model will allow consideration of development impacts.

### 6.1.5. Improvements and Updates

Some improvements and updates to the transit accessibility model have been implemented in order to address some of the shortcomings mentioned above.

The CTA transit network model used by Busby is updated using more recent data now available from the 2000 Census in the form of the 2000 Census Transportation Planning Package (CTPP). The model now uses updated TAZ definitions for the year 2000 from CMAP(CATS). As in the Busby model, TAZs within a 25 mile radius of the Loop (3153 in total), including TAZs in Indiana, are used. These TAZs are linked to updated socio-economic

\(^{20}\) For example, in the impedance function estimation, 8 minutes of in-vehicle time and 2 minutes of waiting time for CTA rail totals 10 minutes, but after using the weights the calculated travel times used in the model totals 12 minutes.
data from the 2000 CTPP, including the number of opportunities (households and jobs) at each TAZ. Figure 6-2 shows TAZs from 1990 and from 2000.

**Figure 6-2: 1990 and 2000 TAZs**

Table 6-2 shows some of the important statistics of interest at the TAZ level from 1990 and 2000. This table suggests that TAZs from 2000 are less numerous but larger than from 1990.

**Table 6-2: TAZ Changes Between 1990 and 2000**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>1990 TAZs</th>
<th>2000 TAZs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>4,002</td>
<td>3,153</td>
</tr>
<tr>
<td>Average area (acres)</td>
<td>154</td>
<td>205</td>
</tr>
<tr>
<td>Median number of households</td>
<td>350</td>
<td>445</td>
</tr>
<tr>
<td>Median number of jobs</td>
<td>307</td>
<td>370</td>
</tr>
</tbody>
</table>

Source: CMAP(CATS), and 1990 and 2000 CTPP Part 1 (at place of residence) and Part 2 (at place of work)
The street and rail infrastructure layers in the CTA transit network model have not been modified (Figure 6-3).

**Figure 6-3: Street and Rail Infrastructure Layers in TransCAD**

Table 6-3 shows statistics for the street and rail infrastructure layers.

**Table 6-3: Street and Rail Infrastructure Layer Statistics**

<table>
<thead>
<tr>
<th>Street Infrastructure Layer</th>
<th>Links</th>
<th>Rail Infrastructure Layer</th>
<th>Links</th>
<th>Connectors</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expressways</td>
<td>3,048</td>
<td>CTA Rail 2004</td>
<td>153</td>
<td>Centroid Connectors</td>
<td>9,423</td>
</tr>
<tr>
<td>Ramps</td>
<td>2,287</td>
<td>Circle Line Phase 1 (Pink Line)</td>
<td>4</td>
<td>CTA Rail Walk Access</td>
<td>220</td>
</tr>
<tr>
<td>Major Arterials</td>
<td>4,443</td>
<td>Circle Line Phase 2</td>
<td>4</td>
<td>Metra Rail Walk Access</td>
<td>227</td>
</tr>
<tr>
<td>Minor Arterials</td>
<td>6,914</td>
<td>Circle Line Phase 3</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Streets</td>
<td>81,889</td>
<td>Metra Rail</td>
<td>463</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: CTA Transit Network Model
The CTA transit network model update includes the latest information regarding transit routes (Figure 6-4), including information regarding Phase 1 of the Circle Line project as implemented in summer 2006, and updated dwell times for all CTA rail lines.

**Figure 6-4: Rail and Bus Transit Route Layer in TransCAD**

Table 6-4 shows statistics for the transit route layer.

**Table 6-4: Transit Route Layer Statistics**

<table>
<thead>
<tr>
<th>Routes</th>
<th>Routes</th>
<th>Stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA Rail</td>
<td>CTA Rail</td>
<td></td>
</tr>
<tr>
<td>in 2004</td>
<td>15</td>
<td>361</td>
</tr>
<tr>
<td>after Circle Line Phase 1 (incl. Pink Line)</td>
<td>14 after Circle Line Phase 1 (incl. Pink Line)</td>
<td>396</td>
</tr>
<tr>
<td>after Circle Line Completion</td>
<td>16 after Circle Line Completion</td>
<td>440</td>
</tr>
<tr>
<td>CTA Bus</td>
<td>129 CTA Bus</td>
<td>14,074</td>
</tr>
<tr>
<td>Metra Rail</td>
<td>30 Metra Rail</td>
<td>517</td>
</tr>
</tbody>
</table>

Source: CTA Transit Network Model
An attempt was made to update the method used to compute travel times between TAZs in TransCAD from the shortest path method to the pathfinder method. This would take advantage of the multiple feasible paths between locations offered by the CTA transit network. However, the results obtained by this method showed some unexpected instabilities at localized places. Therefore, the shortest path method is again used to compute travel times between TAZs. However, unlike the Busby model, these travel times are clock times and not perceived times: that is, the components of travel time like in-vehicle, waiting, transfer, and walk access and egress times are not weighted differently. This is because the observed trip travel times used in the estimation of the impedance function are also clock times and not perceived/weighted times. This change removes user’s perceptions from the accessibility calculation, but this decision was made to avoid a mismatch between clock times reported in the CTPP data used in the estimation of the impedance function, and travel times calculated using the transit network model.

The impedance function is updated using more recent data now available from the 2000 CTPP. The impedance function is estimated by fitting it to a cumulative distribution of observed trip travel times for all bus and rail transit trips whose origin was a TAZ in the model, sourced from the 2000 CTPP. Figure 6-5 shows the data used for estimation of the impedance function.

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21 In some cases waiting times increased by more than 10 minutes after implementation of the Pink Line, which is not possible considering the 7.5 minute headways on the Pink Line.

22 Before, this decision was made, accessibility was calculated with both clock times and weighted times, and then compared. Only marginal differences were found between the two.

23 These times are reported by users, and so may or may not account for the effect of traffic congestion on bus travel times.

24 Bus and rail trips were combined as they have similar trip travel time distributions.
Figure 6-5: Data used for Estimation of Impedance Function in Transit Accessibility Model

![Graph showing data used for estimation of impedance function.]

Source: 2000 CTPP Part 1 (at place of residence)

Figure 6-6 shows the estimation of the impedance function by fitting it to the cumulative distribution of observed transit travel times.

Figure 6-6: Impedance Function Estimation in Transit Accessibility Model

![Graph showing the estimation of the impedance function.](image)

Source: Author

The impedance function shown above suggests that an impedance factor of 0.5 represents a transit trip of about 45 minutes.

The gravity-based approach used to compute accessibility has also been updated. Local and regional accessibility are measured using potential accessibility index measures, in addition to potential accessibility.

6. Accessibility Models
measures. These index measures allow easy comparison between zones and between modes. Equation 6-3 shows the computation of these measures:

**Equation 6-3: Computation of Accessibility Measures in Transit Accessibility Model**

\[
\begin{align*}
A_i &= \sum_j B_j f(C_{ij}) \\
A_R &= \sum_{i \in R} \sum_j B_j f(C_{ij}) \\
A_{li} &= \frac{\sum_{j \in R} B_j f(C_{ij})}{\sum_{j \in R} B_j} \\
A_{lR} &= \sum_{i \in R} \frac{\sum_{j \in R} B_j f(C_{ij})}{\sum_{j \in R} B_j}
\end{align*}
\]

Where:

- \( R \) = set of locations within a region
- \( i \) = origin location
- \( j \) = destination location
- \( A_i \) = accessibility at location \( i \)
- \( A_R \) = regional accessibility
- \( A_{li} \) = accessibility index at location \( i \)
- \( A_{lR} \) = regional accessibility index
- \( B_j \) = number of opportunities (households and jobs) at location \( j \)
- \( C_{ij} \) = travel time (or distance or cost) from \( i \) to \( j \)
- \( f(C_{ij}) \) = impedance function

The transit accessibility model, incorporating the CTA transit network model, can be used to compute transit accessibility measures at the TAZ level and for the region with the existing CTA transit network. The resulting measures of local and regional transit accessibility represent the baseline against which the transit accessibility impacts of the Pink Line and the Circle Line project can be estimated.

The transit accessibility model can also be used to compute transit accessibility measures at the TAZ level and for the region after implementation of the Pink Line and the Circle Line projects. Consequently, this model allows the computation of the short run and long run changes in transit accessibility due to the Pink Line and Circle Line projects at the local level (each TAZ) and for the region as a whole (all TAZs).

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25 The existing situation in this case has been defined as just before implementation of the Pink Line project. This has been done so that the accessibility impacts of the Pink Line project can also be calculated.
6.2. **Walk Accessibility Model**

The transit network model described earlier is used as the basis of a walk accessibility model.

The walk accessibility model uses local streets, from the transit network model, to obtain a skim matrix of walking times between all TAZs. The form of the gravity-based approach used for the walk accessibility model is similar to that for the transit accessibility model. An impedance function for walking trips is estimated from observed walk trip times from the 2000 CTPP journey-to-work data. Figure 6-7 shows the data used for estimation of the impedance function, including the frequency and cumulative distribution of observed walk travel times.

**Figure 6-7: Data used for Estimation of Impedance Function in Walk Accessibility Model**

Source: 2000 CTPP Part 1 (at place of residence)
Figure 6-8 shows the estimation of the walk impedance function by fitting it to the cumulative distribution of observed walk travel times, in the same manner as the estimation of the impedance function for transit travel times.

Figure 6-8: Impedance Function Estimation in Walk Accessibility Model

The impedance function shown in Figure 6-8 suggests that an impedance factor of 0.5 represents a walk trip of about 15 minutes. As expected, this value is much lower than for transit trips (45 minutes), also suggesting that a 15 minute walk trip is more onerous than a 15 minute transit trip.

Using the walk time matrix, the impedance function estimated for walk trips, and the number of opportunities in each TAZ derived from the 2000 CTPP, the walk accessibility model can be used to compute the baseline (before the Pink Line project) walk accessibility from TAZs. This accessibility model can also be used to compute both the short run and long run accessibility changes due to the Pink Line and Circle Line projects.
6.3. Automobile Accessibility Model

An automobile accessibility model is also developed using a streets and highways network model\textsuperscript{26}, which contains information regarding free and congested speeds during the AM peak period\textsuperscript{27}. This network model is used to obtain a skim matrix of AM Peak period automobile trip times between all TAZs using congested speeds. One limitation of this model is that it considers only travel times and not generalized costs, and so does not incorporate parking charges, congestion costs, tolls etc.

A gravity-based approach of the same form as that for the transit and walk accessibility models is used for the automobile accessibility model. An impedance function for automobile trips is estimated from observed automobile trip times from the 2000 CTPP journey-to-work data. This data is shown in Figure 6-9.

Figure 6-9: Data used for Estimation of Impedance Function in Automobile Accessibility Model

![Data used for Estimation of Impedance Function in Automobile Accessibility Model](image)

Source: 2000 Census Transportation Planning Package Part 1 (at place of residence)

\textsuperscript{26} The streets and highways network model was provided by Ms. Claire Bozic, Director of Plan Implementation, at the CATS part of CMAP. This model was originally released in EMME/2 format, and has been migrated to TransCAD by Prof. Mikel Murga at MIT.

\textsuperscript{27} The transit network also contains information regarding scheduled headways and running times for the same period, while the CTPP data is for journey-to-work trips and so can be assumed to be similar to AM Peak period trips.
Figure 6-10 shows the estimation of the automobile impedance function. This is again done by fitting it to the cumulative distribution of observed automobile travel times.

**Figure 6-10: Impedance Function Estimation in Automobile Accessibility Model**

![Impedance Function Graph](image)

Source: Author

The impedance function shown in Figure 6-10 suggests that an impedance factor of 0.5 represents an automobile trip of about 30 minutes, as opposed to 45 minutes for transit trips. It also suggests that a 45 minute automobile trip is more onerous than a 45 minute transit trip.¹²

The automobile accessibility model can be used to compute the baseline automobile accessibility. With the relevant information, this model can also be used to compute the short run and long run changes in automobile accessibility.

### 6.4. Conclusions

The transit, walk and automobile accessibility models can be used to compute the baseline accessibility for their respective modes at the TAZ level and for the whole Chicago region. If travel times by any one mode, or a combination of modes change due to a policy or infrastructure change, then these models can be used to compute short run changes in accessibility by transit, automobile and walk modes. If the number and/or distribution of opportunities at any location changes, due to either transportation system changes or land use policy changes, then these accessibility models can be used to compute long run changes in accessibility by transit, automobile and walk modes.

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¹² This is possible considering that a user can sometimes read or work while making a transit trip.
7. Development Intensity Models

The development intensity model provides the 'other part' of the quasi-integrated land use transportation model. This model considers the effect on development of changes in accessibility, development-supportive public policies including zoning regulations and urban design guidelines, socio-economic characteristics and location factors. Two development intensity models have been estimated: one for residential development in terms of household density, and the second for commercial development in terms of job density.

This chapter describes and estimates development intensity models for the Chicago region, and is organized in 5 sections: a description of the model approach; a description of the variables used in the model; the estimated models; an analysis of these models; and conclusions.

7.1. Model Approach

This section presents the approach used for estimating the development intensity models.

7.1.1. Model Theory and Expectations

Chapter 2, and specifically Section 2.3, outlined the factors expected to influence development patterns. Those factors inform the model specification and expectations regarding the directionality of effects.

- **Accessibility**: For all modes – transit, automobiles, walking - accessibility is expected to influence both residential and commercial development intensity. This follows from the theory that accessibility is a factor affecting the location decision of households and firms (and so jobs). All else equal, we expect that households prefer to locate at places with high accessibility to jobs, and to goods and services, etc., while firms prefer to locate at places with high accessibility to households, and to other firms. Furthermore, accessibility improvements get capitalized into the value of land, which leads to pressures for increasing the intensity of development at that place. Consequently, all else equal, places with higher accessibility should also have higher development intensity. Transit accessibility to jobs, automobile accessibility to jobs, and walk accessibility to jobs is thus expected to positively influence residential development intensity. Furthermore, transit, walk and automobile accessibility to households and to other jobs is expected to positively influence commercial development intensity.
— **Zoning Requirements**: In terms of zoning requirements, density, parking, and land use requirements are expected to affect development intensity.

- For zoning density requirements, this follows from the theory that developers tend to develop land to its highest possible density in order to make the maximum use of available resources (in this case land), but that zoning maximum density requirements impose a limit upon the intensity of development that a developer can achieve. Therefore developers tend to develop land to (or near) its highest permissible zoning limit barring any other limits, or other regulations. Consequently, all else equal, places with higher zoning maximum density requirements should have higher development intensity. Zoning maximum density requirements are thus expected to positively influence both residential and commercial development intensity.

- Zoning parking requirements are expected to affect development intensity, based on the theory that as the development of parking spaces also requires land, more parking spaces mean that lesser amount of land is available for development in terms of households and jobs. Zoning minimum parking requirements specify the minimum number of parking spaces per unit of development. Consequently, all else equal, places with higher zoning minimum parking requirements should have lower development intensity. Zoning minimum parking requirements are thus expected to negatively influence both residential and commercial development intensity.

- The percentage of land zoned for residential uses in a place is expected to positively influence residential development intensity, based on the theory that more land zoned for residential uses means that more households can locate in a place. Also, the percentage of land zoned for business-commercial uses in a place is expected to positively influence commercial development intensity, based on the theory that more land zoned for business-commercial uses means that more firms, can locate in a place.

— **Urban design characteristics**: Urban design characteristics of locations, in terms of the degree of urban connectivity, and the amount of buildable land, are also expected to be factors affecting development intensity.

- Based on the theory that places with a high degree of connectivity - having a dense network of streets and blocks - also have a high intensity of development, e.g. downtowns, town centers, neighborhood centers etc., urban connectivity is expected to positively influence both residential and commercial development intensity.
Based on the theory that more buildable land allows more development to occur, the percentage of buildable land in a place is expected to positively influence both residential and commercial development intensity.

**Location factors:** Location factors are expected to affect development intensity in terms of both household density and job density.

- Lake Michigan is an amenity which most households would like to be in proximity to, and development at high densities will allow more households to take advantage of this amenity. Consequently, all else equal, places near Lake Michigan should have higher development intensity in terms of household density, as compared to places farther away from Lake Michigan. Proximity to Lake Michigan is thus expected to positively influence residential development intensity.

- Similarly, the Loop provides a number of advantages like the presence of amenities (e.g. cultural institutions, parks etc.) that households and jobs would like to be in proximity to, and also easy transport access via a number of modes to most parts of the city and the region. Development at high densities will allow more households and jobs to take advantage of these amenities and access. Consequently, all else equal, places in the Loop should have higher development intensity in terms of household density and job density, than places not in the Loop. Presence in the Loop is thus expected to positively influence both residential and commercial development intensity.

**Socio-economic characteristics:** In terms of socio-economic characteristics, household income, household size, access to automobiles, and the presence of immigrants are expected to influence residential development intensity.

- Theory suggests that households will trade-off between transport costs and land rents. Households with high incomes can choose to either buy bigger and more land-intensive houses, in which case it follows that household income negatively influences residential development intensity; or they can choose to live in denser, but more expensive places (e.g. the North Shore in Chicago), with lower transport costs and easier access to jobs, services, amenities etc, in which case it follows that in some cases household income positively influences residential development intensity. Thus, while household income is expected to influence residential development intensity, the direction of influence could be either positive or negative.

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29 Buildable land here mean land which is not streets, alleys etc. This is dependent upon the urban design guidelines used to lay out streets and blocks.
Theory suggests that lack of an automobile encourages households to locate in dense places with a large number of opportunities and activities (e.g. jobs, shopping, entertainments etc.) which are easily accessible by non-automobile modes of travel like walking or transit, and so places with a lack of household access to an automobile also have higher residential development intensity, all else equal. The lack of household access to an automobile is thus expected to positively influence development intensity in terms of household density.

The presence of immigrants is also expected to positively influence residential development intensity, based on the theory that immigrants tend to form closer social networks, which are better served and accommodated in denser areas.

Household size is expected to negatively influence residential development intensity, based on the theory that large households require bigger houses and generally prefer lower density suburban locations.

### 7.1.2. Data Sources and Description

Data sources for factors considered in the development intensity model are described below.

- **Development intensity**: Household and job density at the TAZ level are used as measures of development intensity. Household density is used as a proxy for the amount of residential development within a TAZ. Similarly, job density is used as a proxy for the amount of commercial, business and retail development within a TAZ. Household data is sourced from 2000 Census Transportation Planning Package (CTPP) Part 1 (at place of residence). Job numbers are derived from the journey-to-work trip ends, given in the CTPP Part 2 (at place of work). TAZ area data is derived from GIS shapefiles in the CTPP data CD.

- **Accessibility**: Transit, auto and walk accessibility to jobs and to households are calculated at the TAZ level with the data and procedures outlined in the previous chapter (see Sections 6.1, 6.2, and 6).  

- **Zoning requirements**: Zoning maximum density, minimum parking, and land use requirements are given at the zoning district level (ratios for each district) by the city of Chicago’s Zoning Ordinance. This data (districts, area and requirements) are sourced from Chicago’s online Zoning Ordinance and GIS Zoning Maps. All variables are calculated at the zoning district level and then aggregated to the TAZ level (see equation for each variable). Zoning districts, in most cases, are much smaller than TAZs and have their boundaries coinciding with or completely within TAZ boundaries. In cases where zoning districts cross two or more TAZs, the zoning districts are broken into smaller districts using the TAZ boundaries,
calculations are made for these smaller zoning districts by spatial averaging, and then aggregated to the TAZ level with other zoning districts within that TAZ.

- Zoned maximum floor area ratio (FAR)\(^{30}\) and zoned maximum residential dwelling units per acre are used as measures for zoning maximum density requirements. Zoned maximum FAR is a measure of the maximum allowable density at which development for all land uses (e.g. residential, commercial, etc.) can take place. Maximum residential dwelling units per acre is a measure of the maximum allowable density at which residential development can take place.

- Zoned minimum overall parking spaces per 1000 sq. ft. and zoned minimum residential parking spaces per residential dwelling unit are used as measures for zoning minimum parking requirements. Zoned minimum overall parking spaces per 1000 sq. ft. is a measure of the minimum allowable amount of parking that must be provided when any kind of development takes place, while zoned minimum residential parking spaces per residential dwelling unit is a measure of the minimum allowable amount of parking that must be provided when residential development takes place.

- The percentage of land zoned for different land uses - residential, business-commercial, institutional, manufacturing, open space, and other uses – are used as measures of zoning land use requirements. The percentage of land zoned for a specific use (e.g. residential) is a measure of the amount of land at a location that must be dedicated to development of that specific land use.

- **Urban Design Characteristics:** Block data (number and area) are sourced from the city of Chicago’s GIS shapefiles. Block density is a proxy for urban connectivity. Block density is a measure of the density of the block structure at a location - as a dense block structure usually goes hand in hand with a dense network of interconnected streets. The percentage of land covered by blocks is used as a measure for the amount of buildable land - as blocks define buildable land i.e. land which are not streets or alleys etc. and where buildings can be placed.

- **Location factors:** The location of Lake Michigan, the Loop and O'Hare or Midway Airports is sourced from the city of Chicago’s GIS files.

- **Socio-economic characteristics:** All socio-economic data are derived from 2000 Census Transportation Planning Package (CTPP) Part 1 (at place of residence). Median household income at the TAZ level is used as a measure of the economic profile of a location. Percentage of households

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\(^{30}\) FAR is a ratio of the amount of buildable floor space at a location and the size of land at that location.
without an automobile is used as a proxy for the lack of access to the driving mode of transport available at a location. A better measure of lack of household access to an automobile would be the median or average number of automobiles per household; however this measure was not used due to lack of data. Percentage of workers not born in the US is used as a proxy for the presence of immigrants in a location. Percentage of households with household size of 3 or more is used as a proxy for the size of households and the presence of families at a location. A better measure of household size would have been median or average household size; however this measure was not used due to lack of data.

7.1.3. Geographical Scope

The proposed development intensity model, like the transit accessibility model, should ideally cover the whole Chicago region defined as all TAZs (3153 in number) within a 25 mile radius from the Loop. However, the development intensity model is restricted to TAZs (930 in number) within the city of Chicago (Figure 7-1). The primary reason for doing so is the lack of data regarding zoning regulations for other cities in the region, apart from Chicago.

**Figure 7-1: Circle Line Location and Model Scope**

Source: (Chicago Transit Authority, 2002)
Prior research into the interaction between transport, accessibility and development, shows that most if not all of the development impacts of new transit infrastructure projects occurs in the immediate vicinity of stations (Parsons Brinckerhoff Inc., 1999). In this case, not only is the Circle Line completely contained within the city of Chicago, but also the boundary of the city of Chicago is more than 3.6 miles away from the Circle Line in all directions (Figure 7-1). Therefore, most of the development impacts of the Circle Line project can be expected to occur within the City of Chicago\(^\text{31}\).

Furthermore, restricting the model to the city of Chicago has some major advantages. The primary one is that this ensures that the entire model area is subject to a consistent set of public policies, that is of the city of Chicago. Hence all locations in the model are subject to the same set of zoning regulations, design guidelines, economic development policies, school districts, etc.

### 7.1.4. Specification

The models are specified as a linear equation (Equation 7-1) for development intensity in terms of household or job density at the TAZ level, as a function of factors affecting development intensity in the TAZ.

**Equation 7-1: Development Intensity Model Specification**

\[
DI_i = B_0 + B_1 A_i + B_2 F_i + B_3 P_i + B_4 L_i + B_5 C_i + B_6 N_i + B_7 S_i + \epsilon_i
\]

Where

- \(DI_i\) = Development intensity at TAZ \(i\)
- \(A_i\) = Accessibility at TAZ \(i\)
- \(F_i\) = Zoning maximum density requirements in TAZ \(i\)
- \(P_i\) = Zoning minimum parking requirements in TAZ \(i\)
- \(L_i\) = Zoning land use requirements in TAZ \(i\)
- \(C_i\) = Urban design characterisitics of TAZ \(i\)
- \(N_i\) = Location factors at TAZ \(i\)
- \(S_i\) = Socioeconomic characteristics of TAZ \(i\)
- \(\epsilon_i\) = Random error term for TAZ \(i\)
- \(B_0\) to \(B_7\) = Coefficients to be estimated

These factors include transit accessibility at the TAZ, automobile accessibility at the TAZ, walk accessibility at the TAZ, zoning maximum density requirements in the TAZ, zoning minimum parking requirements in the TAZ, zoning land use requirements for different uses (commercial, residential, industrial etc.) in the TAZ, urban design

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\(^{31}\) Except in cases where accessibility improvements occur for some zones outside the city of Chicago.
characteristics of the TAZ, socio-economic characteristics of people in the TAZ, and location factors at the TAZ. Socio-economic characteristics are considered as influencing factors only in the estimation of the development intensity model for household density, and not for the development intensity model for job density.

The coefficients in Equation 7-1 are estimated by means of a linear regression analysis of spatial data at the TAZ level using the ordinary least squares (OLS) method.

### 7.1.5. Spatial Autocorrelation

According to Waldo Tobler's so-called 'first law of geography' "everything is related to everything else, but near things are more related to each other" (Tobler, 1970). In terms of spatial data, this law manifests itself as spatial autocorrelation. Spatial autocorrelation occurs when the value of spatial data at a location is dependent upon values at surrounding locations, and so the arrangement of values of spatial data at locations is not random (Frei, 2005). Positive spatial autocorrelation occurs when similar values tend to be near one another, while negative autocorrelation occurs when dissimilar values tend to be near each other.

Spatial correlation is an issue that needs to be addressed in models estimated using OLS (Frei, 2005). This is because OLS assumes that random error terms are statistically independent - not related or dependent on one another. However, if spatial autocorrelation occurs, then cases are not independent and so the assumption of independent cases in OLS is violated. Violation of this assumption in OLS due to spatial autocorrelation, leads to the model systematically overestimating the observed values at some locations, and underestimating the observed values at other locations (Frei, 2005). Also, the model will show inaccurate values for the significance and confidence limits for the estimated coefficients. Consequently, spatial autocorrelation, if present and not corrected for can lead to inaccurate inferences.

Spatial autocorrelation can occur in two different forms. The first is related to the spatial lag term on the dependent variable, which has been defined as substantive spatial dependence (Anselin, 1993). The second occurs when the error term follows a spatial autoregressive process, which has been defined as spatial error dependence (Anselin, 1993). Spatial autocorrelation can be detected and can be corrected for using software packages like GeoDa. With GeoDa the presence and form of spatial autocorrelation can be detected using standard and robust forms of Lagrange Multiplier (LM) tests (Anselin, 2005). Where spatial autocorrelation is detected, a spatial error model or a spatial lag model, which are modified forms of the OLS model that correct for spatial autocorrelation, can be estimated. Anselin (Anselin, 2005) describes a decision rule for a spatial regression model where spatial autocorrelation is detected. This decision rule is illustrated in Figure 7-2.
Run an OLS regression. Consider the standard LM error and lag test results. If neither rejects the null hypothesis that there is no spatial autocorrelation, then use the OLS results.

- If one of the standard LM tests rejects the null hypothesis, and the other does not, then estimate the alternative spatial regression model that matches the test statistic that rejects the null. For example, if the standard LM error test rejects the null, but standard LM lag test does not, then estimate a spatial error model, and vice versa.

- If both LM test statistics reject the null hypothesis, then consider the robust LM error and lag test results. According to Anselin, "Typically, only one of them will be significant, or one will be orders of magnitude more significant than the other (e.g., $p < 0.00000$ compared to $p < 0.03$)" (Anselin, 2005).

Source: (Anselin, 2005)
If this is the case, estimate the spatial regression model matching the (most) significant statistic. For example, if the robust LM error test is significant at the 99% level, while the robust LM lag test is significant at the 95% level, then estimate a spatial error model, and vice versa. Anselin goes on to say that "in the rare instance that both would be highly significant, go with the model with the largest value for the test statistic. However, in this situation, some caution is needed, since there may be other sources of misspecification" (Anselin, 2005).

The development intensity model uses spatial multivariate data at the TAZ level. Therefore, the issue of spatial autocorrelation must be addressed. In this research effort, GeoDa has been used to detect spatial autocorrelation and to estimate spatial regression models.

### 7.2. Variables

The section presents the variables used in the model, and their calculation.

#### 7.2.1. Development Intensity

Development intensity at the TAZ level is considered in terms of the following variables:

- Household Density (HH_D) in terms of the number of households per acre
- Job Density (JOB_D) in terms of the number of jobs per acre

These variables are calculated as shown below (Equation 7-2).

**Equation 7-2: Calculation of Households Density (HH_D) and Job Density (JOB_D)**

\[
HH_D = \frac{HH_i}{TAZ_A}
\]

\[
JOB_D = \frac{JOB_i}{TAZ_A}
\]

Where:

- \(i = TAZ\)
- \(HH_D = \text{Household density in TAZ } i\)
- \(JOB_D = \text{Job density in TAZ } i\)
- \(HH_i = \text{Number of households in TAZ } i\)
- \(JOB_i = \text{Number of jobs in TAZ } i\)
- \(TAZ_A = \text{Area of TAZ } i \text{ in acres}\)
Figure 7-3 shows the pattern of household density at the TAZ level for the Chicago region and within the city of Chicago. At the regional level, these maps reveal that TAZs north of the Loop along Lake Michigan have the highest household density in the region, and that TAZs in the city of Chicago have higher household density than TAZs in the rest of the region. At the city level, these maps reveal that TAZs in the northern part of the city near Lake Michigan have the highest household density in the city, and that TAZs in the north and northwestern parts of the city have higher household density than TAZs in the western and southern parts of the city. The highest value of household density at the TAZ level in the region is 109.70 households per acre.

Figure 7-3: Household Density (HH_D)

Source: 2000 CTPP Part 1
Figure 7-4 shows the pattern of job density at the TAZ level for the Chicago region and within the city of Chicago. At the regional level, these maps reveal that TAZs in the Loop have the highest job density in the region, and that job density in the rest of the region is much lower than that in the Loop. At the city level, these maps reveal that TAZs in the Loop have the highest job density in the city, and that TAZs in the north, northwestern and western parts of the city have slightly higher job density than TAZs in the southern part of the city. The highest value of job density at the TAZ level in the region is 2697.15 jobs per acre. On closer inspections this high figure is an outlier where 195 jobs are located on a 0.07 acre TAZ located in the suburban periphery of the Chicago region. This TAZ is a small part of a much bigger TAZ, where all jobs in the two TAZs have been allocated to the smaller TAZ. Not considering this outlier the highest value of job density at the TAZ level in the region is 1319 jobs per acre.

Figure 7-4: Job Density (JOB_D)

Source: 2000 CTPP Part 2
7.2.2. Transit Accessibility

Transit accessibility at the TAZ level is considered in terms of the following variables:

- Transit Accessibility to Households (TR_AH) in terms of an index between 0 and 1
- Transit Accessibility to Jobs (TR_AJ) in terms of an index between 0 and 1

These variables are calculated as shown below (Equation 7-3) using the transit accessibility model described in the preceding chapter.

**Equation 7-3: Calculation of Transit Accessibility to Households (TR_AH) and to Jobs (TR_AJ)**

\[
TR_{AHi} = \frac{\sum_{j \in R} HH_j \times f(C_{ij})}{\sum_{j \in R} HH_j}
\]

\[
TR_{AJi} = \frac{\sum_{j \in R} JOB_j \times f(C_{ij})}{\sum_{j \in R} JOB_j}
\]

Where:

\[
f(C_{ij}) = \frac{1.027}{\left(1 + 0.027 \times e^{0.083 \times C_{ij}}\right)}
\]

- \( R \) = set of TAZs within the Chicago region
- \( i \) = origin TAZ
- \( j \) = destination TAZ

\( TR_{AHi} \) = transit accessibility index to households at TAZ \( i \)
\( TR_{AJi} \) = transit accessibility index to jobs at TAZ \( i \)

\( HH_j \) = number of households at TAZ \( j \)
\( JOB_j \) = number of jobs at TAZ \( j \)

\( C_{ij} \) = transit travel time from TAZ \( i \) to TAZ \( j \)

Both the index values and the number of equivalent households and jobs accessible from each zone have been calculated. The index values are used in the development intensity model.
Figure 7-5 shows the pattern of transit accessibility to households at the TAZ level for the Chicago region and within the city of Chicago, in terms of both the index value and the number of equivalent households accessible from a zone. At the regional level, these maps reveal that transit accessibility to households at the TAZ level generally decreases as distance from the Loop increases, and that TAZs near rail transit lines (CTA or Metra) generally have higher transit accessibility to households than other TAZs. At the city level, these maps reveal that TAZs in the Loop and some TAZs in the northern and northwestern parts of the city have the highest transit accessibility to households in the city, and that TAZs in the Loop and TAZs in the northern and northwestern parts of the city generally have higher transit accessibility to households than TAZs in the southwestern and southern parts of the city. These maps also show that, at most, about 638,000 equivalent households are accessible from a zone in the region by transit. The highest transit accessibility to households at the TAZ level in the region is 0.31 suggesting that, at most, some TAZs have access to approximately one third of all households in the region by transit. The lowest transit accessibility to households at the TAZ level in the region is 0, suggesting that there are a few TAZs with access to almost no households in the region by transit.

Figure 7-5: Transit Accessibility to Households (TR_AH)

Source: Author

The ‘number of equivalent households accessible from a zone’ is a measure of accessibility to households at that zone. This measure reflects the number of households accessible from a zone after accounting for the time required to travel to those households. A household which is a factor of 0.5 away (as calculated by the travel time impedance function) is counted as half an equivalent household, and so on. The same is true for equivalent jobs.
Figure 7-6 shows the pattern of transit accessibility to jobs at the TAZ level for the Chicago region and within the city of Chicago, in terms of both the index value and the number of equivalent jobs accessible from a zone. At the regional level, these maps reveal that transit accessibility to jobs at the TAZ level generally decreases as distance from the Loop increases, and that TAZs near rail transit lines (CTA or Metra) generally have higher transit accessibility to jobs than other TAZs. At the city level, these maps reveal that TAZs in the Loop and some TAZs in the northern and northwestern parts of the city have the highest transit accessibility to jobs in the city, and that generally TAZs in the Loop and TAZs in the northern and northwestern parts of the city have higher, transit accessibility to jobs than TAZs in the southwestern and southern parts of the city. These maps also show that, at most, about 958,000 equivalent jobs are accessible from a zone in the region by transit. The highest transit accessibility to jobs at the TAZ level in the region is 0.34 suggesting that, at most, some TAZs have access to approximately one third of all jobs in the region by transit within reasonable travel times. The lowest transit accessibility to jobs at the TAZ level in the region is 0, suggesting that there are a few TAZs with access to almost no jobs in the region by transit within reasonable travel times.

**Figure 7-6: Transit Accessibility to Jobs (TR_AJ)**

Source: Author
7.2.3. Automobile Accessibility

Automobile accessibility at the TAZ level is considered in terms of the following variables:

- Automobile Accessibility (congested speeds/times) to Households (AC_AH) in terms of an index between 0 and 1
- Automobile Accessibility (congested speeds/times) to Jobs (AC_AJ) in terms of an index between 0 and 1

These variables are calculated as shown below (Equation 7-4) using the automobile accessibility model described in the preceding chapter.

Equation 7-4: Calculation of Automobile Accessibility to Households (AC_AH) and to Jobs (AC_AJ)

\[
AC_AH_i = \frac{\sum_{j \in R} HH_j \times f(C_{ij})}{\sum_{j \in R} HH_j}
\]

\[
AC_AJ_i = \frac{\sum_{j \in R} JOB_j \times f(C_{ij})}{\sum_{j \in R} JOB_j}
\]

Where:

\[f(C_{ij}) = \frac{1.13}{\left(1 + 0.13 \times e^{(0.077 \times C_{ij})}\right)}\]

- \(R = \) set of TAZs within the Chicago region
- \(i = \) origin TAZ
- \(j = \) destination TAZ
- \(AC_AH_i = \) automobile accessibility index to households at TAZ \(i\)
- \(AC_AJ_i = \) automobile accessibility index to jobs at TAZ \(i\)
- \(HH_j = \) number of households at TAZ \(j\)
- \(JOB_j = \) number of jobs at TAZ \(j\)
- \(C_{ij} = \) automobile travel time from TAZ \(i\) to TAZ \(j\) using congested speeds

Both the index values and the number of equivalent households and jobs accessible from each zone have been calculated. The index values are used in the development intensity model.
Figure 7-7 shows the pattern of automobile accessibility to households at the TAZ level for the Chicago region and within the city of Chicago, in terms of both the index value and the number of equivalent households accessible from a zone. At the regional level, these maps reveal that automobile accessibility to households at the TAZ level generally decreases as distance from the Loop increases. At the city level, these maps also reveal that automobile accessibility to households at the TAZ level generally decreases as distance from the Loop increases. Both maps show that most TAZs in the region have good automobile accessibility to households. These maps also show that, at most, about 1 million equivalent households are accessible from a zone in the region by automobiles. The range of automobile accessibility to households for TAZs is between a high of 0.49 and a low of 0.07, suggesting that, at most, some TAZs have access to about half the number of households in the region by automobiles, while, at worst, some TAZs have access to a small proportion of the number of households in the region by automobiles. Both the high and low values for automobile accessibility to households at the TAZ level are higher than that for transit accessibility to households, showing that automobile accessibility to households is higher than transit accessibility to households for most TAZs.

**Figure 7-7: Automobile Accessibility to Households (AC_AH)**

Source: Author
Figure 7-8 shows the pattern of automobile accessibility to jobs at the TAZ level for the Chicago region and within the city of Chicago, in terms of both the index value and the number of equivalent jobs accessible from a zone. At the regional level, these maps reveal that automobile accessibility to jobs at the TAZ level generally decreases as distance from the Loop increases. At the city level, these maps also reveal that automobile accessibility to jobs at the TAZ level generally decreases as distance from the Loop increases. Both maps show that most TAZs in the region have good automobile accessibility to jobs. There is a skew in the northwest direction for automobile accessibility to jobs, which is probably a result of the high number of jobs in and around O'Hare airport which is located in the northwest part of the city of Chicago. These maps also show that, at most, about 1.38 million equivalent jobs are accessible from a zone in the region by automobiles. The range of automobile accessibility to jobs for TAZs is between a high of 0.49 and a low of 0.05, suggesting that, at most, some TAZs have access to about half the number of jobs in the region by automobiles, while, at worst, some TAZs have access to a small proportion of the number of jobs in the region by automobiles. Both the high and low values for automobile accessibility to jobs at the TAZ level are higher than that for transit accessibility to households, again showing that automobile accessibility to jobs is higher than transit accessibility to households for most TAZs.

Figure 7-8: Automobile Accessibility to Jobs (AC_AJ)

Source: Author
7.2.4. Walk Accessibility

Walk accessibility at the TAZ level is considered in terms of the following variables:

- Walk Accessibility to Households (WA_AH) in terms of an index between 0 and 1
- Walk Accessibility to Jobs (WA_AJ) in terms of an index between 0 and 1

These variables are calculated as shown below (Equation 7-5) using the walk accessibility model described in the preceding chapter.

**Equation 7-5: Calculation of Walk Accessibility to Households (WA_AH) and to Jobs (WA_AJ)**

\[
WA_{AH_i} = \frac{\sum_{j \in R} HH_j \times f(C_{ij})}{\sum_{j \in R} HH_j}
\]

\[
WA_{AJ_i} = \frac{\sum_{j \in R} JOB_j \times f(C_{ij})}{\sum_{j \in R} JOB_j}
\]

Where:

\[
f(C_{ij}) = \frac{1.357}{1 + 0.357 \times e^{(0.118 \times C_{ij})}}
\]

- \( R \) = set of TAZs within the Chicago region
- \( i \) = origin TAZ
- \( j \) = destination TAZ

\( WA_{AH_i} \) = walk accessibility index to households at TAZ \( i \)

\( WA_{AJ_i} \) = walk accessibility index to jobs at TAZ \( i \)

\( HH_j \) = number of households at TAZ \( j \)

\( JOB_j \) = number of jobs at TAZ \( j \)

\( C_{ij} \) = walk travel time from TAZ \( i \) to TAZ \( j \)

Both the index values and the number of equivalent households and jobs accessible from each zone have been calculated. The index values are used in the development intensity model.
Figure 7-9 shows the pattern of walk accessibility to households at the TAZ level for the Chicago region and within the city of Chicago, in terms of both the index value and the number of equivalent households accessible from a zone. At the regional level, these maps reveal that walk accessibility to households at the TAZ level generally decreases as distance from the Loop increases, and that TAZs north of the Loop along Lake Michigan have the highest walk accessibility to households in the region. At the city level, these maps reveal that TAZs in the Loop and some TAZs in the northern and northwestern parts of the city have the highest walk accessibility to households in the city, and that TAZs in the Loop and TAZs in the northern and northwestern parts of the city generally have high transit accessibility to households, while TAZs in the southwestern and southern parts of the city generally have low transit accessibility to households. These maps also show that, at most, about 34,000 equivalent households are accessible from a zone in the region by walking. The highest values for walks accessibility to households at the TAZ level in the region is 0.0167, suggesting that, at most, some TAZs have access to a small proportion of the number of households in the region, and that most TAZs have access to almost no households in the region. Values for walk accessibility to households at the TAZ level are significantly lower than those for automobile and also transit accessibility to households for most TAZs.

Source: Author
Figure 7-10 shows the pattern of walk accessibility to jobs at the TAZ level for the Chicago region and within the city of Chicago, in terms of both the index value and the number of equivalent jobs accessible from a zone. At the regional level, these maps reveal that TAZs in the Loop have the highest walk accessibility to jobs in the region, and that TAZs in the city of Chicago have slightly higher walk accessibility to jobs than TAZs in the rest of the region. At the city level, these maps reveal that TAZs in the Loop have the highest walk accessibility to jobs by far in the city, and that TAZs in the north, northwestern and western parts of the city have higher job density than TAZs in the southern part of the city. These maps also show that, at most, about 315,000 equivalent jobs are accessible from a zone in the region by walking. The highest values for walks accessibility to jobs at the TAZ level in the region is 0.1126, suggesting that, at most, some TAZs have access to a small proportion of the number of jobs in the region, and that most TAZs have access to almost no jobs in the region. Values for walk accessibility to jobs at the TAZ level are significantly lower than those for automobile and also transit accessibility to jobs.

Figure 7-10: Walk Accessibility to Jobs (WA_AJ)
7.2.5. Zoning Maximum Density and Minimum Parking Requirements

Maximum density and minimum parking zoning requirements overall (all land uses) and for residential uses at the TAZ level is considered in terms of the following variables:

- Zoning maximum floor area ratio or FAR (MX\_FR) requirement in terms of ratio of buildable to land area
- Zoning maximum residential dwelling unit density (MX\_RD) requirement in terms of number of dwelling units per acre
- Zoning minimum overall parking requirement (MN\_OP) requirement in terms of number of parking spaces per 1000 square feet of buildable area
- Zoning minimum residential parking requirement (MN\_RP) requirement in terms of number of parking spaces per residential dwelling unit

These variables are calculated as shown below (Equation 7-6)

**Equation 7-6: Calculation of Zoning Max. Density and Min. Parking Requirement Variables**

\[
MX\_FR_i = \frac{\sum_k ZD\_A_{ik} \times ZD\_FR_{ik}}{\sum_k ZD\_A_{ik}}
\]

\[
MX\_RD_i = \frac{\sum_k ZD\_A_{ik} \times ZD\_RD_{ik}}{\sum_k ZD\_A_{ik}}
\]

\[
MN\_OP_i = \frac{\sum_k ZD\_A_{ik} \times ZD\_FR_{ik} \times ZD\_OP_{ik}}{\sum_k ZD\_A_{ik}}
\]

\[
MN\_RP_i = \frac{\sum_k ZD\_A_{ik} \times ZD\_RD_{ik} \times ZD\_RP_{ik}}{\sum_k ZD\_A_{ik}}
\]

Where:

- \( i = TAZ \)
- \( k = Zoning\ District \)
- \( MX\_FR_i = Max.\ FAR\ (ratio)\ requirement\ in\ TAZ\ i \)
- \( MX\_RD_i = Max.\ residential\ dwelling\ units\ requirement\ (per\ acre)\ in\ TAZ\ i \)
- \( MN\_OP_i = Min.\ overall\ parking\ requirement\ (per\ 1000\ sq.\ ft.)\ in\ TAZ\ i \)
- \( MN\_RP_i = Min.\ residential\ parking\ requirement\ (per\ dwelling\ unit)\ in\ TAZ\ i \)
- \( ZD\_A_{ik} = Area\ of\ zoning\ district\ k\ within\ TAZ\ i \)
- \( ZD\_FR_{ik} = Max.\ FAR\ (ratio)\ requirement\ of\ zoning\ district\ k\ within\ TAZ\ i \)
- \( ZD\_RD_{ik} = Max.\ resi.\ dwelling\ units\ requirement\ (per\ acre)\ of\ zoning\ district\ k\ within\ TAZ\ i \)
- \( ZD\_OP_{ik} = Min.\ overall\ parking\ requirement\ (per\ 1000\ sq.\ ft.)\ of\ zoning\ district\ k\ within\ TAZ\ i \)
- \( ZD\_RP_{ik} = Min.\ resi.\ parking\ requirement\ (per\ dwelling\ unit)\ of\ zoning\ district\ k\ within\ TAZ\ i \)
Figure 7-11 shows the pattern of zoning maximum density requirements at the TAZ level within the city of Chicago. For all land uses, these maps reveal that maximum permitted density (FAR) at the TAZ level generally decreases as distance from the Loop increases, and that TAZs in the Loop have the highest maximum permitted density in the city. The highest value for maximum FAR is 19.92, while the lowest is 0.0. For residential uses, these maps reveal that maximum permitted density at the TAZ level generally decreases as distance from the Loop increases, that TAZs in the Loop have the highest maximum permitted density in the city, and that TAZs in the northern and southern parts of the city have higher maximum permitted density than TAZs in the northwestern, western and southwestern parts of the city. The highest value for maximum dwelling units per acre is about 402 units per acre, while the lowest value is 0.0.

Figure 7-11: Zoning Max. Density Requirements (MX_F) & (MX_RD)

Source: City of Chicago GIS shapefiles, Author
Figure 7-12 shows the pattern of zoning minimum parking requirements at the TAZ level within the city of Chicago. For all land uses, these maps reveal that TAZs in the Loop have the lowest minimum permitted parking ratio in the city, and that some TAZs in northwestern, western and southern parts of the city have the highest minimum permitted parking ratio in the city. The highest value for minimum overall parking ratio is about 2 parking spaces per 1000 sq.ft. while the lowest value is 0.0. For residential uses, these maps reveal that minimum permitted parking ratio at the TAZ level generally increases as distance from the Loop increases, and that TAZs in the Loop have the lowest minimum permitted parking ratio in the city. The highest value for minimum residential parking ratio is about 2.5 parking spaces per dwelling unit while the lowest value is 0.0.

Figure 7-12: Zoning Min. Parking Regulations (MN_OP) & (MN_RP)

Source: City of Chicago GIS shapefiles, Author
7.2.6. Zoning Land Use Requirements

Zoning land use requirements at the TAZ level is considered in terms of the following variables:

- Percentage of land zoned for business-commercial uses (PC_BC)
- Percentage of land zoned for residential uses (PC_RE)
- Percentage of land zoned for open space (PC_OP)
- Percentage of land zoned for manufacturing uses (PC_MA)
- Percentage of land zoned for institutional uses (PC_IN)
- Percentage of land zoned for other uses (PC_OT)

These variables are calculated as shown below (Equation 7-7)

**Equation 7-7: Calculation of Zoning Land Use Variables**

\[
PC_{LU_i} = \frac{\sum_k ZD_A_{LU_{ik}}}{\sum_k ZD_A_{ik}}
\]

Where
- \( i = TAZ \)
- \( k = Zoning \) district
- \( LU = Land uses (commercial \ (BC), \ residential \ (RE) \ etc.) \)
- \( PC_{LU_i} = Percentage \) of land use \( LU \) in TAZ \( i \)
- \( ZD_A_{LU_{ik}} = Area \) of zoning district \( k \) zoned for land use \( LU \) within TAZ \( i \) in acres
- \( ZD_A_{ik} = Area \) of zoning district \( k \) within TAZ \( i \) in acres
Figure 7-13 shows the pattern of percentage of land zoned for business-commercial and for residential uses at the TAZ level within the city of Chicago. These maps reveal that the percentage of land zoned for business-commercial uses is highest in TAZs in the Loop. Also, these maps reveal that the percentage of land zoned for residential uses is lowest in the Loop, and quite high in the rest of the city. These maps almost mirror each other suggesting that TAZs with a high percentage of land zoned for business-commercial uses has also have a low percentage of land zoned for residential uses, and that zoning tends to maintain a segregation of commercial and residential land uses in the city.

Figure 7-13: Zoning Land Use Requirements (PC_BC) & (PC_RE)

Source: City of Chicago GIS shapefiles, Author
Figure 7-14 shows the pattern of percentage of land zoned for open space and for manufacturing uses at the TAZ level within the city of Chicago. These maps reveal that the percentage of land zoned for open space is highest in TAZs along Lake Michigan reflecting the park system along Lake Michigan, and in some TAZs in the rest of the city. Also, these maps reveal that the percentage of land zoned for manufacturing uses is highest in some TAZs in the western and southern parts of the city. These zones are manufacturing clusters located near rivers and near railroads. Many of the zones with a high percentage of land zoned for manufacturing uses are located along the north and south branches of the Chicago River. These zones are along the proposed Circle Line alignment.

Figure 7-14: Zoning Land use Requirements (PC_OP) & (PC_MA)

Source: City of Chicago GIS shapefiles, Author
Figure 7-15 shows the pattern of percentage of land zoned for institutional uses and for other uses at the TAZ level within the city of Chicago. These maps reveal that the percentage of land zoned for institutional uses is generally low throughout the city, except for some TAZs in the Loop and in the western and southern parts of the city, corresponding to institutions like the University of Illinois at Chicago, the Illinois Medical District and the University of Chicago. Also, these maps reveal that the percentage of land zoned for other uses is generally low throughout the city, except in some TAZs in the city corresponding to O'Hare Airport, Midway Airport, and Navy Pier etc.

Figure 7-15: Zoning Land use Requirements (PC_IN) & (PC_OT)

Source: City of Chicago GIS shapefiles, Author
7.2.7. Urban Design Characteristics

Urban design characteristics at the TAZ level are considered in terms of the following variables:

- Block density (BL_D) in terms of the number of blocks per acre
- Percentage of land covered by blocks (BL_PC)

These variables are calculated as shown below (Equation 7-8)

**Equation 7-8: Calculation of Urban Design Characteristics Variables**

\[
BL_D_i = \frac{BL_N_i}{TAZ_A_i}
\]

\[
BL_PC_i = \frac{\sum_l BL_A_{il}}{TAZ_A_i}
\]

Where

- \( i = TAZ \)
- \( l = Block \)

\( BL_D_i \) = Block density in TAZ \( i \)

\( BL_PC_i \) = Percentage of land in TAZ \( i \) covered by blocks

\( BL_N_i \) = Number of blocks in TAZ \( i \)

\( BL_A_{il} \) = Area of block \( l \) in TAZ \( i \)

\( TAZ_A_i \) = Area of TAZ \( i \) in acres
Figure 7-16 shows the pattern of percentage of land covered by blocks, and block density at the TAZ level within the city of Chicago. These maps reveal that the percentage of land covered by blocks is lowest in TAZs in the Loop. Also, these maps reveal that the block density is highest in TAZs in the Loop.

**Figure 7-16: Urban Design Characteristics (BL_PC) & (BL_D)**

Source: City of Chicago GIS shapefiles, Author
7.2.8. Socio-Economic Characteristics

Socio-economic characteristics at the TAZ level are considered in terms of the following variables:

- Median household income (MD_INC)
- Percentage of workers not born in the US (PC_NUB)
- Percentage of households with household size of 3 or more (PC_3M)
- Percentage of households without an automobile (PC_NOA)

The median household income variable is used directly from the CTPP data. The other variables are calculated as shown below (Equation 7-9)

**Equation 7-9: Calculation of Socio-Economic Characteristics Variables**

\[
PC_{3M_i} = \frac{HH_{3M_i}}{HH_i}
\]
\[
PC_{NOA_i} = \frac{HH_{NOA_i}}{HH_i}
\]
\[
PC_{NUB_i} = \frac{WORK_{NUB_i}}{WORK_i}
\]

Where

\[
i = TAZ
\]

- \(PC_{3M_i}\) = Percentage of households with household size of 3 or more in TAZ \(i\)
- \(PC_{NOA_i}\) = Percentage of households without an automobile in TAZ \(i\)
- \(PC_{NUB_i}\) = Percentage of workers not born in the US in TAZ \(i\)
- \(HH_{3M_i}\) = Number of households with household size of 3 or more in TAZ \(i\)
- \(HH_{NOA_i}\) = Number of households without an automobile in TAZ \(i\)
- \(WORK_{NUB_i}\) = Number of workers not born in the US in TAZ \(i\)
- \(POP_i\) = Number of persons (population) in TAZ \(i\)
- \(HH_i\) = Number of households in TAZ \(i\)
- \(WORK_i\) = Number of workers in TAZ \(i\)

These variables are calculated only for 874 out of 930 TAZs in Chicago. These are TAZs where calculation is possible i.e. where population is more than 0\(^{33}\) and/or data is available.

---

\(^{33}\) Median household income and other variables cannot be calculated for TAZs with zero households.
Figure 7-17 shows the pattern of median household income and percentage of workers not born in the US at the TAZ level within the city of Chicago. These maps reveal that median household income is high in some TAZs north of the Loop near Lake Michigan, and low in some TAZs in the western and southern parts of the city. Also, these maps reveal that percentage of workers not born in the US is high in some TAZs in the northwestern and southwestern parts of the city, and low in some TAZs is the western and southern parts of the city.

**Figure 7-17: Socio-Economic Characteristics (MD_INC) & (PC_NUB)**

Source: 2000 CTPP Part 1
Figure 7-18 shows the pattern of percentage of households with household size of 3 or more and percentage of households without an automobile at the TAZ level within the city of Chicago. These maps reveal that percentage of households with household size of 3 or more is high in some TAZs in the western part of the city, and low in some TAZs in the northern part of the city near Lake Michigan. Also, these maps reveal that percentage of households without an automobile is high in some TAZs in the northern, western and southern parts of the city.

Figure 7-18: Socio-Economic Characteristics (PC_3M) & (PC_NOA)

Source: 2000 CTPP Part 1
7.2.9. Location Factors

Location factors at the TAZ level are considered in terms of the following variables:

- Proximity to Lake Michigan (NR_LK) in terms of TAZs within .5 mile of Lake Michigan
- Presence of TAZs in the Loop (IN_LP)
- Presence of TAZs in airports (IN_AP)

Presence of an airport is included to control for the fact that airports are places with a high number of jobs, but are not subject to the zoning regulations of the city of Chicago in the same manner as other land uses.

7.2.10. Summary

Table 7-1 shows summary statistics for variables used in the model for all TAZs in the Chicago region.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Dev.</th>
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</table>

Source: 2000 CTPP Part 1, Author
Table 7-2 shows summary statistics for variables used in the model for all TAZs in the city of Chicago\textsuperscript{34}.

Table 7-2: Summary Statistics for TAZs in the City of Chicago

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
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<th>Median</th>
<th>Std. Dev.</th>
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<td>211.60</td>
<td>23.76</td>
<td>13.76</td>
<td>30.02</td>
</tr>
<tr>
<td>MN_OP</td>
<td>Zoning min parking spaces per 1000 sq.ft.</td>
<td>0.00</td>
<td>2.01</td>
<td>1.01</td>
<td>0.88</td>
<td>0.45</td>
</tr>
<tr>
<td>MN_RP</td>
<td>Zoning min parking spaces per unit</td>
<td>0.00</td>
<td>3.40</td>
<td>1.26</td>
<td>1.30</td>
<td>0.45</td>
</tr>
<tr>
<td>PC_OP</td>
<td>% of land zoned for open space</td>
<td>0.00%</td>
<td>100.00%</td>
<td>6.25%</td>
<td>0.26%</td>
<td>16.53%</td>
</tr>
<tr>
<td>PC_BC</td>
<td>% of land zoned for busi-comm uses</td>
<td>0.00%</td>
<td>100.00%</td>
<td>10.68%</td>
<td>6.30%</td>
<td>15.50%</td>
</tr>
<tr>
<td>PC_IN</td>
<td>% of land zoned for institutional uses</td>
<td>0.00%</td>
<td>99.69%</td>
<td>2.86%</td>
<td>0.00%</td>
<td>10.31%</td>
</tr>
<tr>
<td>PC_MA</td>
<td>% of land zoned for manufacturing uses</td>
<td>0.00%</td>
<td>100.00%</td>
<td>16.66%</td>
<td>0.88%</td>
<td>27.29%</td>
</tr>
<tr>
<td>PC_RE</td>
<td>% of land zoned for residential uses</td>
<td>0.00%</td>
<td>100.00%</td>
<td>62.20%</td>
<td>74.25%</td>
<td>31.43%</td>
</tr>
<tr>
<td>PC_OT</td>
<td>% of land zoned for other uses</td>
<td>0.00%</td>
<td>99.74%</td>
<td>0.95%</td>
<td>0.00%</td>
<td>7.00%</td>
</tr>
<tr>
<td><strong>Urban Design Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL_D</td>
<td>Block Density</td>
<td>0.00</td>
<td>0.50</td>
<td>0.15</td>
<td>0.16</td>
<td>0.07</td>
</tr>
<tr>
<td>BL_PC</td>
<td>% of land covered by blocks</td>
<td>31.32%</td>
<td>100.00%</td>
<td>73.13%</td>
<td>72.57%</td>
<td>8.58%</td>
</tr>
<tr>
<td><strong>Socioeconomic Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD_INC</td>
<td>Median household income</td>
<td>$0</td>
<td>$200,000</td>
<td>$42,173</td>
<td>$40,525</td>
<td>$21,622</td>
</tr>
<tr>
<td>PC_NUB</td>
<td>% of workers not born in the US</td>
<td>0.00%</td>
<td>100.00%</td>
<td>24.05%</td>
<td>15.53%</td>
<td>24.61%</td>
</tr>
<tr>
<td>PC_3M</td>
<td>% of households with size of 3 or more</td>
<td>0.00%</td>
<td>100.00%</td>
<td>44.39%</td>
<td>47.59%</td>
<td>21.26%</td>
</tr>
<tr>
<td>PC_NOA</td>
<td>% of households without an automobile</td>
<td>0.00%</td>
<td>99.93%</td>
<td>24.74%</td>
<td>21.15%</td>
<td>17.46%</td>
</tr>
</tbody>
</table>

Source: 2000 CTPP Part 1, Author

\textsuperscript{34} Variables for socioeconomic characteristics are only for 874 out of 930 TAZs in Chicago where variable calculation is possible
7.3. Results

Development intensity models were estimated for household and job density using several different functional forms: simple (dependent and independent variables are not transformed), semi-log (the dependent variable is transformed logarithmically, and independent variables are not transformed), and double-log functional (both dependent and independent variables are transformed logarithmically). The semi-log form produced the best results as measured by log-likelihood and has been used. In order to maintain signs (positive/negative) after log transformation, a constant of 1 has been added to the dependent variable. Consequently the final form of the dependent variables are Ln(HH_D+1) and Ln(JOB_D+1).

The null hypothesis that there is no spatial autocorrelation is rejected for both development intensity models (household and job density). That is the OLS models are affected by spatial error dependence which means that the OLS estimates are not efficient. Consequently, spatial error models are estimated for both household and job density following the decision rule outlined above (Section 7.1.5). This spatial error model accounts for spatial autocorrelation, and is expressed as a combination of Equation 7-1 and a spatial autoregressive model in the error term $\varepsilon$. The error term is modeled as:

**Equation 7-10: Error term in Spatial Error Model for Development Intensity**

$\varepsilon_i = \lambda W_i \varepsilon + \xi_i$

Where

$\varepsilon_i =$ Random error term for TAZ $i$

$W_i =$ Spatial weights vector defining contiguity between TAZ $i$ and all other TAZs

$\varepsilon =$ Vector of error terms for all non $i$ TAZs

$\xi_i =$ Error term assumed to be uncorrelated with error for other TAZs and having a fixed nuisance

$\lambda =$ Nuisance parameter to be estimated that filters out the spatial autocorrelation in the error term

The coefficients and parameters in the resultant spatial error model (spatial regression model), a combination of Equation 7-1 and Equation 7-10, are estimated by means of a linear regression analysis of spatial data at the TAZ level using a modified OLS method in GeoDa. A spatial weights matrix is constructed in GeoDa with contiguity defined as all TAZs that share a boundary edge or corner (Queen Contiguity) with the TAZ in question (Anselin, 2005).

For a spatial regression model, pseudo R-square is not comparable to R-square from a simple OLS regression model. Log-likelihood is a more appropriate measure of fit, with the higher the log-likelihood (closer to zero for negative numbers), the better the model fit.
7.3.1. Residential Development Intensity Model

A number of models have been estimated for residential development intensity: model 1 estimates household density as a function of accessibility to jobs for all TAZs in the city of Chicago; model 2 estimates household density as a function of accessibility to jobs, zoning, urban design characteristics, and location factors for all TAZs in the city of Chicago; and model 3 estimates household density as a function of accessibility to jobs, zoning, urban design characteristics, location factors, and socio-economic characteristics for all TAZs in the city of Chicago for which socio-economic data is available. These models are shown in Table 7-3.

Table 7-3: Residential Development Intensity Model – Household Density

<table>
<thead>
<tr>
<th>Dependent variable: Ln(HH_D+1)</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations</td>
<td>930</td>
<td>930</td>
<td>874</td>
</tr>
<tr>
<td>Model fit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo R-square</td>
<td>0.386</td>
<td>0.672</td>
<td>0.698</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-1058.859</td>
<td>-755.827</td>
<td>-573.063</td>
</tr>
<tr>
<td>Constant</td>
<td>1.847 ***</td>
<td>1.309 ***</td>
<td>1.202 ***</td>
</tr>
<tr>
<td>Coeff. Sig.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit accessibility to jobs</td>
<td>5.181 ***</td>
<td>3.248 ***</td>
<td>2.247 ***</td>
</tr>
<tr>
<td>Automobile accessibility to jobs</td>
<td>-2.662 ***</td>
<td>-1.722 ***</td>
<td>-1.093 *</td>
</tr>
<tr>
<td>Walk accessibility to jobs</td>
<td>-32.023 ***</td>
<td>-29.767 ***</td>
<td></td>
</tr>
<tr>
<td>Zoning regulations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoning max dwelling units per acre</td>
<td>0.014 ***</td>
<td>0.011 ***</td>
<td></td>
</tr>
<tr>
<td>Zoning parking spaces per 1000 sq.ft.</td>
<td>-0.386 ***</td>
<td>-0.564 ***</td>
<td></td>
</tr>
<tr>
<td>% of land zoned for residential uses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban design characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of land covered by blocks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block density</td>
<td>5.705 ***</td>
<td>4.663 ***</td>
<td></td>
</tr>
<tr>
<td>Location factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near Lake Michigan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Loop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Socio-economic characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median household income</td>
<td>2.72E-06 ***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of households with size of 3 or more</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of households without an automobile</td>
<td>1.391 ***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of workers not born in the US</td>
<td>0.307 ***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lambda</td>
<td>0.662 ***</td>
<td>0.546 ***</td>
<td>0.592 ***</td>
</tr>
<tr>
<td>Coeff. Sig.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model 1 shows that accessibility to jobs using various modes of travel are moderate (based on log-likelihood) predictors of household density at the TAZ level within the City of Chicago. The model fit improves in model 2.
where zoning variables are also considered. Finally, the model improves further in model 3 where socio-
economic variables are also considered but which is restricted to TAZs within the city of Chicago for which 
socio-economic data is available.

These models reveal that development intensity in terms of household density is:

- Positively influenced by transit accessibility to jobs
- Negatively influenced by automobile accessibility to jobs
- Negatively influenced by walk accessibility to jobs
- Positively influenced by zoning max residential dwelling units per acre
- Negatively influenced by zoning min parking spaces per 1000 sq. ft.
- Positively influenced by block density
- Positively influenced by median income
- Positively influenced by percentage of households with no access to automobiles
- Positively influenced by percentage of workers not born in the US

These results will be analyzed in the ‘Analysis’ section of this chapter.

The following variables were not found to influence development intensity in terms of household density at an 
acceptable level of statistical significance (90%) or more:

- Percentage of land zoned for residential uses
- Percentage of land covered by blocks
- Proximity to Lake Michigan
- Presence in Loop
- Percentage of households with household size of 3 or more

Model 3 has the best model fit of the 3 models estimated (based on log-likelihood). However, this model does 
not cover the whole city of Chicago, but rather is restricted to TAZs in the city of Chicago for which socio-
economic data is available (874 as opposed to 930 TAZs). Consequently, this model cannot be applied to all 
TAZs within the city of Chicago. Therefore, Model 2 is chosen as the basis for the development intensity model 
for household density used in the rest of this thesis. Table 7-4 shows this final model for development intensity 
in terms of household density in more detail. Elasticities are also calculated for significant variables by 
considering the percentage change in the dependent variable as a result of a percentage change in independent 
variables, evaluated at the median value of the independent variables.
Table 7-4: Residential Development Intensity Model – Household Density – Final Model

<table>
<thead>
<tr>
<th>Dependent variable: Ln(HH_D + 1)</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of observations</strong></td>
<td>930</td>
</tr>
<tr>
<td><strong>Model Fit</strong></td>
<td></td>
</tr>
<tr>
<td>Pseudo R-square</td>
<td>0.672</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-755.827</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Coeff.</th>
<th>Std. Error</th>
<th>Z-value</th>
<th>P-value</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>1.309</td>
<td>0.178</td>
<td>7.348</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td><strong>Accessibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit accessibility to jobs</td>
<td>3.248</td>
<td>0.572</td>
<td>5.674</td>
<td>0.000</td>
<td>0.089</td>
</tr>
<tr>
<td>Automobile accessibility to jobs</td>
<td>-1.722</td>
<td>0.608</td>
<td>-2.832</td>
<td>0.004</td>
<td>-0.091</td>
</tr>
<tr>
<td>Walk accessibility to jobs</td>
<td>-32.023</td>
<td>2.577</td>
<td>-11.962</td>
<td>0.000</td>
<td>-0.009</td>
</tr>
<tr>
<td><strong>Zoning regulations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoning max dwelling units per acre</td>
<td>0.014</td>
<td>0.001</td>
<td>13.555</td>
<td>0.000</td>
<td>0.030</td>
</tr>
<tr>
<td>Zoning parking spaces per 1000 sq.ft.</td>
<td>-0.386</td>
<td>0.057</td>
<td>-6.820</td>
<td>0.000</td>
<td>-0.085</td>
</tr>
<tr>
<td><strong>Urban design characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block density</td>
<td>5.705</td>
<td>0.319</td>
<td>17.896</td>
<td>0.000</td>
<td>0.141</td>
</tr>
<tr>
<td><strong>Lambda</strong></td>
<td>0.546</td>
<td>0.040</td>
<td>13.703</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>
### 7.3.2. Commercial Development Intensity

A number of models have been estimated for commercial development intensity: model 1 estimates job density as a function of accessibility to jobs for all TAZs in the city of Chicago; and model 2 estimates job density as a function of accessibility to jobs, zoning, location factors, and urban design characteristics for all TAZs in the city of Chicago. These models are shown in Table 7-5.

#### Table 7-5: Commercial Development Intensity Model – Job Density

<table>
<thead>
<tr>
<th>Dependent variable: Ln(JOB_D+1)</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations</td>
<td>930</td>
<td>930</td>
</tr>
<tr>
<td>Model Fit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo R-square</td>
<td>0.688</td>
<td>0.758</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-922.394</td>
<td>-764.775</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>-0.722 **</td>
<td>0.207 ***</td>
</tr>
<tr>
<td>Accessibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit accessibility to households</td>
<td>5.810 ***</td>
<td>5.550 ***</td>
</tr>
<tr>
<td>Automobile accessibility to households</td>
<td>3.666 ***</td>
<td></td>
</tr>
<tr>
<td>Walk accessibility to households</td>
<td>89.097 ***</td>
<td>63.786 ***</td>
</tr>
<tr>
<td>Zoning regulations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoning max FAR</td>
<td>0.235 ***</td>
<td></td>
</tr>
<tr>
<td>Zoning min parking spaces per 1000 sq.ft.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of land zoned for busi-comm uses</td>
<td>1.050 ***</td>
<td></td>
</tr>
<tr>
<td>Urban design characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of land covered by blocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Loop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Airport</td>
<td>0.819 **</td>
<td></td>
</tr>
<tr>
<td>Lambda</td>
<td>0.706 ***</td>
<td>0.348 ***</td>
</tr>
</tbody>
</table>

* Statistical significance at the 90% level
** Statistical significance at the 95% level
*** Statistical significance at the 99% level

Model 1 shows that accessibility to households using various modes of travel are moderate predictors (based on log-likelihood) of job density at the TAZ level within the City of Chicago. The model fit further improves in model 2 where zoning variables and location factors are also considered.

These models reveal that development intensity in terms of job density is:

- Positively influenced by transit accessibility to jobs
- Positively influenced by automobile accessibility to jobs
- Positively influenced by walk accessibility to jobs
— Positively influenced by zoned maximum FAR (floor area ratio)
— Positively influenced by percentage of land zoned for business-commercial uses
— Positively influenced by presence of an airport

These results will be analyzed in the ‘Analysis’ section of this chapter.

The following variables were not found to influence development intensity in terms of job density at an acceptable level of statistical significance (90%) or more:

— Zoning min parking spaces per 1000 sq.ft
— Percentage of land covered by blocks
— Block density
— Presence in Loop

Model 2 is the basis for the development intensity model for job density used in the rest of this thesis. Table 7-6 shows this final model for development intensity in terms of job density in more detail and with elasticity calculated for significant variables.

<table>
<thead>
<tr>
<th>Table 7-6: Commercial Development Intensity Model – Job Density – Final Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent variable: Ln(JOBD + 1)</td>
</tr>
<tr>
<td>Number of observations</td>
</tr>
<tr>
<td>Model Fit</td>
</tr>
<tr>
<td>Pseudo R-square</td>
</tr>
<tr>
<td>Log likelihood</td>
</tr>
<tr>
<td>Coeff.</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>Accessibility</td>
</tr>
<tr>
<td>Transit accessibility to households</td>
</tr>
<tr>
<td>Walk accessibility to households</td>
</tr>
<tr>
<td>Zoning</td>
</tr>
<tr>
<td>Zoning max FAR</td>
</tr>
<tr>
<td>% of land zoned for busi-comm uses</td>
</tr>
<tr>
<td>Location Factors</td>
</tr>
<tr>
<td>In airport</td>
</tr>
<tr>
<td>Lambda</td>
</tr>
</tbody>
</table>

This development intensity model for job density can be used in conjunction with the accessibility model to estimate the commercial development impacts of the Circle Line project.
7.4. Analysis

The development intensity models reveal several insights regarding development patterns and influencing characteristics in Chicago.

Transit accessibility positively influences the intensity of development. As expected, the commercial development intensity model suggests a positive relationship between job density and accessibility to households using transit, automobiles and walking. However, the models show no relationship between job density and accessibility to other jobs (and so firms), by all 3 modes. This is likely a reflection of the fact that the jobs data is not segmented by sector.\(^{35}\)

The residential development intensity model suggests a positive relationship between household density and transit accessibility to jobs, but a negative relationship between household density and accessibility to jobs using automobiles or walking. There are a number of possible explanations for the negative relationship between automobile accessibility with household density, including that the near ubiquitous nature of automobile access and use has made automobile accessibility a non-factor in the location decisions of households, and that some places with better automobile accessibility, e.g. near highways, are not desirable residential locations due to noise, pollution, etc. The negative relationship between household density and walk accessibility can possibly be explained by the fact that the walk accessibility metric does not take into consideration the pedestrian environment and comfort levels, and so some places which are a few minutes walking distance away from jobs may be separated from those jobs by a highway or may lack good sidewalks; such places will not be desirable locations for residential development.

The calculated elasticities also suggest that transit accessibility to jobs and households have the strongest, or one of the strongest, positive effects on household and job density respectively among the various influencing factors, including accessibility by other modes. Therefore it can be concluded that transit accessibility has a strong positive influence on the intensity of residential and commercial development.

Zoning maximum density requirements positively influences the intensity of development: As expected, the development intensity models suggest a positive relationship between household density and zoned maximum number of dwelling units per acre, and between job density and zoned maximum FAR. Furthermore, the elasticity of zoned maximum FAR shows that this factor is second only to transit accessibility to households in

\(^{35}\) Some sectors like finance and services are more likely to value access to other jobs, but the model treats all jobs as the same.
terms of its effect on job density. Therefore it can be concluded that zoning maximum density requirements have a strong positive influence on the intensity of residential and commercial development.

**Zoning minimum parking requirements negatively influences the intensity of residential development:** As expected, the residential development intensity model suggests a negative relationship between household density and zoned minimum overall parking requirements, which includes residential parking requirements. However, the commercial development intensity model shows that is not the case for job density. Therefore it can be concluded that zoning minimum parking requirements have a negative influence on the intensity of residential development.

**Zoning land use requirements influence the intensity of commercial development:** As expected, the commercial development intensity model suggests a positive relationship between the percentage of land zoned for business commercial uses and job density. There is also a positive relationship between the percentage of land zoned for residential uses and household density. However, this variable is not considered in the residential development intensity model due to colinearity with maximum zoned residential units per acre. Therefore it can be concluded that zoning land use requirements have a positive influence on commercial development intensity.

**Urban design characteristics influence the intensity of residential development:** As expected, the residential development intensity model suggests that block density has a positive relationship with household density. However, the commercial development intensity model shows that is not the case for job density. This might be a reflection of the fact that jobs in Chicago are concentrated not only in the Loop which has high block density, and also in place like the Illinois Medical District and O'Hare airport and in office parks which have low block density. Therefore, it can be concluded that urban design characteristics have a positive influence on the residential development intensity.

**Location is an important influence on the intensity of development:** The development intensity models suggest a positive relationship between having an airport and job densities. Proximity to Lake Michigan shows a positive relationship with household density, and presence in the Loop shows a positive relationship with job density when considered individually. However, these variables are not considered in the development intensity model due to potential multi-colinearity with other factors like transit accessibility, automobile accessibility, zoned maximum FAR, and zoned maximum residential dwelling units per acre, etc.
Socio-economic characteristics are influencing factors on residential development intensity: The residential development intensity models suggest that median household income, percentage of households without an automobile, and percentage of workers not born in the US all have a positive relationship with household density, which is expected. Percentage of households with household size of 3 or more has a negative relationship with household density when considered alone, but is not considered in the development intensity models due to colinearity with other included variables. This suggests that the influence of socio-economic factors on household density must be taken into consideration when a neighborhood or place is undergoing socio-economic change, for example, gentrification or in-migration.

7.4.1. Policy Implications

The development intensity models presented above suggest that policy can influence development intensity in the areas around new Circle Line transit stations.

Specifically, in order to increase residential development intensity (household density):

- Increase transit accessibility to jobs by reducing transit travel times using strategies such as increasing frequency, reducing dwell times, reducing stoppages etc,
- Increase zoned maximum residential dwelling units per acre
- Reduce zoned overall and/or residential parking ratios
- Rezone from manufacturing and other uses to residential uses. This will also help in increasing the zoned maximum residential dwelling units per acre.
- Apply urban design guidelines that promote greater block density.

In order to increase commercial development intensity (job density):

- Increase transit accessibility to households by reducing transit travel times using some of the strategies stated above
- Increase automobile accessibility to households by reducing automobile travel times using strategies such as reducing congestion, adding capacity etc.
- Increase walk accessibility to households by reducing walk travel times using strategies such as improving sidewalks, removing pedestrian obstacles etc.
- Increase zoned maximum FAR
- Reduce zoned overall parking ratios
- Rezone from manufacturing and other uses to business-commercial uses.
Transit changes can be initiated by the CTA. However, the CTA has no control over zoning regulations and guidelines governing urban design characteristics. To increase the development impacts of the Circle Line project, the Chicago Transit Authority and the city of Chicago’s Department of Planning and Development must work together to craft and implement an aligned set of transportation and land use policies.

7.4.2. Limitations

The development intensity models show that factors like accessibility, zoning regulations and urban design characteristics influence development intensity (household and job density). Based on this model, and the theories of transport and land use change outlined in Chapter 2, an inference can be drawn that changes in factors like accessibility, zoning regulations and urban design characteristics create the potential for changes in development intensity (household and job density), but not that changes in these factors necessarily cause changes in development intensity. Therefore, the development intensity models developed do not prove causation, but rather only estimate the strength and direction of influence.

This is aligned with the modeling approach for the development intensity model used in this thesis, which estimates a spatial regression model using cross-sectional data. This approach allows for the relationship between development density and influencing factors affecting development intensity to be statistically tested. This approach does not allow a causal relationship to be established. Therefore, this thesis does not attempt to verify a causal relationship between development intensity and other factors, but rather assumes that such a relationship exists. This is an acknowledged shortcoming of the (development intensity) modeling approach taken in this thesis, and one which has not been addressed given time and data constraints.

Causality is almost impossible to prove. However, the methodology used for this model can be improved in a number of ways. One approach is to use time series data, and estimate the development intensity model over time. This is currently precluded by a lack of historical data, and specifically by a lack of historical travel time and zoning data. Another approach involves using an integrated land use transportation model with market-based mechanisms, which simulates the process of development; models the location and travel decisions of households and firms, and developers’ decisions; and incorporates land and space prices, vacancy rates, etc. Lack of data regarding land prices, vacancy rates, and the choices of individuals, firms, and developers currently precludes the use of this approach. These approaches are not mutually exclusive.
7.4.3. **Shortcomings**

Besides the above stated limitations, the development intensity models have a number of shortcomings. These include:

- The influence of regional economic conditions is not incorporated.
- Commercial development is considered only in terms of jobs, and not firms. Moreover, jobs are not categorized by sector – service, manufacturing, finance, etc. Also, job data is derived from journey-to-work trip ends.
- Households are not categorized by type – income, age, presence of children, household size, etc.
- Other policy factors like development fees, taxes, etc. are not considered.

7.5. **Conclusions**

The development intensity models verify prior research into the interaction between transit and development. These models suggest that transit accessibility is a strong positive influencing factor on both residential and commercial development intensity. These models also suggest that zoning regulations and urban design characteristics influence the intensity of commercial and residential development. Increases in transit accessibility, and some changes in zoning and urban design characteristics will positively affect development in targeted areas. If this development around the Circle Line in Chicago is to be increased then the Chicago Transit Authority and the city of Chicago’s Department of Planning and Development must work together, to implement a coordinated set of policies.

These development intensity models can be used to consider and quantify development changes due to infrastructure projects like the Circle Line and Pink Line project, and policy changes like zoning regulation and urban design guideline changes. The development intensity models, combined with the accessibility models described in the preceding chapter, form a quasi-integrated land use transportation model. This model can be used to consider the effect of infrastructure and policy changes on the LUT, and thereby quantify the short run accessibility impacts, and the long run accessibility and development impacts of the Circle Line project.
8. Scenario Analyses

This chapter applies the quasi-integrated land use transportation model to the Circle Line project in Chicago. This effort aims to provide the CTA with an indication of the magnitude of the potential accessibility and development impacts of the Circle Line project under various scenarios.

This chapter is organized in 7 sections: a description of the approach used; a delineation of a baseline; a calculation of the short run accessibility impacts of the Circle Line project; an estimation of the potential long run development impacts of the Circle Line project; an estimation of the long run accessibility impacts of the Circle; and conclusions.

8.1. Approach

The process of accessibility and development change is cyclical, and so ideally an integrated land use transportation model should consider this process iteratively, to reach an equilibrium state. However, due to time restrictions the approach used to calculate short run and long run impacts followed in this thesis considers only one complete loop of this process - travel time changes lead to short run accessibility changes, which in turn lead to long run development changes, which finally lead to long run accessibility changes.

A scenario analysis approach is used. Service options are constructed for different service frequencies (different headways) for the Circle Line project. The short run accessibility impacts for each of these service options are calculated using the accessibility models considering only changes in travel times. Scenarios are then constructed using the short run accessibility impacts, and different zoning regulations and urban design characteristics around Circle Line stations. The long run development impacts for each of these scenarios are estimated using the development intensity model. Then, the long run accessibility impacts for each of these scenarios are calculated considering the estimated long run development impacts of each scenario in addition to changes in travel times.
8.2. Baseline

The baseline represents conditions at the start of the scenario analysis, in this case, year 2000. This baseline considers that no part of the Circle Line including Phase 1 (which includes the Pink Line) has been implemented. Furthermore, this baseline is the same as the accessibility and development intensity used in the estimation of the development intensity model - using household and job data from the 2000 CTPP and travel times from the CTA transit network model before any part of the Circle Line has been implemented.

8.2.1. Baseline Development Intensity

Table 8-1 shows the baseline development intensity in terms of the total number of households and jobs in the region and the overall household density and job density of the region.

<table>
<thead>
<tr>
<th>Table 8-1: Baseline Household Density and Job Density</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Households</strong></td>
</tr>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Baseline</td>
</tr>
<tr>
<td><strong>Jobs</strong></td>
</tr>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Baseline</td>
</tr>
</tbody>
</table>

The entire Chicago region, defined as all TAZs within a 25 mile radius from the Loop, has an area of slightly more than 640,000 acres. This area has about 2 million households giving an overall household density of about 3.2 households per acre. This area also has about 2.8 million jobs, at an overall job density of about 4.3 jobs per acre. Further discussion and maps showing the pattern of household and job density for the Chicago region and the city of Chicago are presented in the preceding chapter (Section 7.2.1).
8.2.2. Baseline Transit Accessibility

Table 8-2 shows the baseline regional transit accessibility in terms of the number of equivalent households and jobs accessible by transit from a zone summed over all zones (3153) in the Chicago region, the value of indexed transit accessibility to households and jobs of a zone summed over all zones in the region, and averages per zone for both these measures (i.e. divided by the number of zones in the region).

Table 8-2: Baseline Regional Transit Accessibility to Households and to Jobs

<table>
<thead>
<tr>
<th>Transit accessibility to households</th>
<th>Equivalent households</th>
<th>Indexed value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum for all zones</td>
<td>Average per zone</td>
<td>Sum for all zones</td>
</tr>
<tr>
<td>Baseline</td>
<td>350,729,155</td>
<td>111,237</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transit accessibility to jobs</th>
<th>Equivalent jobs</th>
<th>Indexed value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum for all zones</td>
<td>Average per zone</td>
<td>Sum for all zones</td>
</tr>
<tr>
<td>Baseline</td>
<td>557,516,438</td>
<td>176,821</td>
</tr>
</tbody>
</table>

For the entire Chicago region, the value of the regional transit accessibility to households measure is about 350 million, which translates to an average of 111,000 equivalent households accessible from each zone. In terms of the indexed transit accessibility to households this translates to a value of about 168 for all zones and an average value of about 0.05 for each zone.

For the entire Chicago region, the value of the regional transit accessibility to jobs measure is about 557 million, which translates to an average of 176,000 equivalent jobs accessible from each zone. In terms of the indexed transit accessibility to jobs this translates to a value of about 199 for all zones and an average value of about 0.06 for each zone.

Further discussion and maps showing the pattern of transit accessibility to households and jobs for the Chicago region and the city of Chicago are presented in the preceding chapter (Section 7.2.2).

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36 The 'number of equivalent households accessible from a zone' is a measure of accessibility to households at that zone. This measure reflects the number of households accessible from a zone after accounting for the time required to travel to those households. A household which is a factor of 0.5 away (as calculated by the travel time impedance function) is counted as half an equivalent household, and so on. The same is true for equivalent jobs.

37 The 'number of equivalent households accessible from a zone' measure can be converted to the 'indexed accessibility to households' measure by dividing the former by the total number of households in the region. The same is true for equivalent jobs.

38 This value is the number of equivalent households accessible from each zone in the region, summed over all zones. It is not the total number of households in the region. The same is true for equivalent jobs.
8.2.3. Baseline Automobile Accessibility

Table 8-3 shows the baseline regional automobile accessibility measures for the Chicago region.

Table 8-3: Baseline Regional Automobile Accessibility to Households and to Jobs

<table>
<thead>
<tr>
<th></th>
<th>Equivalent households</th>
<th>Indexed value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum for all zones</td>
<td>Average per zone</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td>1,783,264,530</td>
<td>565,577</td>
</tr>
</tbody>
</table>

**Automobile accessibility to jobs**

<table>
<thead>
<tr>
<th></th>
<th>Equivalent jobs</th>
<th>Indexed value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum for all zones</td>
<td>Average per zone</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td>2,222,423,865</td>
<td>704,860</td>
</tr>
</tbody>
</table>

For the entire Chicago region, the value of the regional automobile accessibility to households measure is about 1.7 billion, which translates to an average of 565,000 equivalent households accessible from each zone; and the value of the regional automobile accessibility to jobs measure is about 2.2 billion, which translates to an average of 704,000 equivalent jobs accessible from each zone.

Further discussion and maps showing the pattern of automobile accessibility to households and jobs for the Chicago region and the city of Chicago are presented in the preceding chapter (Section 7.2.3).

8.2.4. Baseline Walk Accessibility

Table 8-4 shows the baseline regional walk accessibility measures for the Chicago region.

Table 8-4: Baseline Regional Walk Accessibility to Households and to Jobs

<table>
<thead>
<tr>
<th></th>
<th>Equivalent households</th>
<th>Indexed value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum for all zones</td>
<td>Average per zone</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td>11,187,483</td>
<td>3,548</td>
</tr>
</tbody>
</table>

**Walk accessibility to jobs**

<table>
<thead>
<tr>
<th></th>
<th>Equivalent jobs</th>
<th>Indexed value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sum for all zones</td>
<td>Average per zone</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td>22,446,169</td>
<td>7,119</td>
</tr>
</tbody>
</table>

For the entire Chicago region, the value of the regional walk accessibility to households measure is about 11 million, which translates to an average of 3,500 equivalent households accessible from each zone; and the value of the regional walk accessibility to jobs measure is about 22 million, which translates to an average of 7,000 equivalent jobs accessible from each zone.
Further discussion and maps showing the pattern of walk accessibility to households and jobs for the Chicago region and the city of Chicago are presented in the preceding chapter (Section 7.2.4).

### 8.3. Short Run Accessibility Changes

4 transit service options are defined for evaluating the short run accessibility impacts of the Circle Line project:

- **Pink Line project**: This includes the new Pink Line, as well as modification of existing rail transit routes and an increase in service frequencies, but no new infrastructure development. This project was implemented in Summer 2006.

- **Circle Line (4 trains/hour or 15 minute headway) + Pink Line project**: This includes the new circumferential Circle Line project with 15 minute headways in addition to the Pink Line project. This is the most conservative estimate of Circle Line frequency, and is the easiest to achieve.

- **Circle Line (6 trains/hour or 10 minute headway) + Pink Line project**: This includes the new circumferential Circle Line project with 10 minute headways in addition to the Pink Line project. This is an optimistic yet achievable frequency.

- **Circle Line (12 trains/hour or 5 minute headway) + Pink Line project**: This includes the new circumferential Circle Line project with 5 minute headways in addition to the Pink Line project. This is the most optimistic estimate of Circle Line frequency. However, this might not be possible due to capacity constraints on a portion of the Circle Line that goes through the Red Line Tunnel in the Loop.

These 4 service options are modeled in the CTA transit network model, which is then used to calculate changed travel times between TAZs. The changed travel times are used as inputs in the accessibility model to calculate the short run transit accessibility impacts for each of the 4 service options.

It is assumed that no changes occur to the baseline number, distribution and density of households and jobs in the region in the short run. Therefore, the calculated short run changes in accessibility are solely the result of changes in travel times between TAZs. Furthermore, an assumption is made that no changes occur to the road and pedestrian transportation systems in the short run. Consequently, there is no change in automobile and walk accessibility to households and to jobs in the short run.
8.3.1. Short Run Changes in Transit Accessibility to Households

Table 8-5 shows the short run changes in regional transit accessibility to households for each service option in comparison to the baseline. This table also shows a comparison with the accessibility changes due to the Pink Line project in order to show the magnitude of changes due to the Circle Line project above and beyond the Pink Line project.

Table 8-5: Short Run Changes in Regional Transit Accessibility to Households

<table>
<thead>
<tr>
<th>Equivalent Households</th>
<th>from Baseline</th>
<th>from Pink Line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Avg. per zone</td>
</tr>
<tr>
<td>Change</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Short Run Changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>6,982,779</td>
<td>2,215</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>7,177,713</td>
<td>2,276</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>7,736,514</td>
<td>2,454</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>9,226,545</td>
<td>2,926</td>
</tr>
</tbody>
</table>

These results show that the regional transit accessibility to households measure increased by about 7 million\(^{39}\) in the short run (i.e. only due to changes in travel times), which translates to an average of about 2,200 additional equivalent households accessible from each zone, after implementation of the Pink Line project when compared to the baseline. Furthermore, the regional accessibility measure will increase by between 190,000 and 2.2 million in the short run, which translates to an average of between 60 and 710 additional equivalent households accessible from each zone, after implementation of the Circle Line project depending upon the frequency of service when compared to the Pink Line project\(^{40}\). These results suggest that for the Circle Line to have the maximum possible impact on short run accessibility to households, service frequencies on the Circle Line must be as high as is possible, and that the CTA should aim to achieve the 5 minute frequency level\(^{41}\).

These results also show that regional transit accessibility to households increased in the short run by about 2% after implementation of the Pink Line project, and will increase by about 2.05 to 2.63% after implementation of the Circle Line project depending upon the frequency of service. This suggests that the majority of the transit accessibility to households impacts of the Circle Line project have already been achieved after implementation.

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\(^{39}\) This is the change in the accessibility measure for the entire region, which has no meaning except when compared to the baseline.

\(^{40}\) A comparison has been made with the Pink Line instead of with the baseline in order to show the future effect of the Circle Line above and beyond that of the currently operational Pink Line.

\(^{41}\) This does not, however, consider if the monetary value of the benefits of the accessibility increase will be higher than the corresponding cost increase. That would require monetization of benefits, and a benefit-cost analysis.
of the Pink Line project (which somewhat mirrors Busby’s conclusions), and that travel time reductions are not sufficient for the Circle Line project to have substantial accessibility impacts above and beyond those of the Pink Line project. This underlies the critical importance of considering long run development impacts due to the Circle Line in order to demonstrate its accessibility impacts.

Figure 8-1 shows the pattern of short run change in transit accessibility to households, in terms of the additional number of equivalent households accessible from a zone, after the Pink Line in comparison to the baseline at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the accessibility benefits conferred by implementation of the Pink Line project.

**Figure 8-1: Short Run Change in Transit Accessibility to Households of Pink Line Project over Baseline**

These maps show that, at most, about 52,000 additional equivalent households were accessible from a zone in the region after implementation of the Pink Line project when compared to the baseline. These maps also show that the most significant increases in transit accessibility to households occur at the ends of and along the Blue and Pink Lines. This is primarily a result of the increased frequency on the Blue Line and the portion of the Blue Line which has been reconfigured as the Pink Line. Minor increases in transit accessibility to households also occur along other CTA rail lines.

### Table: Change in Transit Accessibility to Households

<table>
<thead>
<tr>
<th>Equivalent Hh</th>
<th>Change in Tr. Acc. to HHs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1645</td>
<td></td>
</tr>
<tr>
<td>1646 - 3596</td>
<td></td>
</tr>
<tr>
<td>3597 - 5891</td>
<td></td>
</tr>
<tr>
<td>5892 - 8932</td>
<td></td>
</tr>
<tr>
<td>8933 - 12968</td>
<td></td>
</tr>
<tr>
<td>12969 - 18382</td>
<td></td>
</tr>
<tr>
<td>18383 - 26510</td>
<td></td>
</tr>
<tr>
<td>26511 - 41082</td>
<td></td>
</tr>
</tbody>
</table>

8. Scenario Analyses

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Figure 8-2 shows the pattern of short run change in transit accessibility to households, in terms of the additional number of equivalent households accessible from a zone, after the Circle Line project with 10 minute headways in comparison to the Pink Line project at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the accessibility benefits conferred by implementation of the Circle Line project above and beyond the Pink Line project.

**Figure 8-2: Short Run Change in Transit Accessibility to Households of Circle Line Project (10 min) over Pink Line Project**

These maps show that, at most, about 34,000 additional equivalent households will be accessible from a zone in the region after implementation of the Circle Line project with 10 minute headways when compared to the Pink Line project. These changes would be even higher for the Circle Line with 5 minute headways. These maps also show that the most significant increases in transit accessibility to households occur around stations along the northern, western and southern sections of the Circle Line ‘loop’. Minor increases in transit accessibility to households also occur along other CTA rail lines.

Both these sets of maps show the pattern of additional accessibility benefits, in terms of access to households, conferred by these transit infrastructure projects on zones in the region. Firms (and so jobs) in the affected zones will be able to access an increased number of households, thus creating the potential for job growth and development of new job facilities, and so increasing job density in these zones. The development intensity
model can be used to estimate the magnitude of potential increase in development intensity in terms of job density due to these changes in transit accessibility to households.

8.3.2. Short Run Changes in Transit Accessibility to Jobs

Table 8-6 shows the short run changes in regional transit accessibility to jobs for each service option in comparison to the baseline. This table also shows a comparison with the accessibility changes due to the Pink Line project.

Table 8-6: Short Run Changes in Regional Transit Accessibility to Jobs

<table>
<thead>
<tr>
<th>Transit Accessibility to Jobs</th>
<th>Overall</th>
<th>Avg. per zone</th>
<th>%</th>
<th>Overall</th>
<th>Avg. per zone</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Jobs Change</td>
<td>from Baseline</td>
<td>from Pink Line</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>12,831,246</td>
<td>283,113</td>
<td>2.30%</td>
<td>13,114,359</td>
<td>90</td>
<td>0.05%</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>13,114,359</td>
<td>283,113</td>
<td>2.35%</td>
<td>13,943,174</td>
<td>353</td>
<td>0.19%</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>13,943,174</td>
<td>1,111,928</td>
<td>2.50%</td>
<td>16,179,627</td>
<td>1,062</td>
<td>0.59%</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>16,179,627</td>
<td>3,348,381</td>
<td>2.90%</td>
<td>15,560,046</td>
<td>1,062</td>
<td>0.59%</td>
</tr>
</tbody>
</table>

These results show that the regional transit accessibility to jobs measure increased by about 12.8 million\(^{42}\) in the short run, which translates to an average of about 4,000 additional equivalent jobs accessible from each zone, after implementation of the Pink Line project when compared to the baseline. Furthermore, the regional transit accessibility to jobs measure will increase by between 280,000 and 3.3 million in the short run, which translates to an average of between 90 and 1060 additional equivalent jobs accessible from each zone, after implementation of the Circle Line project depending upon the frequency of service when compared to the Pink Line project. These results also suggest that for the Circle Line to have the maximum possible impact on short run accessibility to jobs, service frequencies on the Circle Line must be as high as is possible.

These results also show that regional transit accessibility to jobs increased in the short run by about 2.3% after implementation of the Pink Line project, and will increase by about 2.35 to 2.90% after implementation of the Circle Line project depending upon the frequency of service. This again suggests that the majority of the transit accessibility to jobs impacts of the Circle Line project have already been achieved after implementation of the

\(^{42}\) Again, this is the change in the accessibility measure for the entire region, which has no meaning except when compared to the baseline.
Pink Line project and that travel time reductions are not sufficient for the Circle Line project to have substantial accessibility impacts above and beyond those of the Pink Line project. This again underlies the critical importance of considering long run development impacts due to the Circle Line in order to demonstrate its accessibility impacts.

Figure 8-3 shows the pattern of short run change in transit accessibility to jobs, in terms of the number of additional equivalent jobs accessible from a zone, after the Pink Line in comparison to the baseline at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the accessibility benefits conferred by implementation of the Pink Line project.

**Figure 8-3: Short Run Change in Transit Accessibility to Jobs of Pink Line Project over Baseline**

These maps show that, at most, about 83,000 additional equivalent jobs were accessible from a zone in the region after implementation of the Pink Line project when compared to the baseline. These maps also show that the most significant increases in transit accessibility to jobs occur at the ends and along the Blue and Pink Lines. This is also primarily a result of the increased frequency on the Blue Line and the portion of the Blue Line which has been reconfigured as the Pink Line. Minor increases in transit accessibility to jobs also occur along other CTA rail lines.
Figure 8-4 shows the pattern of short run change in transit accessibility to jobs, in terms of the number of additional equivalent jobs accessible from a zone, after the Circle Line project with 10 minute headways in comparison to the Pink Line project at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the accessibility benefits conferred by implementation of the Circle Line project above and beyond the Pink Line project.

Figure 8-4: Short Run Change in Transit Accessibility to Jobs of Circle Line Project (10 min) over Pink Line Project

These maps show that, at most, about 40,000 additional equivalent jobs will be accessible from a zone in the region after implementation of the Circle Line project with 10 minute headways when compared to the Pink Line project. These changes would be even higher for the Circle Line with 5 minute headways. These maps also show that the most significant increases in transit accessibility to jobs occur around stations along the northern, western and southern sections of the Circle Line 'loop'. Minor increases in transit accessibility to jobs also occur along other CTA rail lines.

Both these sets of maps show the pattern of additional accessibility benefits, in terms of access to jobs, conferred by these transit infrastructure projects on zones in the region. Households in the affected zones will be able to access an increased number of jobs, thus creating the potential for residential growth and development of new residential projects, and so increasing household density in these zones. The development intensity model can be used to estimate the magnitude of potential increase in development intensity in terms of household density due to these changes in transit accessibility to jobs.
8.4. Long Run Development Changes

The preceding section suggests that the Pink Line and Circle Line projects create accessibility changes throughout the city, which in turn creates the potential for increased development intensity. In this section, the development intensity models are used to estimate the magnitude of increase in development intensity due to these changes in transit accessibility, and implementation of development-supportive public policies, over time. This model, however, cannot estimate whether the increase in development is due to a redistribution of existing development, or due to regional growth, over time. The increases in development intensity should thus be interpreted as the additional amount of development that can be accommodated due to the infrastructure and policy changes.

These development intensity models cover only the city of Chicago, so any increase in development intensity outside the borders of the city of Chicago is not estimated or included. Some of the highest increases in short run accessibility due to the Pink Line project occurs in zones at the ends of the Blue and Pink Lines, which fall outside the city of Chicago, and so the development intensity models will likely underestimate the increase in development intensity for the whole region.

Figure 8-5: Identified Circle Line Stations

Redistribution would mean that some TAZs decrease in household and job density.

43 Redistribution would mean that some TAZs decrease in household and job density.
In addition to the accessibility increases, a set of development-supportive public policies can be implemented in certain locations in order to spur increase in development intensity (both household density and job density) over time. In order to build upon the accessibility benefits conferred by the Circle Line project, any changes to zoning regulations and guidelines governing urban design characteristics should be made at locations where the most significant short run accessibility impacts due to the Circle Line project occur i.e. along the northern, western and southern sections of the Circle Line ‘loop’. To this end, proposed Circle Line stations have been identified (Figure 8-5) around which the most significant short run accessibility impacts of the Circle Line project will take place (based on the calculated short run accessibility impacts of the Circle Line project).

The city of Chicago’s Department of Planning and Development, as part of the Zoning Remap Project in 2004, has stated an aim of ‘encouraging density near mass transit’: “Many areas of the city have access to the “L”, commuter trains or buses. Having zoning that would allow the construction of relatively higher density buildings within a ¼ or ½ mile of transit stations helps make the most of this valuable transportation resource” (City of Chicago, Department of Planning And Development, 2004). In the past few years, the City of Chicago has implemented the Zoning Remap Project. However, the implemented zoning changes were substantially less far-reaching than the stated goals. No increases in density were allowed; only a “reduction in the number of required parking spaces by 50% for reuse of existing structures in business-, commercial-, or downtown-zoned districts” was allowed, and that too only “if they are within 600 feet of a CTA or Metra rail station” (City of Chicago, Department of Planning And Development, 2006). The possible reasons why the implemented zoning changes were substantially less far-reaching than the stated goals include a failure by decision makers to understand the benefits of building near transit, or opposition from neighbors due to concerns regarding additional congestion, or increased noise during construction, etc. These reasons must be researched and taken into account before any changes can be made to zoning regulations and guidelines governing urban design characteristics of the sort shown in this thesis.

Based on the original intention of the Zoning Remap Project areas all parcels that fall within or touch a quarter mile buffer around the indentified stations are considered as the target area for potential changes to zoning regulations and guidelines governing urban design characteristics. In this section, scenarios are constructed for changes to zoning regulations and guidelines governing urban design characteristics in these target areas, and then the development intensity models are used to estimate the magnitude of increase in household and job density due to these potential changes (in each scenario) in addition to changes in transit accessibility.
8.4.1. Long Run Changes in Household Development Intensity

Based on the development intensity model for household density, a number of possible residential development-supportive public policies have been explored.

- No changes in zoning, only changes in short run accessibility to jobs are considered.
- Increase in zoned dwelling units per acre of 25% or 50% for all parcels that fall within or touch a quarter mile buffer around the identified stations. These zoning changes are realistic absent widespread or strong opposition, if there are market pressures for residential development, or if the current zoning density regulations are too low, especially in comparison to nearby parcels which are not near transit.
- Rezoning to residential uses of 25% or 50% or 100% of manufacturing parcels that fall within or touch a quarter mile buffer around the identified stations. These changes are realistic if the parcels currently zoned for manufacturing uses are being underutilized, or have manufacturing firms that are willing to locate elsewhere, or if there is there is a strong political will and/or economic rationale to relocate manufacturing firms.
- Decrease in parking requirement of 10%, 20% or 40% for all parcels that fall within or touch a quarter mile buffer around the identified stations. These zoning changes are realistic if there is no widespread or strong opposition to the same, or if strategies like temporal sharing of parking (by retail and commercial establishments in the day, and by residences at night), ride sharing, short-term car rentals like Zipcars are implemented. This policy, if implemented, should go hand in hand with strict enforcement of on-street parking requirements.
- Increase in block density to standard Chicago block density of 0.1 blocks/acre for TAZs that fall within or touch a quarter mile buffer around the identified stations, but currently have block density less than 0.1 blocks/acre. These changes are possible only in areas where large scale new developments are built, as it is very difficult to change the urban design characteristics of established neighborhoods.

Table 8-7 shows the predicted changes in household development considering only short run changes in accessibility to jobs due to the 4 Service Options alone, and also the above enumerated possible changes in zoning regulations and guidelines governing urban design characteristics in combination with implementation of the Circle Line with 10 minute headways, all in comparison with the baseline. This table also shows a comparison with the development intensity changes due to the Pink Line project in order to show the magnitude

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44 Each development-supportive public policy has been tried out separately from one another, to show the range of possibilities.
of changes due to the Circle Line project above and beyond the Pink Line project. Finally, this table shows a comparison with the development intensity changes due to the Circle Line project with 10 minute headways in order to show the magnitude of changes due to the zoning changes above and beyond the Circle Line project.

Table 8-7: Predicted Long Run Changes in Regional Development in terms of Households (Possibilities)

<table>
<thead>
<tr>
<th>Households</th>
<th>from Baseline</th>
<th>from Pink Line</th>
<th>from Circle Line (10 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change</td>
<td>% Change</td>
<td>Change</td>
</tr>
<tr>
<td><strong>Short Run Changes in Transit Accessibility to Jobs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>14,968</td>
<td>0.72%</td>
<td>15,283</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>16,245</td>
<td>0.78%</td>
<td>1,257</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>18,795</td>
<td>0.90%</td>
<td>3,807</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Decreases in Zoned Parking Requirements + Circle Line (10 min)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>17,479</td>
<td>0.84%</td>
<td>2,491</td>
</tr>
<tr>
<td>20%</td>
<td>18,765</td>
<td>0.90%</td>
<td>3,777</td>
</tr>
<tr>
<td>40%</td>
<td>19,381</td>
<td>0.93%</td>
<td>4,393</td>
</tr>
<tr>
<td><strong>Increases in Block Density + Circle Line (10 min)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to 0.1 block/acre</td>
<td>17,367</td>
<td>0.83%</td>
<td>2,379</td>
</tr>
</tbody>
</table>

These results show that household development is estimated to increase by about 15,000 households, all in the city of Chicago, or by about 0.72% region wide after implementation of the Pink Line project when compared to the baseline. Also, household development is estimated to increase by between 295 and 3,800 households, all in the city of Chicago, or by about 0.01 to 0.18% region-wide after implementation of the Circle Line project depending upon the frequency of service when compared to the Pink Line project. This suggests that the majority of the increases in household development due to short run changes alone will be realized upon implementation of the Pink Line. These results also suggest that for the Circle Line to have the maximum

These are actual households and not equivalent households. This reflects the number of new households that can be accommodated in the vicinity of the Circle Line project.

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possible impact on household development, service frequencies on the Circle Line must be as high as is possible.

These results also allow assessment of the relative development impacts of each of the possible changes in zoning regulations and guidelines governing urban design characteristics. Increasing zoned dwelling units per acre by 50% produces the highest increases in development (1% above the baseline, and 0.3% above the change due to the Circle Line with 10 minute headways but no changes in zoning regulations). High increases in development (0.9% above the baseline, and 0.2% above the change due to the Circle Line with 10 minute headways but no changes in zoning regulations) are produced by rezoning all manufacturing uses to residential uses and by reducing overall parking requirements by 40%. Increasing block density to 0.1 blocks/acre, rezoning 25% of manufacturing uses to residential uses, and decreasing overall parking requirements by 10% produce relatively small changes in development. These results provide a menu of policy options for the CTA and the city of Chicago’s Department of Planning and Development.

Based on the above possibilities, 3 scenarios with a combination of Service Options and changes to zoning regulations and guidelines governing urban design characteristics are defined. These scenarios represent a spectrum of future transit service level improvements and policy changes from the relatively modest to the highly speculative.

- **Scenario 1:** Short run changes in accessibility due to Circle Line (4 trains/hour or 15 minute headway) + 25% increase in zoned dwelling units per acre + 10% decrease in overall parking requirements. This scenario comprises a relatively modest set of development-supportive policies implemented around Circle Line stations along with the most conservative and achievable estimate of Circle Line frequency.

- **Scenario 2:** Short run changes in accessibility due to Circle Line (6 trains/hour or 10 minute headway) + 25% increase in zoned dwelling units per acre + 50% rezoning from manufacturing to residential uses + 20% decrease in overall parking requirements + Increase in block density (to standard Chicago blocks of 0.1 blocks/acre). This scenario comprises of a more aggressive set of development-supportive policies implemented around Circle Line stations along with an optimistic yet achievable estimate of Circle Line frequency.

- **Scenario 3:** Short run changes in accessibility due to Circle Line (12 trains/hour or 5 minute headway) + 50% increase in zoned dwelling units per acre + 100% rezoning from manufacturing to residential uses.

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46 This does not, however, consider if the monetary value of the benefits due to the development increase will be higher than the corresponding cost increase. That would require monetization of benefits, and a benefit-cost analysis.
uses + 40% decrease in overall parking requirements + Increase in block density (to standard Chicago blocks of 0.1 blocks/acre). This scenario comprises of a very aggressive set of development-supportive policies implemented around Circle Line stations along a very optimistic estimate of Circle Line frequency.

Table 8-8 shows the predicted increases in household development considering only short run changes in accessibility to jobs due to the 4 Service Options alone, and also estimated increases in development intensity for the 3 defined scenarios, all in comparison with the baseline. As before, this table also shows a comparison with the development intensity changes due to the Pink Line project and due to the Circle Line project with 10 minute headways.

**Table 8-8: Predicted Long Run Changes in Regional Development in terms of Households (Scenarios)**

<table>
<thead>
<tr>
<th>Households</th>
<th>from Baseline</th>
<th>from Pink Line</th>
<th>from Circle Line (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change</td>
<td>% Change</td>
<td>Change</td>
<td>% Change</td>
</tr>
<tr>
<td><strong>Short Run Changes in Transit Accessibility to Jobs due to Service Options</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>14,988</td>
<td>0.72%</td>
<td></td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>15,283</td>
<td>0.73%</td>
<td>295</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>16,245</td>
<td>0.78%</td>
<td>1,257</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>18,795</td>
<td>0.90%</td>
<td>3,807</td>
</tr>
<tr>
<td><strong>Scenarios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td>19,152</td>
<td>0.92%</td>
<td>4,164</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>24,619</td>
<td>1.18%</td>
<td>9,631</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>36,438</td>
<td>1.75%</td>
<td>21,450</td>
</tr>
</tbody>
</table>

These results show that household development is estimated to increase by between 19,000 and 36,000 households, all in the city of Chicago, or about 0.92 to 1.75 % region wide after implementation of the Scenarios when compared to the baseline. All scenarios show an estimated increase in household development (0.9-1.8% above the baseline, and 0.2-1% above the change due to the Circle Line with 10 minute headways but no changes in zoning regulations). This suggests that the combined effect of various Service Options and possible changes in zoning regulations and guidelines governing urban design characteristics on household development is greater than that due to any one possible change. This also suggests that the residential development impacts of the Circle Line project can be significantly greater than that of the Pink Line project if adequate and complementary development-supportive public policies are also put in place.
Figure 8-6 shows the pattern of predicted long run change in household development intensity, after the Pink Line project in comparison to the baseline at the TAZ level for the city of Chicago. These changes reflect the household development impacts of the Pink Line project alone.

**Figure 8-6: Predicted Long Run Change in Household Development Intensity due to Pink Line Project over Baseline**

This map shows that, at most, household development intensity at a zone in the city of Chicago will increase by a predicted 1.65 households per acre after implementation of the Pink Line project when compared to the baseline. These maps also show that the most significant increases in household development intensity occur along the Blue and Pink Lines.
Figure 8-7 shows the pattern of predicted long run change in household development intensity, after the Circle Line project with 10 minute headways in comparison to the Pink Line project at the TAZ level for the city of Chicago. These changes reflect the household development impacts of the Circle Line project above and beyond the Pink Line project.

This map shows that, at most, household development intensity at a zone in the city of Chicago will increase by a predicted 0.6 households per acre after the Circle Line project with 10 minute headways in comparison to the Pink Line project. These changes would be even higher for the Circle Line with 5 minute headways. These maps also show that the most significant increases in household development intensity occur around stations along the northern, western and southern sections of the Circle Line 'loop'.
Figure 8-8 shows the pattern of predicted long run change in household development intensity, after implementation of Scenario 2 in comparison to the Circle Line project with 10 minute headways at the TAZ level for the city of Chicago. These changes reflect the household development impacts of the changes in zoning regulations and guidelines governing urban design characteristics above and beyond the Circle Line project alone.

**Figure 8-8: Predicted Long Run Change in Household Development Intensity due to Scenario 2 over Circle Line Project (10 min)**

This map shows that, at most, household development intensity at a zone in the city of Chicago will increase by a predicted 13 households per acre after implementation of the changes in zoning regulations and guidelines governing urban design characteristics in comparison to the Circle Line project with 10 minute headways. These changes would be even higher for Scenario 3. These maps also show that the most significant increases in household development intensity occur around the identified stations.
8.4.2. Long Run Changes in Job Development Intensity

Based on the development intensity model for job density, a number of possible commercial development-supportive public policies have been explored.

- No changes in zoning, only changes in short run accessibility are considered.
- Increase in FAR of 25% or 50% for all parcels that fall within or touch a quarter mile buffer around the identified stations. These zoning changes are realistic if there is no widespread or strong opposition to the same, if there are market pressures for increasing zoned density, or if the current zoning density regulations are too low, especially in comparison to nearby parcels which are not near transit.
- Increase in land zoned for business-commercial uses of 25% or 50% or 100% for parcels that fall within or touch a quarter mile buffer around the identified stations. These zoning changes are realistic if the affected parcels are currently being underutilized, or if there is there is a strong political will and/or economic rationale to increase retail and business-commercial firms.

Table 8-9 shows the predicted increases in job development considering only short run changes in accessibility to households due to the 4 Service Options alone, and also estimated increases in job development considering the above enumerated possible changes in zoning regulations in addition to changes in short run accessibility due to implementation of the Circle Line with 10 minute headways, all in comparison with the baseline. This table also shows a comparison with the development intensity changes due to the Pink Line project in order to show the magnitude of changes due to the Circle Line project above and beyond the Pink Line project. Finally, this table also shows a comparison with the development intensity changes due to the Circle Line project with 10 minute headways in order to show the magnitude of changes due to the zoning changes above and beyond the Circle Line project.
Table 8-9: Predicted Long Run Changes in Regional Development in terms of Jobs (Possibilities)

<table>
<thead>
<tr>
<th>Jobs</th>
<th>Change</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>from Baseline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>from Pink Line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>from Circle Line (10)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Short Run Changes in Transit Accessibility to Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pink Line</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Increases in FAR Requirements + Circle Line (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
</tr>
<tr>
<td>50%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Increases in Business-Commercial Uses + Circle Line (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td>100%</td>
</tr>
</tbody>
</table>

These results show that job development is estimated to increase by about 42,000 jobs\(^{47}\), all in the city of Chicago, or by about 1.49% region wide after implementation of the Pink Line project when compared to the baseline. Also, job development is estimated to increase by between 546 and 7,200 jobs, all in the city of Chicago, or by about 0.02 to 0.25% region-wide after implementation of the Circle Line project depending upon the frequency of service when compared to the Pink Line project. This suggests that the majority of the increases in job development due to short run changes alone will be realized upon implementation of the Pink Line. These results also suggest that for the Circle Line to have the maximum possible impact on job development, service frequencies on the Circle Line must be as high as is possible, and that the CTA should aim to achieve the 5 minute frequency level.

The results allow assessment of the relative development impacts of each of the possible changes in zoning regulations. Increasing FAR by 50% produces the highest increases (2.1% above the baseline, and 0.5% above the change due to the Circle Line with 10 minute headways but no changes in zoning regulations) in development. High increases in development are produced by increasing the amount of land zoned for business-commercial uses by 100% and increasing FAR by 25%. Increasing the amount of land zoned for business-commercial uses by 25% and 50% produce relative small changes in development. Again, these results present a menu of options for the CTA and the city of Chicago' Department of Planning and Development.

\(^{47}\) These are actual jobs and not equivalent jobs. This reflects the number of new households that can be accommodated in the vicinity of the Circle Line project.
Based on the above possibilities, 3 scenarios with a combination of Service Options and changes to zoning regulations are defined. These scenarios represent a spectrum of future transit service level improvements and policy changes from the relatively modest to the highly speculative.

- **Scenario 1**: Short run changes in accessibility due to Circle Line (4 trains/hour or 15 minute headway) + 25% increase in FAR. This scenario comprises of a relatively modest set of development-supportive policies implemented around Circle Line stations along with the most conservative and achievable estimate of Circle Line frequency.

- **Scenario 2**: Short run changes in accessibility due to Circle Line (6 trains/hour or 10 minute headway) + 25% increase in FAR + 50% increase in amount of land zoned for business-commercial uses. This scenario comprises of a slightly more aggressive set of development-supportive policies implemented around Circle Line stations along with an optimistic yet achievable estimate of Circle Line frequency.

- **Scenario 3**: Short run changes in accessibility due to Circle Line (12 trains/hour or 5 minute headway) + 50% increase in FAR + 100% increase in amount of land zoned for business-commercial uses. This scenario comprises of a very aggressive set of development-supportive policies implemented around Circle Line stations along a very optimistic estimate of Circle Line frequency.

Table 8-10 shows the predicted increases in job development considering only short run changes in accessibility to households due to the 4 Service Options alone, and also estimated increases in development intensity for the 3 defined scenarios, all in comparison with the baseline. As before, this table also shows a comparison with the development intensity changes due to the Pink Line project and due to the Circle Line project with 10 minute headways.

<table>
<thead>
<tr>
<th>Scenario Analyses 183</th>
</tr>
</thead>
</table>

### Table 8-10: Predicted Long Run Changes in Regional Development in terms of Jobs (Scenarios)

<table>
<thead>
<tr>
<th>Jobs</th>
<th>from Baseline</th>
<th>from Pink Line (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change % Change</td>
<td>Change % Change</td>
</tr>
<tr>
<td><strong>Short Run Changes in Transit Accessibility to Households due to Service Options</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>41,791 1.49%</td>
<td>546 0.02%</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>42,337 1.51%</td>
<td>546 0.02%</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>44,096 1.57%</td>
<td>2,305 0.08%</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>48,997 1.75%</td>
<td>7,206 0.25%</td>
</tr>
<tr>
<td><strong>Scenarios</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td>49,753 1.78%</td>
<td>7,962 0.28%</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>53,794 1.92%</td>
<td>12,003 0.42%</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>70,532 2.52%</td>
<td>28,741 1.01%</td>
</tr>
</tbody>
</table>

8. Scenario Analyses
These results show that job development is estimated to increase by between 50,000 and 70,000 jobs, all in the city of Chicago, or about 1.78 to 2.52% region wide after implementation of the Scenarios when compared to the baseline. All scenarios show an increase in development potential (1.8-2.5% above the baseline, and 0.2-0.9% above the change due to the Circle Line with 10 minute headways but no changes in zoning regulations). This suggests that the combined effect of various Service Options and possible changes in zoning regulations on job development is greater than that due to any one possible change. This also suggests that the commercial development impacts of the Circle Line project can be significantly greater than that of the Pink Line project if adequate and complementary development-supportive public policies are also put in place.

Figure 8-9 shows the pattern of predicted long run change in job development intensity, after the Pink Line project in comparison to the baseline at the TAZ level for the city of Chicago. These changes reflect the job development impacts of the Pink Line project alone.

**Figure 8-9: Predicted Long Run Change in Job Development Intensity due to Pink Line Project over Baseline**

This map shows that, at most, job development intensity at a zone in the city of Chicago will increase by a predicted 56 jobs per acre after implementation of the Pink Line project when compared to the baseline. These maps also show that the most significant increases in job development intensity occur in the Loop and along the Blue and Pink Lines.
Figure 8-10 shows the pattern of predicted long run change in job development intensity, after the Circle Line project with 10 minute headways in comparison to the Pink Line project at the TAZ level for the city of Chicago. These changes reflect the job development impacts of the Circle Line project above and beyond the Pink Line project.

Figure 8-10: Predicted Long Run Change in Job Development Intensity due to Circle Line Project (10 min) over Pink Line Project

This map shows that, at most, job development intensity at a zone in the city of Chicago will increase by a predicted 1.2 households per acre after the Circle Line project with 10 minute headways in comparison to the Pink Line project. These changes would be even higher for the Circle Line with 5 minute headways. These maps also show that the most significant increases in job development intensity occur around stations along the northern, western and southern sections of the Circle Line 'loop'.

8. Scenario Analyses
Figure 8-11 shows the pattern of predicted long run change in job development intensity, after implementation of Scenario 2 in comparison to the Circle Line project with 10 minute headways at the TAZ level for the city of Chicago. These changes reflect the household development impacts of the changes in zoning regulations above and beyond the Circle Line project alone.

**Figure 8-11: Predicted Long Run Change in Job Development Intensity due to Scenario 2 over Circle Line Project (10 min)**

This map shows that, at most, job development intensity at a zone in the city of Chicago will increase by a predicted 17 jobs per acre after implementation of the changes in zoning regulations in comparison to the Circle Line project with 10 minute headways. These changes would be even higher for Scenario 3. These maps also show that the most significant increases in job development intensity occur around the identified stations.

### 8.5. Long Run Accessibility Changes

The preceding section suggests that the short run accessibility benefits conferred by the Pink Line and Circle Line projects and changes in zoning regulations and guidelines governing urban design characteristics will increase household and job development in the long run. In this section, the accessibility models are used to estimate the magnitude of the long run increase in accessibility to households and to jobs by transit, automobiles and walking in the long run due to these estimated long run changes in household and job
development. As the increase in household and jobs density for the region are likely to be underestimated, the calculated changes in accessibility to households and jobs in the long run, are also likely to be underestimated.

8.5.1. Long Run Changes in Transit Accessibility to Households

Table 8-11 shows the predicted long run changes in regional transit accessibility to households considering the development impacts for each Service Option and Scenario in comparison to the baseline. This table also shows a comparison with the long run accessibility changes due to the Pink Line project with no development-supportive public policies in order to show the magnitude of changes due to the Circle Line project above and beyond the Pink Line project, and a comparison with the long run accessibility changes due to the Circle Line project with 10 minute headways but no development-supportive public policies in order to show the magnitude of changes due to the changes in zoning regulations and guidelines governing urban design characteristics above and beyond the Circle Line project.

Table 8-11: Predicted Long Run Changes in Regional Transit Accessibility to Households

<table>
<thead>
<tr>
<th>Equivalent Households</th>
<th>from Baseline</th>
<th>from Pink Line no policy changes</th>
<th>from Circle Line (10) no policy changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change</td>
<td>Overall</td>
<td>Avg. per zone</td>
<td>Overall</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td></td>
<td>Avg. per zone</td>
</tr>
<tr>
<td>Short Run Changes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>6,982,779</td>
<td>2,215</td>
<td>1.99%</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>7,177,713</td>
<td>2,276</td>
<td>2.05%</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>7,736,514</td>
<td>2,454</td>
<td>2.21%</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>9,226,545</td>
<td>2,926</td>
<td>2.63%</td>
</tr>
<tr>
<td>Long Run Changes (only Service Options)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>11,908,991</td>
<td>3,777</td>
<td>3.40%</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>12,205,124</td>
<td>3,871</td>
<td>3.48%</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>13,098,836</td>
<td>4,154</td>
<td>3.73%</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>15,490,088</td>
<td>4,913</td>
<td>4.42%</td>
</tr>
<tr>
<td>Long Run Changes (Scenarios)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td>13,835,957</td>
<td>4,388</td>
<td>3.94%</td>
</tr>
<tr>
<td></td>
<td>1,926,966</td>
<td>611</td>
<td>0.53%</td>
</tr>
<tr>
<td></td>
<td>737,121</td>
<td>234</td>
<td>0.20%</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>16,587,648</td>
<td>5,261</td>
<td>4.73%</td>
</tr>
<tr>
<td></td>
<td>4,678,657</td>
<td>1,484</td>
<td>1.29%</td>
</tr>
<tr>
<td></td>
<td>3,488,812</td>
<td>1,107</td>
<td>0.96%</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>23,046,118</td>
<td>7,309</td>
<td>6.57%</td>
</tr>
<tr>
<td></td>
<td>11,137,127</td>
<td>3,532</td>
<td>3.07%</td>
</tr>
<tr>
<td></td>
<td>9,947,282</td>
<td>3,155</td>
<td>2.73%</td>
</tr>
</tbody>
</table>

These results show that the regional transit accessibility to households measure is estimated to increase by about 12 million\(^4\) in the long run, which translates to an average of about 3,800 additional equivalent

\(^4\) This is the change in the accessibility measure for the entire region, which has no meaning except when compared to the baseline.
households\(^{49}\) accessible from each zone, after implementation of the Pink Line project with no development-supportive public policies when compared to the baseline. Furthermore, the regional accessibility measure is estimated to increase by between 300,000 and 3.5 million in the long run, which translates to an average of between 94 and 1,100 additional equivalent households accessible from each zone, after implementation of the Circle Line project depending upon the frequency of service when compared to the Pink Line project, both considering no development-supportive public policies. Finally, the regional accessibility measure is estimated to increase by between 730,000 and 9.9 million in the long run, which translates to an average of between 230 and 3,100 additional equivalent households accessible from each zone, after implementation of the changes in zoning regulations and guidelines governing urban design characteristics for the various Scenarios when compared to the Circle Line project with 10 minute headways but no development-supportive public policies. Scenario 3 generates the most increases in long run transit accessibility to households. These results suggest that for the Circle Line to have the maximum possible impact on long run transit accessibility to households, the CTA should aim to achieve the 5 minute frequency level, and that the city of Chicago’s Department of Planning and Development should aim to implement the most aggressive set of development-supportive public policies around proposed Circle Line stations\(^{50}\).

These results also show that the Circle Line is estimated to have only minor impacts on regional transit accessibility to households (2 to 2.5%) when only changes in travel times are considered. These impacts increase substantially (almost double to 3.5 to 4.4%) when long run development impacts due to short run changes in accessibility are also considered. Furthermore, when zoning changes are also considered, these impacts increase even more (almost triple to 4.0 to 6.5%). Therefore, these results show that the long run accessibility impacts of the Circle Line project are much higher when the long run development impacts of the Circle Line project are considered in addition to the changes in travel times that will occur due to the project.

These results suggest that the long run accessibility impacts of the Circle Line project are potentially much higher than due to the Pink Line project alone, and that the Circle Line project will generate substantial benefits in terms of transit accessibility to households in the long run.

---

\(^{49}\) The 'number of equivalent households accessible from a zone' is a measure of accessibility to households at that zone. This measure reflects the number of households accessible from a zone after accounting for the time required to travel to those households. A household which is a factor of 0.5 away (as calculated by the travel time impedance function) is counted as half an equivalent household, and so on. The same is true for equivalent jobs.

\(^{50}\) This does not, however, consider if the monetary value of the benefits of the accessibility increase will be higher than the corresponding cost increase. That would require monetization of benefits, and a benefit-cost analysis.
Figure 8-12 shows the pattern of predicted long run change in transit accessibility to households, in terms of the number of additional equivalent households accessible from a zone, after the Pink Line with no development-supportive public policies in comparison to the baseline at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the long run accessibility benefits conferred by implementation of the Pink Line project with no development-supportive public policies.

These maps show that, at most, a predicted 58,000 additional equivalent households will be accessible in the long run from a zone in the region after implementation of the Pink Line project with no development-supportive public policies when compared to the baseline. These maps also show that the most significant increases in long run transit accessibility to households due to the Pink Line project occur along the Blue and Pink Lines.
Figure 8-13 shows the pattern of predicted long run change in transit accessibility to households, in terms of the number of additional equivalent households accessible from a zone, after the Circle Line project with 10 minute headways in comparison to the Pink Line project, both with no development-supportive public policies, at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the long run accessibility benefits conferred by implementation of the Circle Line project above and beyond the Pink Line project.

Figure 8-13: Predicted Long Run Change in Transit Accessibility to Households of Circle Line Project (10 min) over Pink Line Project, both with no Development-Supportive Public Policies

These maps show that, at most, a predicted 35,000 additional equivalent households will be accessible in the long run from a zone in the region after implementation of the Circle Line project with 10 minute headways when compared to the Pink Line project, both with no development-supportive public policies. These maps also show that the most significant increases in long run transit accessibility to households due to the Circle Line project occur around stations along the northern, western and southern sections of the Circle Line ‘loop’.
Figure 8-14 shows the pattern of predicted long run change in transit accessibility to households, in terms of the number of additional equivalent households accessible from a zone, after Scenario 2 in comparison to the Circle Line project with 10 minute headways with no development-supportive public policies, at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the long run accessibility benefits conferred by implementation of the development-supportive public policies above and beyond the Circle Line project.

Figure 8-14: Predicted Long Run Change in Transit Accessibility to Households of Scenario 2 over Circle Line Project (10 min) with no Development-Supportive Public Policies

These maps show that, at most, a predicted 5,000 additional equivalent households will be accessible in the long run from a zone in the region after implementation of Scenario 2 when compared to the Circle Line project with 10 minute headways with no development-supportive public policies. These maps also show that the most significant increases in long run transit accessibility to households due to development-supportive public policies occur in the center of the region and around the Circle Line ‘loop’.
8.5.2. Long Run Changes in Transit Accessibility to Jobs

Table 8-12 shows the predicted long run changes in regional transit accessibility to jobs considering the development impacts for each Service Option and Scenario in comparison to the baseline. This table also shows a comparison with the Pink Line project to show the magnitude of changes due to the Circle Line project above and beyond the Pink Line project, and a comparison with the long run accessibility changes due to the Circle Line project with 10 minute headways in order to show the magnitude of changes due to the changes in zoning regulations and guidelines governing urban design characteristics above and beyond the Circle Line project.

Table 8-12: Predicted Long Run Changes in Regional Transit Accessibility to Jobs

<table>
<thead>
<tr>
<th>Transit Accessibility to Jobs</th>
<th>Equivalent Jobs</th>
<th>from Baseline</th>
<th>from Pink Line no policy changes</th>
<th>from Circle Line (10) no policy changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change</td>
<td>Overall</td>
<td>Avg. per zone</td>
<td>Overall</td>
<td>Avg. per zone</td>
</tr>
<tr>
<td><strong>Short Run Changes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>12,831,246</td>
<td>4,070</td>
<td>2.30%</td>
<td>13,114,359</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>13,943,174</td>
<td>4,422</td>
<td>2.50%</td>
<td>16,179,627</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>13,943,174</td>
<td>4,422</td>
<td>2.50%</td>
<td>16,179,627</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>13,943,174</td>
<td>4,422</td>
<td>2.50%</td>
<td>16,179,627</td>
</tr>
<tr>
<td><strong>Long Run Changes (only Service Options)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink Line</td>
<td>31,370,012</td>
<td>9,949</td>
<td>5.63%</td>
<td>31,876,450</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>33,417,122</td>
<td>10,599</td>
<td>5.99%</td>
<td>37,672,124</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>33,417,122</td>
<td>10,599</td>
<td>5.99%</td>
<td>37,672,124</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>37,672,124</td>
<td>11,948</td>
<td>6.76%</td>
<td>37,672,124</td>
</tr>
<tr>
<td><strong>Long Run Changes (Scenarios)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td>35,090,231</td>
<td>11,129</td>
<td>6.29%</td>
<td>3,720,219</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>37,682,359</td>
<td>11,951</td>
<td>6.76%</td>
<td>6,312,347</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>47,388,703</td>
<td>15,030</td>
<td>8.50%</td>
<td>16,018,891</td>
</tr>
</tbody>
</table>

These results show that the regional transit accessibility to jobs measure is estimated to increase by about 31 million in the long run, which translates to an average of about 9,900 additional equivalent jobs accessible from each zone, after implementation of the Pink Line project with no development-supportive public policies when compared to the baseline. Furthermore, the regional transit accessibility to jobs measure is estimated to increase by between 500,000 and 6.3 million in the long run, which translates to an average of between 160 and 2,000 additional equivalent jobs accessible from each zone, after implementation of the Circle Line project depending upon the frequency of service when compared to the Pink Line project, both considering no development-supportive public policies. Finally, the regional transit accessibility to jobs measure is estimated to increase by between 1.6 and 14 million in the long run, which translates to an average of between 500 and 4,431 additional equivalent jobs accessible from each zone.
4,400 additional equivalent jobs accessible from each zone, after implementation of the changes in zoning regulations for the various Scenarios when compared to the Circle Line project with 10 minute headways but no development-supportive public policies. Scenario 3 generates the most increases in long run transit accessibility to jobs. These results suggest that for the Circle Line to have the maximum possible impact on long run transit accessibility to jobs, the CTA should aim to achieve the 5 minute frequency level, and that the city of Chicago's Department of Planning and Development should aim to implement the most aggressive set of development-supportive public policies around proposed Circle Line stations.

These results also show that the Circle Line is estimated to have only minor impacts on regional transit accessibility to jobs (2.3 to 2.9%) when only changes in travel times are considered. These impacts increase substantially (almost double to 5.6 to 6.8%) when long run development impacts due to short run changes in accessibility are also considered. Furthermore, when zoning changes are also considered, these impacts increase even more (almost triple to 6.3 to 8.5%). Therefore, these results show that the long run accessibility impacts of the Circle Line project are much higher when the long run development impacts of the Circle Line project are considered in addition to the changes in travel times that will occur due to the project.

These results again suggest that the long run accessibility impacts of the Circle Line project are potentially much higher than due to the Pink Line project alone, and that the Circle Line project will generate substantial benefits in terms of transit accessibility to jobs in the long run.
Figure 8-15 shows the pattern of predicted long run change in transit accessibility to jobs, in terms of the number of additional equivalent jobs accessible from a zone, after the Pink Line with no development-supportive public policies in comparison to the baseline at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the long run accessibility benefits conferred by implementation of the Pink Line project with no development-supportive public policies.

Figure 8-15: Predicted Long Run Change in Transit Accessibility to Jobs of Pink Line Project with no Development-Supportive Public Policies over Baseline

These maps show that, at most, a predicted 100,000 additional equivalent jobs will be accessible in the long run from a zone in the region after implementation of the Pink Line project with no development-supportive public policies when compared to the baseline. These maps also show that the most significant increases in long run transit accessibility to jobs due to the Pink Line project occur along the Blue and Pink Lines.
Figure 8-16 shows the pattern of predicted long run change in transit accessibility to jobs, in terms of the number of additional equivalent jobs accessible from a zone, after the Circle Line project with 10 minute headways in comparison to the Pink Line project, both with no development-supportive public policies, at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the long run accessibility benefits conferred by implementation of the Circle Line project above and beyond the Pink Line project.

Figure 8-16: Predicted Long Run Change in Transit Accessibility to Jobs of Circle Line Project (10 min) over Pink Line Project, both with no Development-Supportive Public Policies

These maps show that, at most, a predicted 43,000 additional equivalent jobs will be accessible in the long run from a zone in the region after implementation of the Circle Line project with 10 minute headways when compared to the Pink Line project, both with no development-supportive public policies. These maps also show that the most significant increases in long run transit accessibility to jobs due to the Circle Line project occur around stations along the northern, western and southern sections of the Circle Line 'loop'.
Figure 8-17 shows the pattern of predicted long run change in transit accessibility to jobs, in terms of the number of additional equivalent jobs accessible from a zone, after Scenario 2 in comparison to the Circle Line project with 10 minute headways with no development-supportive public policies, at the TAZ level for the entire Chicago region and for the city of Chicago. These changes reflect the long run accessibility benefits conferred by implementation of the development-supportive public policies above and beyond the Circle Line project.

Figure 8-17: Predicted Long Run Change in Transit Accessibility to Jobs of Scenario 2 over Circle Line Project (10 min) with no Development-Supportive Public Policies

These maps show that, at most, a predicted 8,500 additional equivalent households will be accessible in the long run from a zone in the region after implementation of Scenario 2 when compared to the Circle Line project with 10 minute headways with no development-supportive public policies. These maps also show that the most significant increases in long run transit accessibility to households due to development-supportive public policies occur in the center of the region and around the Circle Line 'loop'.
8.5.3. Long Run Changes in Automobile Accessibility

Table 8-13 shows the predicted long run changes in regional automobile accessibility to households and to jobs considering the development impacts for each Service Option and Scenario in comparison to the baseline.

Table 8-13: Predicted Long Run Changes in Regional Automobile Accessibility to Households and to Jobs

<table>
<thead>
<tr>
<th></th>
<th>Automobile Accessibility to Households</th>
<th>Automobile Accessibility to Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equivalent Households</td>
<td></td>
</tr>
<tr>
<td></td>
<td>from Baseline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>Avg. per zone</td>
</tr>
<tr>
<td>Long Run Changes (only Service Options)</td>
<td>Pink Line</td>
<td>13,068,585</td>
</tr>
<tr>
<td></td>
<td>Circle Line (15 min)</td>
<td>13,335,789</td>
</tr>
<tr>
<td></td>
<td>Circle Line (10 min)</td>
<td>14,207,447</td>
</tr>
<tr>
<td></td>
<td>Circle Line (5 min)</td>
<td>16,510,279</td>
</tr>
<tr>
<td>Long Run Changes (Scenarios)</td>
<td>Scenario 1</td>
<td>16,609,301</td>
</tr>
<tr>
<td></td>
<td>Scenario 2</td>
<td>21,436,430</td>
</tr>
<tr>
<td></td>
<td>Scenario 3</td>
<td>31,703,186</td>
</tr>
</tbody>
</table>

These results show that after implementation of the various Service Options and Scenarios, the regional automobile accessibility to households measure is estimated to increase by between 13.0 and 31.7 million in the long run, which translates to an average of between 4,100 and 10,000 additional equivalent households accessible from each zone; and the regional automobile accessibility to jobs measure is estimated to increase by between 30.4 and 55 million in the long run, which translates to an average of between 9,600 and 17,000 additional equivalent jobs accessible from each zone, when compared to the baseline.

These results suggest that transit infrastructure projects like the Circle Line project is estimated to generate substantial benefits in terms of automobile accessibility to households (increases of up to 1.7%), and automobile accessibility to jobs (increases of up to 2.5%) in the long run, in addition to transit accessibility benefits. Also, these automobile accessibility benefits can be increased by the implementation of development-supportive land use policies in areas around transit stations.

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51 Not considering congestion costs due to additional traffic.
8.5.4. Long Run Changes in Walk Accessibility

Table 8-14 shows the predicted long run changes in regional walk accessibility to households and to jobs considering the development impacts for each Service Option and Scenario in comparison to the baseline.

Table 8-14: Predicted Long Run Changes in Regional Walk Accessibility to Households and to Jobs

<table>
<thead>
<tr>
<th>Walk Accessibility to Households</th>
<th>Walk Accessibility to Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Households Change</td>
<td>Equivalent Jobs Change</td>
</tr>
<tr>
<td>from Baseline Overall</td>
<td>from Baseline Overall</td>
</tr>
<tr>
<td>Avg. per zone %</td>
<td>Avg. per zone %</td>
</tr>
<tr>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Long Run Changes (only Service Options)</td>
<td>Long Run Changes (only Service Options)</td>
</tr>
<tr>
<td>Pink Line</td>
<td>Pink Line</td>
</tr>
<tr>
<td>109,675</td>
<td>653,617</td>
</tr>
<tr>
<td>35</td>
<td>207</td>
</tr>
<tr>
<td>0.98%</td>
<td>2.91%</td>
</tr>
<tr>
<td>Circle Line (15 min)</td>
<td>Circle Line (15 min)</td>
</tr>
<tr>
<td>112,314</td>
<td>659,269</td>
</tr>
<tr>
<td>36</td>
<td>209</td>
</tr>
<tr>
<td>1.00%</td>
<td>2.94%</td>
</tr>
<tr>
<td>Circle Line (10 min)</td>
<td>Circle Line (10 min)</td>
</tr>
<tr>
<td>120,018</td>
<td>676,924</td>
</tr>
<tr>
<td>38</td>
<td>215</td>
</tr>
<tr>
<td>1.07%</td>
<td>3.02%</td>
</tr>
<tr>
<td>Circle Line (5 min)</td>
<td>Circle Line (5 min)</td>
</tr>
<tr>
<td>139,797</td>
<td>727,060</td>
</tr>
<tr>
<td>44</td>
<td>231</td>
</tr>
<tr>
<td>1.25%</td>
<td>3.24%</td>
</tr>
<tr>
<td>Long Run Changes (Scenarios)</td>
<td>Long Run Changes (Scenarios)</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>Scenario 1</td>
</tr>
<tr>
<td>159,714</td>
<td>748,509</td>
</tr>
<tr>
<td>51</td>
<td>237</td>
</tr>
<tr>
<td>1.43%</td>
<td>3.33%</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Scenario 2</td>
</tr>
<tr>
<td>216,581</td>
<td>795,939</td>
</tr>
<tr>
<td>69</td>
<td>252</td>
</tr>
<tr>
<td>1.94%</td>
<td>3.55%</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Scenario 3</td>
</tr>
<tr>
<td>343,360</td>
<td>991,308</td>
</tr>
<tr>
<td>109</td>
<td>314</td>
</tr>
<tr>
<td>3.07%</td>
<td>4.42%</td>
</tr>
</tbody>
</table>

These results show that after implementation of the various Service Options and Scenarios the regional walk accessibility to households measure is estimated to increase by between 109,000 and 343,000 in the long run, which translates to an average of between 35 and 110 additional equivalent households accessible from each zone; and the regional walk accessibility to jobs measure is estimated to increase by between 653,000 and 991,000 in the long run, which translates to an average of between 207 and 314 additional equivalent jobs accessible from each zone, when compared to the baseline.

These results suggest that, in addition to transit accessibility and automobile accessibility benefits, transit infrastructure projects like the Circle Line project is estimated to also generate substantial benefits in terms of walk accessibility to households (increases of up to 3.1%), and walk accessibility to jobs (increases of up to 4.4%) in the long run. These walk accessibility benefits can also be increased by the implementation of development-supportive land use policies in areas around transit stations.
8.6. Shortcomings

The preceding sections estimate the short run and long run accessibility impacts and long run development impacts of new transit infrastructure projects like the Circle Line and the Pink Line and of development-supportive public policies around these new projects, using the quasi-integrated land use transportation model. However, the methodology used and the estimates reached have a number of shortcomings.

- The development intensity models can only be used to estimate the increase in development at zones, but not where this new development will come from. Development increases at zones may occur due to the overall growth of the region or due to a redistribution of development through the region. The development intensity models do not distinguish between the two. The current estimates are based on all additional growth and no redistribution\(^{52}\), which is possible if the entire region is growing. If this is not the case, then the scenario results will need to be adjusted.

- Regional populations and employment forecasts, including the effects of natural growth, are not incorporated. These will help indicate whether the region is growing in population and/or employment.

- Journey-to-work trip data is used in the accessibility models and to derive the existing number of jobs at locations. This data ignores many other trip purposes like shopping, education, etc., and gives an incomplete account of jobs.

- Road congestion due to the additional automobile traffic generated by new development is not incorporated in the estimation of automobile accessibility impacts.

These shortcomings suggest that the quasi-integrated land use transportation model can be improved in a number of ways.

8.7. Conclusions

As shown by the case of the Circle Line, new transit infrastructure projects can have substantial short run accessibility impacts due to transit service level improvements. New transit infrastructure projects can also have significant long run development impacts due to the transit service level improvements. These long run development impacts can be increased by implementing development supportive public policies. Furthermore, new transit infrastructure projects can have substantial long run accessibility impacts due to service level improvements and long run development impacts. The long run accessibility impacts of new transit

\(^{52}\) Redistribution would mean that some TAZs decrease in household and job density.
infrastructure projects can be improved by considering long run development impacts in addition to transit service level improvements.

The scenario analyses give an indication of the magnitude of the potential regional development impacts of the Circle Line project, when only transit service level improvements are considered: a 0.7-0.9% increase in household development, which translates to between 15,000 and 19,000 additional households, and a 1.5-1.8% increase in job development, which translates to between 42,000 and 49,000 additional jobs. When development-supportive public policies are considered in addition to transit service level improvements, the potential regional development impacts of the Circle Line project further increase: a 0.9-1.8% increase in household development, which translates to between 19,000 and 36,000 additional households, and a 1.8-2.5% increase in job development, which translates to between 50,000 and 70,000 additional jobs.

The scenario analyses also give an indication of the magnitude of the potential regional transit accessibility impacts of the Circle Line project, when only transit service level improvements are considered: a 3.5-4.4% increase in transit accessibility to households, which translates to an average of between 3,900 and 4,900 additional equivalent households accessible from each zone, and a 5.7-6.7% increase in transit accessibility to jobs, which translates to an average of between 10,000 and 12,000 additional equivalent jobs accessible from each zone. When development-supportive public policies are considered in addition to transit service level improvements, the potential regional transit accessibility impacts of the Circle Line project further increase: a 4.1-6.1% increase in transit accessibility to households, which translates to an average of between 4,500 and 6,700 additional equivalent households accessible from each zone, and a 5.7-6.7% increase in transit accessibility to jobs, which translates to an average of between 10,000 and 12,000 additional equivalent jobs accessible from each zone.

The benefits of new transit infrastructure projects are not confined to the transit system. New transit infrastructure projects can also have substantial automobile and walk accessibility impacts and benefits in the long run. These accessibility benefits are a result of the additional development spurred by the project. Based on the scenarios developed, the Circle Line will improve automobile accessibility to households by, at most, 1.8%, and to jobs by, at most, 2.5%. Similarly, the Circle Line will improve walk accessibility to households by, at most, 3.1%, and to jobs by, at most, 4.4%.

These findings show that the Circle Line will have substantial accessibility and development impacts, which should be considered when evaluating the case of the Circle Line project.
9. Conclusions

This chapter builds upon the preceding chapters and presents the conclusions drawn from this research effort. These conclusions are presented in 3 parts: general conclusions; implications for the Chicago region and the Circle Line in Chicago; and areas of future research.

9.1. General Conclusions

Based on the research presented in the preceding chapters, the following general conclusions can be drawn

**Accessibility is Key to Understanding the Interaction between Transport and Land use**

The interaction between transport and land use is complex, in that transportation changes affect land use patterns, and land use changes affect travel patterns, and both are influenced by a number of other factors including socio-economic conditions, personal preferences, infrastructure projects, public policies like zoning regulations and urban design guidelines, and market conditions, etc. Accessibility conceptually links the land use and transportation systems and is both a measure of the benefits afforded by the land use transportation system (LUT), and a measure of the impact of infrastructure and policy changes on the LUT. Consequently, accessibility is an important measure of the benefits of new transport infrastructure projects.

**Current FTA Methodology does not Comprehensively Consider Accessibility and Development Impacts of Projects**

New transport infrastructure projects potentially generate a number of impacts (benefits and costs) including accessibility and development impacts. These projects must be evaluated using comprehensive evaluation frameworks which consider all project impacts, and where all tangible impacts are completely and accurately quantified. The FTA New Starts evaluation framework, which is used to appraise new transit infrastructure projects in the United States in order to make federal funding decisions, considers a measure of accessibility calculated from a mode choice model. This mode choice model does not account for other decisions (besides mode choice) made by households and firms like location, path, and destination choices, etc. Consequently, this model provides a narrow measure of transportation system improvements, and does not account for changes in land use patterns.
This approach cannot be used to compute development impacts. In fact, the FTA New Starts evaluation framework considers development impacts in mainly qualitative terms, and never requires that these impacts be quantified. Furthermore, the calculation of a project's rating does not incorporate economic development benefits. Consequently, the FTA New Starts evaluation framework may underestimate, and in some cases ignore, the potentially substantial accessibility, land development, and economic development impacts of some projects.

**Integrated Land Use Transportation Models are Helpful but not Always Available**

Integrated land use transportation models consider the cyclical process of land use and transportation interaction, and the effects of other influencing factors such as macro-economic conditions, demographic trends, development-supportive public policies, etc. These integrated models, in theory, allow comprehensive quantification of the accessibility and development impacts of new transport infrastructure projects. Such integrated models are better than travel demand forecasting models, which predict the effect of land use and transportation system changes on travel patterns and traffic flows, and land use forecasting methods and models, which predict the effect of macroeconomic conditions, public policies etc. on land use patterns. Separate models do not fully capture the complexities of land use and transport interactions, including the feedback loop between the two. Most regions in the United States use travel demand forecasting models and some land use forecasting methods or models, but few regions use integrated land use transportation models. This is a major limitation for regions as they attempt to quantify the future impacts of new transport infrastructure projects.

Integrated land use transportation models improve the current FTA New Starts evaluation framework with a computation of development impacts, and a better, more complete measure of accessibility impacts than is currently possible.

This thesis has developed a quasi-integrated land use transportation model for, and has applied it to, a specific new transit infrastructure project applying for federal funding: the Circle Line project in Chicago. This case represents an example of how to improve the current FTA evaluation framework.

**New Transit Infrastructure Projects have Substantial Accessibility and Development Impacts**

The results of the scenario analyses using the quasi-integrated land use transportation model suggest that new transit infrastructure projects potentially have substantial accessibility and development impacts. Therefore, the quantification and inclusion of these accessibility and development impacts within an evaluation framework
strengthens the argument for investing in new transit infrastructure. This argument is especially strong for new transit infrastructure projects in the urban core of cities as they will have substantially greater accessibility and development impacts, than projects in the suburban and ex-urban fringes of cities.

**Transport Investments and Land Use Policies should be Coordinated**

The estimated development intensity models suggest that transit accessibility and development-supportive public policies like zoning requirements and urban design guidelines are linked with high intensity residential and commercial development. Transit agencies can initiate transportation system improvements, and so affect transit accessibility. However, development-supportive public policies are generally the responsibility of city planning departments. This suggests that transit agencies and city planning departments must work together to coordinate infrastructure investments and land use policies in order to realize the potentially substantial accessibility and development benefits of new transit infrastructure projects.

**Non-Transit Users also Benefit from New Transit Infrastructure Projects**

The residential and commercial development spurred by new transit infrastructure projects, increases the number of jobs accessible from existing residential locations, and the number of households accessible from existing employment centers. This generates accessibility improvements, not just for users of the transit system, but also for users of other modes like automobiles and walking, as shown by the results of the scenario analyses. This suggests that when the entire LUT is considered, new transit infrastructure projects also provide benefits for non-transit users.
9.2. Implications for the Chicago Region and the Circle Line Project

The research presented in the preceding chapters has a number of implications for the Chicago region, and specifically for the Circle Line project.

Current FTA Methodology does not Comprehensively Consider the Circle Line’s Accessibility and Development Impacts

The Circle Line project, which is a circumferential rail transit line serving the urban core, will potentially generate substantial accessibility and development impacts. The FTA New Starts evaluation framework, which will be used to evaluate the Circle Line project, does not comprehensively consider accessibility and development impacts in the determination of a project’s final rating. Hence the need to improve the FTA’s current evaluation framework.

Current Land Use and Transportation Models in the Chicago Region are Inadequate

Land use and transportation models currently operational in the Chicago region include a travel demand forecasting model based on a 4-step approach developed by CMAP (CATS), a Regional Econometric Input-Output Model (REIM)\(^{53}\), a land use forecasting methodology developed by CMAP (NIPC), and a transit accessibility model (gravity model) developed by Busby (2004). The mode choice model in the 4-step model and the transit accessibility models can both be used to estimate the accessibility impacts of the Circle Line project. However, the mode choice model provides a narrow measure of accessibility; the Busby model does not consider impacts on accessibility by other modes besides transit like automobiles and walking; and both models ignore the effect on accessibility of changes in land use patterns. The REIM and the NIPC land use forecasting methodology do not explicitly consider land use transportation interactions, and so cannot be used to estimate the development impacts of the Circle Line project. Consequently, these models cannot be used to comprehensively quantify the accessibility and development impacts of the Circle Line project.

The Merger of NIPC and CATS to form CMAP provides an Opportunity to Improve Current Land Use and Transportation Models in the Chicago Region

The merger of NIPC and CATS has brought the previously separate functions of regional transportation planning (CATS), and regional land use planning, into one agency CMAP, which now has the responsibility for pursuing

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\(^{53}\) Developed by the Regional Economics Application Laboratory, which is a joint effort between the University of Illinois at Urbana-Champaign and the Chicago Federal Reserve Bank
integrated land use transportation planning in the Chicago region. Besides improving regional planning, this merger also provides an opportunity to improve current land use and transportation models – the CATS travel demand forecasting model, and the NIPC land use forecasting methodology - by developing an integrated land use transportation model for the Chicago region.

**The Quasi-Integrated Land Use Transport Model is an Improvement on Current Models**

Picking up from the previous two points, the Chicago region does not currently have an operational integrated land use transportation model which computes the development impacts (and as a result changes in land use patterns) of the Circle Line project. In addition, lack of such a model prevents computation of the long run accessibility impacts of the Circle Line project. A quasi-integrated land use transport model for the Chicago region has been developed as part of this research effort in order to overcome this shortcoming. This model has two major parts, an accessibility model(s) and a development intensity model(s). The quasi-integrated land use transportation model can improve the FTA New Starts evaluation framework as it is used to quantify the accessibility and development impacts of the Circle Line project.

**Transit Accessibility and Land Use Policies Affect Development Intensity**

The results of the Chicago development intensity model indicate that development intensity in terms of household density is positively influenced by transit accessibility to jobs, zoned residential dwelling units per acre, block density, and negatively influenced by zoned minimum parking requirements. Similarly, development intensity in terms of job density is positively influenced by transit accessibility to households, zoned FAR (floor area ratio), and the percentage of land zoned for business-commercial land uses. This suggests that transit accessibility, and land use policies like zoning requirements and urban design guidelines, are important factors affecting the intensity of development in Chicago.

**A Number of Actions can be taken to Increase Development Intensity around Circle Line Stations**

The results of the development intensity model suggest that if increasing development around transit is the aim, then the following actions can be taken: transit service level improvements e.g. increasing service frequencies on the Circle Line to improve transit accessibility; and implementation of development-supportive public policies. Possible development-supportive public policies include: increasing maximum zoned FAR and/or dwelling units per acre; decreasing overall and/or residential parking ratios; rezoning from manufacturing and other uses to residential and/or commercial uses; and applying design guidelines that promote street

9. Conclusions

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connectivity and small block sizes. These potential actions provide a menu of options for policy makers if they want to promote development around new Circle Line stations.

**The Circle Line Project will have an Immediate Effect on Transit Accessibility**

The results of the scenario analyses using the quasi-integrated land use transportation model suggest that the Circle Line project will positively impact transit accessibility to households and to jobs in the short run due to transit service level improvements. Furthermore, these impacts will be greater if higher service levels in terms of more frequent service are achieved. These results, summarized in Table 9-1, suggest that upon implementation of the Circle Line project, on average, between 2,200 and 2,900 additional equivalent households\(^5\), and between 4,100 and 5,000 additional equivalent jobs are predicted to be accessible from zones in the Chicago region by transit over existing levels (prior to the Pink Line) in the short run. For some zones in the region, the Circle Line is predicted to increase transit accessibility to households by as much as 12%, and transit accessibility to jobs by as much as 18%, over existing levels in the short run. These impacts are the immediate result of travel time reductions due to the Circle Line project.

**Table 9-1: Summary of Predicted Changes in Regional Transit Accessibility to Households and to Jobs**

<table>
<thead>
<tr>
<th>Range of Changes over the Baseline</th>
<th>Transit Accessibility to Households</th>
<th>Transit Accessibility to Jobs</th>
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<tr>
<td></td>
<td>Avg. Num. of Accessible Equi.</td>
<td>Percentage</td>
</tr>
<tr>
<td></td>
<td>HHs per zone</td>
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</tr>
<tr>
<td>Short Run Changes</td>
<td>2,276 to 2,926</td>
<td>2.05% to 2.63%</td>
</tr>
<tr>
<td>(considering changes in travel times only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Run Changes (Service Options)</td>
<td>3,871 to 4,913</td>
<td>3.48% to 4.42%</td>
</tr>
<tr>
<td>(considering changes in travel times, and changes in development due to increased short run accessibility only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Run Changes (Scenarios)</td>
<td>4,388 to 7,309</td>
<td>3.94% to 6.57%</td>
</tr>
<tr>
<td>(considering changes in travel times, and changes in development due to increased short run accessibility and development-supportive public policies)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^5\) The 'number of equivalent households accessible from a zone' is a measure of accessibility to households at that zone. This measure reflects the number of households accessible from a zone after accounting for the time required to travel to those households. A household which is a factor of 0.5 away (as calculated by the travel time impedance function) is counted as half an equivalent household, and so on. The same is true for equivalent jobs.
The Circle Line Project will have Substantial Development Impacts over time

The results of the scenario analyses also indicate that the Circle Line project will have substantial long run development impacts. These development impacts are the result of short run accessibility improvements fostered by the Circle Line project, and can be amplified by the implementation of development-supportive public policies around Circle Line stations. The results of the models, summarized in Table 9-2, suggest that, given high service levels on the Circle Line and the implementation of aggressive development-supportive public policies, current residential and employment levels are predicted to increase by as much as 36,000 additional households and 70,000 additional jobs in Chicago alone. These impacts are not immediate, but rather take place over time as residential and commercial development occurs in response to accessibility improvements and public policies.

Table 9-2: Summary of Predicted Changes in Regional Development in terms of Households and Jobs

<table>
<thead>
<tr>
<th>Range of Changes over the Baseline</th>
<th>Households</th>
<th>Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Num. of HHs</td>
<td>Percentage</td>
<td>Num. of Jobs</td>
</tr>
<tr>
<td>Long Run Changes (Service Options) (considering short run changes in accessibility only)</td>
<td>15,283 to 18,795, 0.73% to 0.90%</td>
<td>42,337 to 48,997, 1.51% to 1.75%</td>
</tr>
<tr>
<td>Long Run Changes (Scenarios) (considering short run changes in accessibility, and implementation of development-supportive public policies)</td>
<td>19,152 to 36,438, 3.94% to 6.57%</td>
<td>49,753 to 70,532, 1.78% to 2.52%</td>
</tr>
</tbody>
</table>

The Accessibility Impacts of the Circle Line Project will Increase over time

The Circle Line will have significant long run accessibility impacts as a result of increases in development over time, which are over and above the short run accessibility improvements. These long run accessibility improvements are dependent upon development impacts, and so are enhanced by the implementation of aggressive development-supportive public policies and high transit service levels. With the most aggressive transportation improvements and development-supportive public policies, on average, up to 7,300 additional

55 These are actual households and not equivalent households. This reflects the number of new households that can be accommodated in the vicinity of the Circle Line project.

56 These are actual jobs and not equivalent jobs. This reflects the number of new jobs that can be accommodated in the vicinity of the Circle Line project.

57 The models predict the number of new households and jobs that can be accommodated due to infrastructure and policy changes. Increases in household and in jobs are not mutually exclusive. However, the models do not incorporate land availability, which may impose limits on these increases.
equivalent households, and 15,000 additional equivalent jobs are predicted to be accessible from zones in the Chicago region by transit over existing levels in the long run (see Table 9-1). The most substantial predicted long run increase in transit accessibility to households at a zone in the region is 15% over existing levels, while the most substantial predicted long run increase in transit accessibility to jobs is 24%. These long run accessibility improvements accrue over time as residential and commercial development occurs.

**CTA and the City of Chicago’s Department of Planning and Development Must Work Together**

Transit service level improvements fall under the purview of the Chicago Transit Authority. However, implementation of development-supportive public policies around Circle Line stations requires coordination with the city of Chicago’s Department of Planning and Development. A coordinated approach will help the Chicago region fully realize the accessibility and development benefits that the Circle Line project promises.

**Quantification of Impacts using the Quasi-Integrated Land Use Transport Model Strengthens the Case for the Circle Line Project**

The long run accessibility impacts of the Circle Line project estimated using the quasi-integrated land use transport model are much greater (2 to 3 times) than the impacts estimated by current models (Busby model). This is primarily due to the fact that current models do not quantify changes in land use patterns, and do not incorporate these changes in the calculation of accessibility impacts. Also, the quasi-integrated land use transport model allows estimation of the long run development impacts of the Circle Line project, which are substantial, and which have never been estimated before.

Moreover, these estimates show the effectiveness of a variety of development-supportive public policies. These estimates, methods and models can be used to make a case to the FTA that the Circle Line project deserves a strong project justification score, or at the very least, deserves a strong score on the ‘transportation supportive land use policies and future patterns’ criterion of the FTA New Starts evaluation framework.

**The Circle Line Project Presents an Opportunity to Change the Current Development Paradigm in the Chicago Region**

For the past half century the Chicago region has increasingly been shaped by the automobile. Most of the recent development in the region has been automobile-oriented, and has taken place in suburban and ex-urban

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58 This again is an accessibility measure.
locations. Automobile-oriented development increases sprawl, and has a deleterious effect on air quality, and road congestion.

The Circle Line project, which promotes transit-oriented development in the urban core of the region, presents an opportunity to initiate a process to partly reverse this trend. Furthermore, the Circle Line project serves a number of places which are ripe for redevelopment, including many sparsely developed, primarily industrial, and sometimes abandoned areas along the north and south branches of the Chicago River. Many of these places do not currently have easy access to the transit system, which will change when/if the Circle Line is implemented.

**The Circle Line Project will Increase Transit Patronage**

The development spurred by the Circle Line project, is by definition, transit-oriented. The residents and firms accommodated by this development will have chosen to locate there and will have easy access to the rail transit system. These are potential new transit riders. Consequently, it is likely that the Circle Line project will serve to increase overall transit patronage.

**The Circle Line Project will also Benefit Non-Transit Users**

The Circle Line is predicted to improve accessibility not only by transit, but also by automobile and walking modes of travel. Automobile accessibility to households is predicted to increase by up to 1.8%, while automobile accessibility to jobs is predicted to increase by up to 2.5%. The corresponding predicted increases in walk accessibility are 3.1% and 4.4% respectively. These accessibility increases are a result of the residential and commercial development encouraged by the Circle Line project.

Furthermore, the current regional transportation system is near or at capacity, both on the road system and the rail transit system. The Circle Line project presents an opportunity to increase overall transport system capacity in the Chicago region. This suggests that the Circle Line project can partly mitigate increasing congestion on both the road and the transit systems.

These two factors suggest that the Circle Line project will improve the wider transportation system, and will provide benefits to transport users of other modes, besides transit.

**A Broad-based Coalition can be formed in support of the Circle Line Project**

This thesis demonstrates that the Circle Line project potentially increases residential and commercial development, provides benefits to non-transit users, and encourages transit-oriented development. This
suggests that a coalition can be built to support the Circle Line project, which is more far-reaching than just transit advocates, to include: the development community, drivers, pedestrians, smart-growth advocates, etc.

9.3. Areas of Future Research

This research effort can be extended and improved upon in a number of ways.

Using Better Data

The models developed in this thesis depend heavily on CTPP data. This data is only for journey-to-work trips, which does not consider many other trip purposes. Consequently, the model is limited in its scope, complexity and application. In addition, the quasi-integrated land use transportation model does not incorporate the effect of prices, vacancy rates, etc., primarily because the relevant data is not available. Finally, the development intensity model uses cross-sectional data to understand how various factors influence development intensity at a point in time. The development process is not modeled over time, primarily due to a lack of historical data.

Use of better data, in the form of travel surveys, origin-destination surveys (to get an o-d matrix), land prices, vacancy rates, and historical information, etc., will improve the model.

Extending the Development Intensity Model to the Entire Chicago Region

The development intensity model is currently limited to the city of Chicago, and as such can be used to estimate development impacts only within its boundaries. This model ignores the effect on development of short run accessibility improvements and any development-supportive public policies at locations outside the city of Chicago, and so likely underestimates the development impacts of the Circle Line project. Consequently, it also likely underestimates long run accessibility impacts. A step to improve this model would be to extend it to the entire Chicago region. This would require zoning and block data for other municipalities in the Chicago region.

Using Better Measures of Accessibility

The accessibility measure currently used in the quasi-integrated land use transportation model is a potential accessibility measure (gravity-based measure). This measure does not consider either competition effects or the temporal and individual components of accessibility. Competition effects can be incorporated using balancing factors from a doubly constrained spatial interaction model. However, such a measure is relatively difficult to calculate and interpret (Geurs & van Wee, 2004). An alternative would be to use a utility-based
measure of accessibility, which when linked to a doubly constrained spatial interaction model can also incorporate competition effects. Such a measure would also incorporate the temporal and individual components of accessibility. Moving to a utility-based measure will improve the accessibility model.

An ideal utility-based measure would be derived from a discrete choice model that models all the decisions of households (or individuals) and firms including location, path, mode, destination choice etc. This would require detailed information regarding the characteristics of households (or individuals) and firms, characteristics of their choices, and their decisions.

**Improving the Quasi-Integrated Land Use Transportation Model**

The quasi-integrated land use transportation model currently does not account for land prices, land availability, vacancy rates, capacity restrictions on street and highway infrastructure links, crowding levels on transit vehicles, and regional macroeconomic and demographic conditions. The model also does not forecast traffic flows. Some of these shortcomings can be addressed by linking the quasi-integrated land use transportation model to the existing Regional Econometric Input-Output Model (REIM) and the EMME/2-based travel demand forecasting model for the Chicago region. This is the logical next step for model improvement. Addressing other shortcomings, and especially issues regarding land prices, land availability etc. will require major adjustments to the modeling framework and approach.

**Incorporating Market-based Mechanisms**

Market-based mechanisms provide a theoretical foundation for modeling the decisions of households, firms, and developers; for incorporating the effect of prices; and for simulating the process of development over time. Incorporation of these market-based mechanisms will improve the quasi-integrated land use transportation model. This will require better data than is currently available, and will require the use of a discrete choice modeling framework.

**Monetizing Accessibility and Development Benefits**

The quasi-integrated land use transportation model can be used to quantify the accessibility and development impacts of infrastructure and policy changes. However, these benefits will need to be monetized in order to include them in a financial evaluation framework like a benefit-cost analysis. Monetization will require further research regarding the willingness-to-pay of households, firms and society in general for increased accessibility and increased development. In addition to benefits, the costs imposed by increasing accessibility and
development e.g. increasing automobile congestion as a result of new development, etc., will also have to be considered.

Monetization of benefits and costs, and the use of benefit-costs analyses will also allow the CTA and the Chicago region to make decisions, such as whether the costs incurred for achieving 5 minute frequencies on the Circle Line are justified by the magnitude of benefits accrued.

**Understanding the Implications for Infrastructure Financing**

An accessibility improvement at some locations in the region due to new transport infrastructure projects increases the value of land at those locations. While land value increases usually benefit the owners of the affected land, they also present a potential revenue source for new transport infrastructure projects. Further research is required into the magnitude of value increases, and the potential ways of capturing this increase in order to fund transport infrastructure projects. Such research can build upon the framework and models developed in this thesis.
References


Caliper Corporation. (2002). *Travel Demand Modeling with TransCAD*.


Ohio Department of Transportation. (2007). Travel Demand Modeling (What is it?). Retrieved May 6, 2007, from Ohio Department of Transportation website: http://www.dot.state.oh.us/urban/AboutUs/TravelDM.htm


References 215


Appendix A: Chicago Maps

Chicago Transit System

LEGEND
- CTA Bus Lines
- Existing CTA Rail Lines
- Loop
- Blue Line
- Red Line
- Green Line
- Orange Line
- Brown Line
- Purple Line
- Yellow Line
- New Pink Line
- Proposed Circle Line

- Existing CTA Rail Station
- Proposed Circle Line Station

Source: CTA GIS shapefiles

Appendices
LEGEND
Household Density
Households/acre
0.00 - 2.65
2.66 - 5.96
5.97 - 9.32
9.33 - 13.73
13.74 - 20.48
20.49 - 31.92
31.93 - 57.12
57.13 - 109.70

Source: CTPP Part 1
Job Density

LEGEND
Job Density
Jobs/acre
0.00 - 4.81
4.82 - 11.68
11.69 - 26.71
26.72 - 60.51
60.52 - 161.01
161.02 - 276.54
276.55 - 661.27
661.28 - 1319.26

Source: CTPP Part 2

Appendices 219
Transit Accessibility to Households

LEGEND
Transit Acc. to Households

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Source: Author
Transit Accessibility to Jobs

Legend
Transit Acc. to Jobs

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0.11 - 0.14 | 270767 - 381871
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0.18 - 0.21 | 486749 - 598038
0.22 - 0.26 | 598039 - 718224
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Source: Author
Automobile Accessibility to Households

LEGEND

Auto Acc. to Households

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Source: Author
Walk Accessibility to Households

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Source: Author
Walk Accessibility to Jobs

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Walk Acc. to Jobs

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</tbody>
</table>

Source: Author
Zoning Land Uses

Source: City of Chicago GIS shapefiles
Zoning Maximum Overall Density Requirement

Source: City of Chicago GIS shapefiles
Zoning Maximum Residential Density Requirement

LEGEND
Zoned Max. Resi. Density
Dwelling units/acre
0.00 - 10.89
10.90 - 19.55
19.56 - 32.30
32.31 - 48.96
48.97 - 82.15
82.16 - 136.36
136.37 - 249.34
249.35 - 597.09

Source: City of Chicago GIS shapefiles
Zoning Minimum Overall Parking Requirement

LEGEND
Zoned Min. Overall Parking
Parking spaces/1000 sq.ft.

0.00 - 0.18
0.19 - 0.42
0.43 - 0.54
0.55 - 0.79
0.80 - 1.15
1.16 - 1.90
1.91 - 3.42
3.43 - 20.39

Source: City of Chicago GIS shapefiles
Zoning Minimum Residential Parking Requirement

LEGEND
Zoned Min. Resi. Parking
Parking spaces/dwelling unit
- 0.00 - 0.13
- 0.14 - 0.41
- 0.42 - 0.61
- 0.62 - 0.75
- 0.76 - 0.90
- 0.91 - 1.25
- 1.26 - 1.81
- 1.82 - 18.50

Source: City of Chicago GIS shapefiles
Block Density

LEGEND
Block Density
Blocks/acre
- 0.00 - 0.04
- 0.05 - 0.08
- 0.09 - 0.13
- 0.14 - 0.16
- 0.17 - 0.19
- 0.20 - 0.22
- 0.23 - 0.30
- 0.31 - 0.50

Source: City of Chicago GIS shapefiles
Percentage of Land Covered by Blocks

LEGEND
% of Land covered by Blocks
Percentage
31.32% - 53.32%
53.33% - 62.67%
62.68% - 67.94%
67.95% - 71.87%
71.88% - 75.73%
75.74% - 81.07%
81.08% - 88.20%
88.21% - 100.00%

Source: City of Chicago GIS shapefiles
Median Household Income

Source: CTPP Part1
Poverty Levels

Source: CTPP Part1

Legend

% of HHs in Poverty
Percentage
- 4.00%
- 9.52%
- 15.47%
- 22.93%
- 31.90%
- 43.69%
- 63.11%
- 99.95%

Source: CTPP Part1
Percentage of Persons from Minority Groups (as defined by the Census)

LEGEND

% of Minority Persons Percentage
0% - 14.83%
14.84% - 28.75%
28.76% - 43.20%
43.21% - 59.02%
59.03% - 72.72%
72.73% - 84.33%
84.34% - 94.83%
94.84% - 100.00%

Source: CTPP Part1
Percentage of Children

LEGEND
% of Persons of Age<16 Percentage
0% - 5.34%
5.35% - 12.66%
12.67% - 18.95%
18.96% - 24.37%
24.38% - 30.05%
30.06% - 38.92%
38.93% - 53.17%
53.18% - 99.90%

Source: CTPP Part1
Percentage of Seniors

LEGEND
% ofPersons of Age>65
Percentage
0% - 2.42%
2.43% - 5.95%
5.96% - 8.99%
9.00% - 12.46%
12.47% - 16.91%
16.92% - 24.31%
24.32% - 48.00%
48.01% - 99.93%

Source: CTPP Part 1
Household Size

LEGEND

% of HHs with size >= 3
Percentage

- 0% - 12.00%
- 12.01% - 26.51%
- 26.52% - 37.38%
- 37.39% - 47.06%
- 47.07% - 55.95%
- 55.96% - 65.92%
- 65.93% - 87.98%
- 87.99% - 100.00%

Source: CTPP Part1
Percentage of Immigrants

LEGEND
% of non-US born Workers
Percentage
0.00% - 4.90%
4.91% - 12.05%
12.06% - 20.48%
20.49% - 30.41%
30.42% - 42.33%
42.34% - 57.16%
57.17% - 81.21%
81.22% - 100.00%

Source: CTPP Part1
Automobile Ownership

LEGEND

% of HHs with no automobile

Percentage

- 0% - 5.81%
- 5.82% - 12.85%
- 12.86% - 19.34%
- 19.35% - 27.27%
- 27.28% - 36.82%
- 36.83% - 48.89%
- 48.90% - 68.23%
- 68.24% - 99.93%

Source: CTPP Part 1
Transit Mode Share at Place-of-Home

LEGEND
Transit Mode Share at Home
Percentage
0% - 4.76%
4.77% - 12.19%
12.20% - 18.75%
18.76% - 25.74%
25.75% - 33.81%
33.82% - 45.01%
45.02% - 66.66%
66.67% - 99.96%

Source: CTPP Part 1
Transit Mode Share at Place-of-Work

LEGEND
Transit Mode Share at Work Percentage
- 0% - 3.25%
- 3.26% - 8.14%
- 8.15% - 12.41%
- 12.42% - 17.07%
- 17.08% - 22.93%
- 22.94% - 31.66%
- 31.67% - 46.61%
- 46.62% - 66.35%

Source: CTPP Part 2