

Accessibility-Based Transit Planning

by

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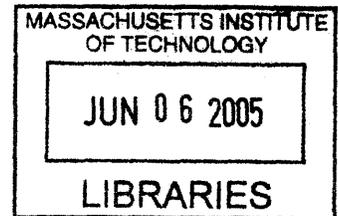
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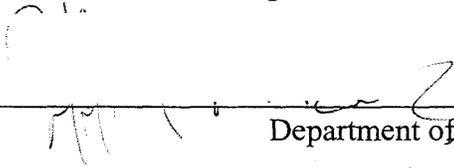
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Abstract

A method for evaluating transit planning proposals using accessibility metrics is advanced in this research. A transit-accessibility model is developed intended for use by in-house transit agency planning staff as a preliminary project design and evaluation tool. It relies on readily available socioeconomic and travel data and a GIS-supported representation of the transit network. It is intended to inform planning decisions using transparent and intuitive models in a less time consuming and expensive manner than more elaborate and comprehensive planning methods. Emphasis is placed on the visualization of changes in transit level of service resulting from major facility investments. In this capacity, the accessibility metric can assist in identifying the potential ridership change and development impacts of a project.

The accessibility model relies on the travel-time outputs of a transit network model, socio-economic data and information on current travel patterns. Development of a network model of transit service in the Chicago region with a focus on CTA bus and rapid transit and METRA commuter rail service is documented. The network model is intended to support on-going research, beyond the scope of this thesis, as part of the collaborative Chicago Transit Authority-MIT research effort.

The impact of the proposed Circle Line rail project on employment access and commercial development potential is analyzed to illustrate the potential of the accessibility metric. The model is also applied as a sketch planning tool for intermediate stations on proposed Airport Express trains between downtown Chicago and its two major airports. Findings suggest that much of the improvements in employment access from the Circle Line occur in early project phases, there is strong potential for increased commercial development in the corridor, and some improvement in regional transit connectivity. The Airport Express train could substantially improve airport accessibility with the addition of an intermediate station on the O'Hare branch.

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I was extremely fortunate to have studied under Professor Nigel Wilson and Fred Salvucci. They are models of what can be achieved in academics and public service, respectively, and their teaching will serve me throughout my career.

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1. INTRODUCTION

This research is motivated by the author's belief in the importance of public transit in creating vibrant, livable, and sustainable cities. The benefits from investing public resources in public transit are more fundamentally justified by its ability to address the negative externalities of automobile travel by encouraging travelers to shift from auto to transit and by providing mobility to those who do not have access to a car. Wilson identifies three primary benefits associated with a strong public transit system in addressing the externalities of auto use:

- **Equity.** Transit provides access and mobility for those who cannot or do not choose to drive. Transit provides potentially life-sustaining access to employment and services for economically disadvantaged, young, elderly and disabled populations whose mobility might otherwise be very limited;
- **Congestion mitigation.** Transit provides more efficient, higher-capacity service than single-occupant automobiles, which can reduce congestion, particularly on corridors leading into the dense urban core and other major activity centers; and
- **Land use influence.** Public transport is a necessary, but not sufficient, means of change existing land use patterns. It is most effective at supporting a vibrant, centralized downtown commercial and business district. On a local scale, high-quality transit also contributes to increased property values and mitigates against high parking requirements.

Environmental benefits and reduced energy consumption are also identified as potential reasons to support public transit, but to-date, vehicle, engine and fuel technologies aimed at reducing these auto-use externalities directly have been more effective than encouraging a shift to public transit at leveraging these benefits (Wilson, 2004).

A quality transit system is a worthy goal of any community, but the resources devoted to transit must compete with other worthy civic investments and are therefore constrained. Recognizing this, transit providers have an obligation to invest their limited resources wisely. Given the complexities of urban transportation patterns, wise choices are not always obvious. This research is intended to aid decision makers in identifying potentially wise investments and prioritizing them for further planning study.

1.1 WHY ACCESSIBILITY?

Many proposals exist to improve transit service. Simultaneously, agency budgets and planning resources are limited. There exist clear needs in the conceptual phase of transit capital improvement projects to assess the network impacts of various proposals. This thesis seeks to inform the design and evaluation of projects providing insights on potential system-wide ridership gains. Furthermore, an easily understood and applied method of ranking capital projects could serve to focus the strategic planning efforts of the agency. Current planning practices often rely on projects "bubbling up" from a number of sources including elected officials, agency officials, and the general public. In this process, where projects advance according to political priorities, limited attention is paid to which projects have the most merit and should be a priority for further study, resulting in potentially wasted planning resources. A

procedure to rapidly evaluate and rank proposals may facilitate a more strategic “top-down” planning approach. This thesis suggests transit accessibility is an appropriate measure of project evaluation and could facilitate strategic planning within a transit agency.

Accessibility, despite being widely referred to in transportation planning, is an abstract concept. Researchers have defined this term in a variety of ways and have developed numerous mathematical formulations to measure its value. Accessibility is an essential concept in evaluating the relationship between land use and transportation. The planning of a transportation system depends on the forecasts of land use and land use is impacted by the transportation system. Therefore, indexes of accessibility are of particular interest in assessing the existing transportation system and predicting its future performance.

This thesis proposes to build on the growing interest in using accessibility measures to aid in transportation policy and investment decision-making specifically applied to transit. Traditional evaluation methods make use of mobility measures like travel-time savings or economic measures like net-cost per rider. Accessibility measures combine the notions of system performance of the network as well as the spatial separation of the activities and number of opportunities available. Furthermore, accessibility is more consistent with the notion that travel is a demand derived from the need to pursue activities, and therefore represents an appropriate objective function for transit agencies to use in evaluation.

As this research is intended to be practical for use in the politically charged, fiscally constrained environment of a transit agency emphasis is given to application of the model rather than furthering the academic state of the art. Specifically, the research assesses the performance of two proposed major investments at the Chicago Transit Authority. In so doing, it is the author’s hope that this research can inform the ongoing planning for these projects at the CTA, facilitate further CTA strategic planning efforts, and illustrate the potential benefits and challenges to using this planning tool in other agencies.

In the broadest sense, his thesis presents a mathematical representation of the customer oriented mission statement of the CTA and uses this representation to evaluate how changes to the transit network through major investments might further the agency’s mission. The author recognizes that ultimately projects that are implemented will require a more rigorous analysis. The research methodology presented in this thesis does not offer a ridership forecast or calculation of transportation system user benefits as required by the Federal Transit Administration. It is intended to illustrate the potential marginal impacts on the existing transit network by visually displaying and quantitatively assessing changes in transit accessibility. This accessibility change can only suggest where ridership growth or changes in development may occur.

1.2 RESEARCH DESIGN

This thesis seeks to answer three fundamental research questions: What is transit accessibility? Does transit accessibility matter? and What project or strategies can be pursued to maximize transit accessibility?

The transportation literature is consulted to explore potential definitions and mathematical representations of accessibility. These accessibility metrics have been used in a variety of applications including econometric analyses, travel demand forecasting models, and policy research. The various means of measuring accessibility are assessed in light of their applicability to the goals of this research and one measure is selected for further analysis.

The performance of the chosen measure is assessed based on comparisons with other measures of transit effectiveness using census data and existing understanding of travel behavior. The assessment of the quality of the measure relies heavily on display and interpretation of its graphical output.

Finally, the strategies for maximizing transit accessibility – that is, for furthering the mission statement of the transit agency – are explored through the application of the model to proposed projects. Considerable effort is devoted to interpreting the performance of these projects and assessing their potential.

1.3 THESIS STRUCTURE

This thesis has six chapters including this first introductory chapter. The second chapter is devoted to a review of the literature on transit benefits generally, measuring accessibility, and visualizing spatial data. This chapter provides background on current transit planning methods, use of geographic information systems and transit network models. An introduction to the Chicago Transit Authority and travel patterns in the Chicago metropolitan region is also provided as background.

The research methodology is presented in chapters three and four. Chapter three is devoted to the development of the accessibility model including the framework used for determining the appropriate measure and implementation of the selected gravity model.

Considerable effort was expended on the development of a transit network model of the Chicago region which includes CTA bus, rapid transit and Metra commuter rail. This collaborative effort of the MIT/CTA research group is documented in chapter four. This network representation continues to be developed incrementally to serve on-going research in addition to this thesis. The accessibility model documented in the third chapter depends on the travel-costs calculated from the transit network model.

Chapter five applies the accessibility model to the CTA and analyzes potential project impacts. The Circle Line and Airport Express projects are introduced. The changes in employment and residential access resulting from the Circle Line are used to evaluate the project phases. The Airport Express train is offered as an example of using the accessibility metric to help design a project still in early planning stages.

Conclusions and future research are presented in the final chapter. The on-going applications of the network model documented in chapter three are showcased, as well as potential applications of the accessibility model to a variety of transit issues facing the CTA and other transit properties. A wide variety of future research questions of importance to the CTA are identified.

2. LITERATURE AND BACKGROUND

2.1 TRANSIT BENEFITS

Public transportation investments require large expenditure of public funds and often require ongoing subsidies once operable. These transit investments are made because of their potential benefits to society, and properly identifying and estimating these benefits has been a central concern in rail transit development.

Zhang, Shen, & Sussman (1998) review the potential benefits associated with rail transit development and suggest they can be grouped into four categories. The first category consists “of the direct benefits: transit itself is an enterprise that employs people in its operation and construction. These direct effects of rail transit development are relatively easy to capture and usually quantified during the environment impact studies, but they are not the main reasons for transit investment” (Zhang, Shen, & Sussman, 1998).

The second category is the environmental benefits. “Transit provides an alternative means of travel. A modal shift from automobile to transit will result in a decrease of total vehicle kilometers traveled the shift will reduce road congestion and air pollution, which is beneficial to the environment and to society” (Zhang, Shen, & Sussman, 1998). These benefits can be quantified using some proxies like annual hours of travel time saved.

The potential contribution of transit, particularly rail transit, to urban development has always been perceived as a major benefit. Transit supports regional and local economic growth. It improves access to the land along transit corridors and in transit station areas. Therefore, land values in station areas increase and urban development accelerates. Extensive empirical studies on the land use–urban economic benefits of rail transit exist and are not examined further in this thesis. A summary of these studies can be found in (Covarrubias, 2004). The results provide evidence of the supporting role of rail transit in local and regional economies, as well as its limitations.

Last, transit developments increase social welfare. “Transit provides services to transportation-disadvantaged groups and fosters transport equity. It reduces the social discrepancy between the poor and the rich through mobility provision and improvement” (Zhang, Shen, & Sussman, 1998).

Rail transit investments are also claimed to improve the overall quality of life in urban areas and contribute to creation of a “world class city”. These effects, however, are rarely rigorously examined and measured in quantitative terms.

The benefits from major transit investments are varied and some cannot be measured objectively, making it challenging to define a single metric upon which to evaluate various proposals. Faced with finite resources for transit investment, it is nonetheless, important to prioritize projects. This thesis identifies a metric by which projects can be prioritized. It is not all-encompassing, but it seeks to capture the primary benefits of a transit investment.

2.2 CURRENT TRANSIT PLANNING PRACTICE

FTA Section 5309 New Starts Program Evaluation Process

Much of the planning activity for major capital transit investments – the investments which are the subject of this thesis – is conducted in accordance with the Federal Transit Administration's planning guidance for applicants to the New Starts program. The simple reason for this is that most major projects are seeking federal funding for the investment. Much of the money invested in new transit facilities is available from what is known as the Section 5309 New Starts Program. The program provides discretionary funds for fixed guideway facilities generally in the categories of rapid rail, light rail, commuter rail, automated guideway transit, people movers, bus rapid transit, or high occupancy vehicle ways (HOVs).

New Starts policy is designed to provide criteria for FTA recommendations to Congress for discretionary transit funds. Projects under \$25 million are exempt from these evaluation criteria although project sponsors are encouraged to follow the guidelines. There are substantially more applicants for New Starts funding than there is funding available so competition for FTA recommendation is fierce although ultimately, funding must be secured in congress as the FTA does not actually control the distribution of New Starts funds.

Much to the frustration of planners seeking New Starts funds across the nation, there is a lack of comprehensive and up-to-date guidance from the FTA. The following description of the project evaluation process was provided by Laurie Hussey of Cambridge Systematics, a consultant on many applications to the FTA.

Evaluation criteria for project justification each receive a 1-5 ranking. Highly recommended projects have an average ranking of 4 on the following criteria.

- Mobility Improvements
- Environmental Benefits
- Operating Efficiencies
- Cost Effectiveness
- Existing land use, transit-supportive land use policies, and future land use patterns

Applicants also receive a project finance rating which evaluates local financial commitment including the non-federal share, capital finance plan and the operating finance plan.

Mobility improvements are measured using the concept of Transportation System User Benefits (TSUB) using the federally mandated SUMMIT software which processes the output of a four-step travel demand model. The software, which relies on outputs of a regional travel demand model "produces multimodal measure of traveler utility for all users of the transportation system" expressed in time equivalent units (Hussey, 2003).

Additional quantitative measures include:

- Number of low-income households served
- Number of jobs near stations

- Change in criteria pollutant and precursor emissions and greenhouse gas emissions using the Environmental Protection Agency's MOBIE emissions model
- Change in regional energy consumption in the forecast year (in BTUs, using regional VMT)
- Current regional air quality designation by EPA
- Change in system-wide operating cost per passenger mile
- Incremental cost divided by TSUB
- Incremental cost per incremental rider

All other factors (land use, environmental justice, welfare-to-work, innovative financing, procurement, and construction, economic development) are assessed qualitatively.

Applications for New Starts funding are the culmination of an extensive planning effort beginning with an Alternatives Analysis which screens a universe of alternatives for a solution to a locally identified transportation problem in the project corridor. The Alternatives Analysis leads to the selection of a Locally Preferred Alternative. If the Alternatives Analysis meets FTA approval the project is given permission to advance into preliminary engineering and a Draft Environmental Impact Statement is crafted in accordance with the National Environmental Policy Act. Another FTA review determines if a project receives a Full Funding Grant Agreement which specifies the Federal financial commitment to the project. Securing a Full Funding Grant Agreement allows an applicant to move to final design of a project. At this point, a project is ready for construction pending congressional appropriation of funds.

The FTA process is time consuming and expensive. In the case of major investments, however, the federal funds available through the program are critical in funding the project and the process is worth the effort. The purpose of introducing the process here is to highlight the difficulty and expense. This thesis suggests a method of system planning which could occur prior to an Alternatives Analysis to assist a transit authority in identifying projects that could perform well. The decision to enter a New Starts application planning process is not one that can be taken lightly given of the years of effort and millions of dollars required to secure federal funding for a project.

2.3 GEOGRAPHIC INFORMATION SYSTEMS AND TRANSIT NETWORK REPRESENTATIONS

Geographic information system (GIS) technology is widely used to process statistical and spatial data (e.g., transportation networks) and to facilitate research through visualizing experimental and final results. Broadly defined, a geographic information system is "a class of software tools dedicated to the storage and display of spatially referenced information" (Grayson, 1993). Much GIS technology is not unique to spatial data and consists of conventional data management tasks in a relational database system. Relational databases organize data in tables and permit a user to generate new tables based on a querying language. The reader is likely to be familiar with the popular relational database software found in the Microsoft Office Suite known as Access although there are a large number of database packages which track much of the world's information.

GIS is an extension of a relational database to encompass spatially referenced data, which allows for spatial queries. The ability to manage large amounts of spatial data holds obvious appeal to transit agency staff ranging from planners who are interested in the spatial distribution of jobs and population to signage crews who maintain thousands of individual bus-stop signs. As a result, most large transit properties have GIS capabilities. At the Chicago Transit Authority, for example, the Data Services division has multiple staff members whose job is to maintain the GIS database keeping track of changes to routes, stop locations, bus turnarounds, construction and maintenance projects and many other changes. The system is linked to the City of Chicago's GIS providing information on streets, schools, housing, zoning, and more. The result is a powerful information source used by analysts and managers throughout the agency.

Writing more than a decade ago, Grayson cites Clarke who laments the failure of GIS to expand analytic capabilities claiming GIS is focused on "technological issues relating to data storage, retrieval, and display" arguing that GIS needs to move "from being an end in itself to becoming an enabling device within a broader decision making environment. This will involve practitioners developing a much broader knowledge of the problems and processes that decision makers are involved in, as well as the incorporation of more powerful, value adding, analytical techniques." (Clarke, 1990). Sadly, much of Clarke's criticism remains true a decade later. Much of the functionality of GIS in transit is one of archiving static information.

New transportation software is, however, beginning to answer Clarke's call for adding analytic value to GIS. One of the objectives of this thesis is to exploit this new software and propose a potential decision support tool which exploits already available GIS resources. The primary innovation of the new transportation planning software is the addition of path capabilities to GIS. By merging representations of transit and road networks with GIS databases, new tools are available to address questions of fleet routing, scheduling, and – of particular interest in this thesis – passenger response to system changes.

The synthesis of GIS with transportation planning tools is evident in all the major planning software packages. TransCAD, the software used for analysis in this thesis, was the first such integrated package and uses the trademark "Transportation GIS Software" to describe itself. Competing software Emme/2 is developing a relationship with the GIS software package Enif. Cube has a very close relationship with ArcView, part of the almost ubiquitous ArcGIS software family. The next software release from Cube will be fully integrated with ArcView eliminating the need to export the outputs of the transportation modeling software into another package for visualization and interpretation. Clearly, the future of transportation planning is moving away from static archival GIS to dynamic analysis of transportation networks.

2.4 MEASURING ACCESSIBILITY

Accessibility is an abstract concept. It is, in effect, the service that transportation and land use provides – representing the ease with which people can pursue activities and businesses can connect with consumers, employees, goods and services.

Existing accessibility metrics fall into three main categories: isochrone, gravity, and logsum.

Isochrone

The isochrone (or cumulative opportunity measure) involves the construction of concentric circles of various cost budgets. The opportunities within each band are then counted and used as a measure of accessibility. This is the least sophisticated of the currently used accessibility measures although it is arguably the most intuitive. The opportunities within the cutoff cost are weighted equally, and the measure is not affected by differences of travel cost within the band.

$$A_i = \sum_j D_j W_j$$

Where:

- i = origin location (often the residence location)
- j = destination location
- A_i = accessibility at location i
- W_j = equals 1 if $C_{ij} < C_{ij}^*$, and 0 otherwise
- D_j = opportunities at location j
- C_{ij} = travel cost from i to j
- C_{ij}^* = the defined band within which the activity opportunities are counted

The units of the accessibility measure depend on the selection of D_j , but are often expressed as number of jobs within a given time or generalized cost.

Wachs & Kumagai (1973) and Vickerman (1974) provide early examples of this metric in the literature.

Gravity

The gravity measure (so called because it is the denominator of the gravity models used for trip distribution in the classic four-step modeling process) is similar to the isochrone, with the addition that opportunities are weighted by the travel cost of reaching them.

The gravity model is represented as follows:

$$A_i = \sum_j D_j f(C_{ij})$$

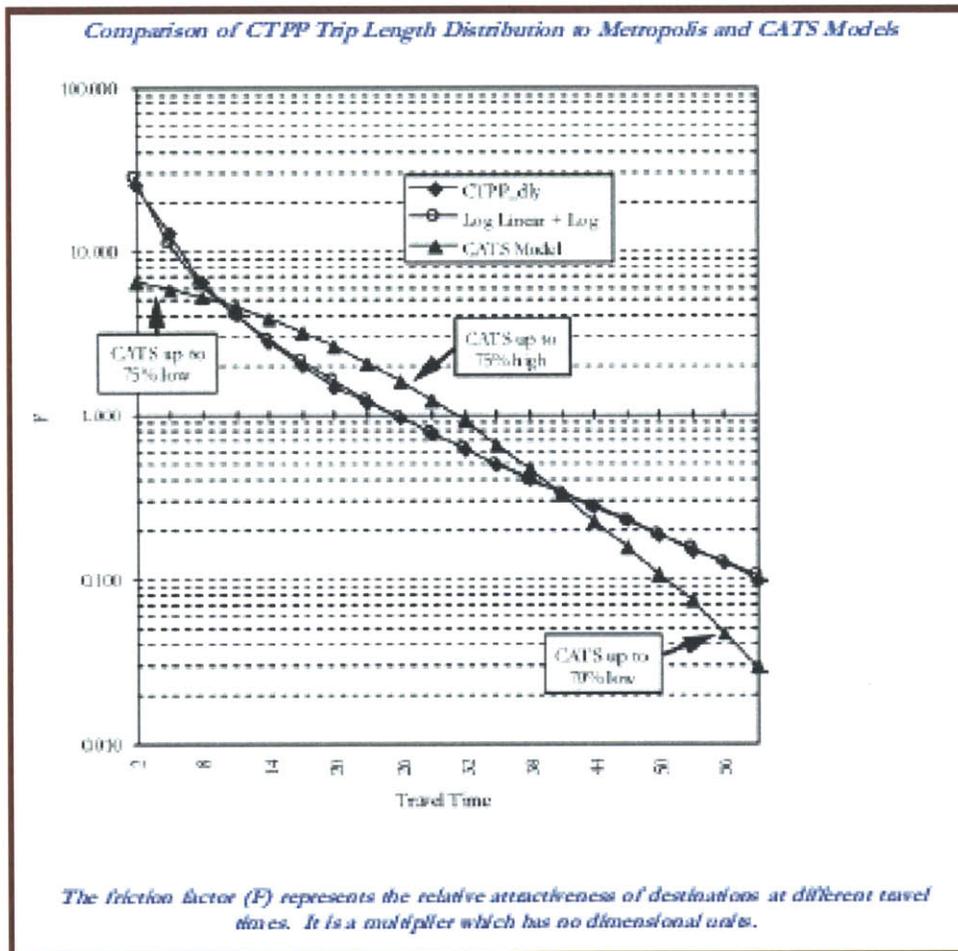
Where:

- i = origin location (often the residence location)
- j = destination location
- A_i = accessibility at location i
- $f(C_{ij})$ = declining function of travel cost, C_{ij}

D_j = opportunities at location j
 C_{ij} = travel cost from i to j

The impedance function is a declining function of travel cost estimated from observed travel behavior. This measure is grounded in the notion that the benefit of a potential activity declines as it becomes more distant. The accessibility for an opportunity will increase if either it becomes more attractive or the travel cost decreases.

Figure 2-1. Trip Length Distribution Comparison between Metropolis 2020 and CATS TDF Models



Source: The Metropolis Plan: Choices for the Chicago Region, Technical Documentation, 2002

For example, Figure 2-1 shows the declining function of travel cost, $f(C_{ij})$ as estimated by CATS and by the Metropolis 2020 advocacy group based on the Census Transportation Planning Package (CTPP). The estimated function from Metropolis 2020 labeled as “Log Linear + Log” appears to closely match observed travel patterns in metropolitan Chicago. The shape of this function represents the relative attractiveness of destinations at different travel times.

In practice, the gravity measure is calculated using aggregate data. D_j can refer to a range of attributes - of specific interest is population and employment. While clearly an oversimplification of the menu of opportunities available at some location, it can be argued that a transit agency will benefit its constituents if it follows the policy of connecting population and employment centers. The continuing delay in release of Parts 1, 2, and 3 of the CTPP at a fine level of disaggregation by the Census Bureau has unfortunately, delayed full implementation of this measure.

The gravity model is a popular means of measuring accessibility due to its relatively low data requirements and ease of use. At MIT, the gravity model has been used in two instances to evaluate the potential impact of San Juan's new rail system - Tren Urbano. The two studies focused on job accessibility by transit, specifically:

- Comparing accessibility to jobs by transit versus accessibility to jobs by auto, and cross-tabulating this information with zonal income data. (Zang, Shen and Sussman, 1999)
- Accessibility of welfare recipients to entry level jobs via transit, and the impact of Tren Urbano on this accessibility (Lane, 1999)

Hansen (1959) and Huff (1963) provide an early example of the gravity metric in the literature.

Expected Maximum Utility

The last commonly used accessibility measure is the *Expected Maximum Utility* (EMU), or Logsum measure, which is an output from the logit discrete choice model. Logit models predict the choice an individual makes when faced with a set of alternatives assuming the individual associates a utility with each alternative and chooses the alternative with the maximum utility. While utility is not directly measurable (it is always relative to other available alternatives) the expected maximum utility of a choice can be derived from the logit model. If the expected maximum utility derived from a set of opportunities represents the attractiveness of the set then the EMU can be interpreted as the benefit derived from the transportation system and the available opportunities.

Activity-Based Accessibility is defined as the expected maximum utility over a choice situation faced by an individual, and formulated as:

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

where V_{in} is the systematic component of utility U_{in} for individual n considering alternative i , and choosing one alternative from the choice set C_n . μ is a scale parameter of the error associated with each alternative. A_n is a disaggregate measure, associated with individual n , and is not comparable across individuals. To compare accessibility across individuals the measure is converted into the units of a variable in the utility function such as time or cost.

The logsum represents the state-of-the-art in measuring accessibility. It is powerful because it recognizes differences in attractiveness of opportunities to various segments of the population. Accessibility measured in this way can vary between people in the same location with different socio-economic characteristics, greatly improving the measure's explanatory power. However, its reliance on disaggregate travel behavior survey data makes data availability a serious concern and limits the application of this measure to the specific case of the CTA.

Ben-Akiva & Lerman, Dong, et al (2002) provide applications of this model in the Portland Metropolitan region assessing the impact of congestion tolls, transit fare hikes, and the Portland MAX light rail system on the accessibility of a variety of population sub-groups.

2.5 VISUALIZING RESULTS

An emphasis of this research is the effective graphical presentation of the accessibility provided by the transit system, both to the analyst and ultimately the public. Earlier projects were examined and consideration is given to the theoretical issues underlying good visualization. Tufte (1990; 1997; 2001) provides an excellent critical analysis using successful and failed examples of representing multidimensional data. Grayson (1993) offers a review of the primary computer-aided visualization techniques and divides them into the categories of theme, scaled symbol and charts

The earliest transportation-oriented GIS made use of the thematic map, which remains popular to this day. In this map, regions are shaded with colors, selected to convey some quantitative concept or "theme." The values of the measure are divided into ranges with a color assigned to each. Grayson notes, "The primary disadvantage to thematic maps is that they emphasize regions according to their area, not just theme. This effect is sometimes desirable and is one of the primary 'geographic' aspects of the display. Nevertheless, the effect may not be what was intended." (Grayson, 1993). Tufte (2001) also cautions that use of areas to represent one-dimensional data may lead to misleading maps.

Data related to arcs can be represented by adjusting the thickness, shading and colors of the lines. Network models make extensive use of this technique to distinguish the various elements of the transportation network (walk links, expressways, rail lines, etc.). Often, the only way to identify coding errors in networks with thousands of links is to visualize the network; coding errors appear much more readily on a map than in a list of numbers. A variant on this scheme is to draw boxes of varying width along a link to represent ridership or traffic flow. Again, care must be taken in this display particularly when displaying traffic flow. The display is scaled to the length of the link and does not represent, for example, the length of a queue resulting from congestion but it can easily be misinterpreted.

Pin maps, or scaled symbols make use of markers of different shapes, sizes or colors to highlight the location of features of different types on the same map. This technique is illustrated in Chapters 3 and 4. The pin map plot overcomes the primary fault of the thematic map as the scale of the marker bears no relation to the underlying region's area. However, at large scales, the symbols can run into one another rendering the meaning less clear. A final variation on the pin map is the "pie chart" graphic in which small pie charts are drawn at

appropriate locations. The size of each chart may correspond to some variable, as well as the magnitude of each of the pie slices. This technique is illustrated in the Chicago Area Mode Split Map in which the size of the pie corresponds to the number of trips in each zone and the pie slices indicate the relative modal split.

2.6 CHICAGO TRANSIT AUTHORITY

The Chicago Transit Authority system and its rail expansion proposals are used for application of the transit accessibility planning and evaluation model. While much of the analysis focuses on the implications of heavy rail expansion proposals on the Chicago region, care is taken to insure the model developed is applicable to any large, multimodal transit system considering a major transit investment.

Operations and Service Area

The CTA operates the nation's second largest public transportation system and covers the City of Chicago and 40 surrounding suburbs. On an average weekday, 1.5 million rides are taken on the CTA.

CTA has approximately 2,000 buses that operate over 148 routes and 2,273 route miles. Buses provide about 1 million passenger trips a day and serve more than 12,000 posted bus stops. CTA's 1,190 rapid transit cars operate over seven routes and 222 miles of track. CTA trains serve about 500,000 customer trips each day at 144 stations (CTA Website, 2004).

Heavy-rail rapid transit is provided by a radial network centered on the downtown. Four heavy rail lines converge on an elevated loop so identified with the downtown that the CBD is almost universally referred to as "The Loop." Rail service is also provided in two subways which run north-south through the central area. The bus system conforms to the City's regular grid of east-west and north-south arterials with an average spacing of ½ mile between routes in most of the city and closer spacing close to the downtown. Many bus routes west of the Loop are very long, extending, in some cases, nearly twenty miles. A network of limited stop bus service (branded as "X" service) is being implemented on many of these long corridors. The high-demand lake-shore corridors north and south of the Loop are served by zonal express buses with trip times and ridership that rivals the rail service.

This transit network configuration results in a very high rate of transferring passengers. Recent CTA market research survey reported 51% of all customers transfer within the CTA with 54% of rail trips involving a transfer and 20% of bus trips (Northwest Research Group, 2003). Transfers times are kept short by intensive service levels with off-peak headways rarely exceeding twenty minutes. A summary of trip transferring behavior is provided in Table 2-1.

Table 2-1. CTA Customer Primary Trip Transfer Behavior

Trip Type	Percentage of Customers
Bus/Rail Transfer to Rail/Bus	34%
Rail Transfer to Rail	6%
Bus Transfer to Bus	11%
Rail No Transfer	19%
Bus No Transfer	25%
Transfer from Another System	4%

Source: Chicago Transit Authority Customer Satisfaction Survey, Northwest Research Group, June 2004.¹ Transfer behavior is reported for a survey respondent's "typical trip" which is defined as the CTA trip which they take most often. Actual transfer volumes may differ significantly.

Public Transportation in the Greater Chicago Region

Region-wide transit service includes radial Metra Commuter Rail which provides service on twelve corridors. Most Metra lines have few stops within the CTA service area beyond the downtown terminals. The exception is the electrified south-shore line which provides in-city service with station spacing more like heavy rail than the other commuter lines. This south-shore line competes for ridership with the CTA south lake shore express bus service. For historical reasons, the downtown commuter rail stations are located outside the office core several blocks south and west of the Loop across the Chicago River. The main terminals are more than a mile from the very desirable retail, residential and tourist center along North Michigan Avenue and are also remote from the lakefront attractions. This observation will have important implications in the analysis of the Circle Line rail proposal in Chapter 5.

Suburban bus service is provided by PACE which offers some "grid-like" bus service close to the CTA service area generally on policy headways of thirty minutes or longer and more frequent peak-hour feeder service to Metra commuter rail and CTA heavy rail stations. Pace provides ADA paratransit, demand-responsive "dial-a-ride" transit and vanpools to expand suburban mobility.

¹ Transfer behavior is reported for a survey respondent's "typical trip" which is defined as the CTA trip which they take most often. Actual transfer volumes may differ significantly.

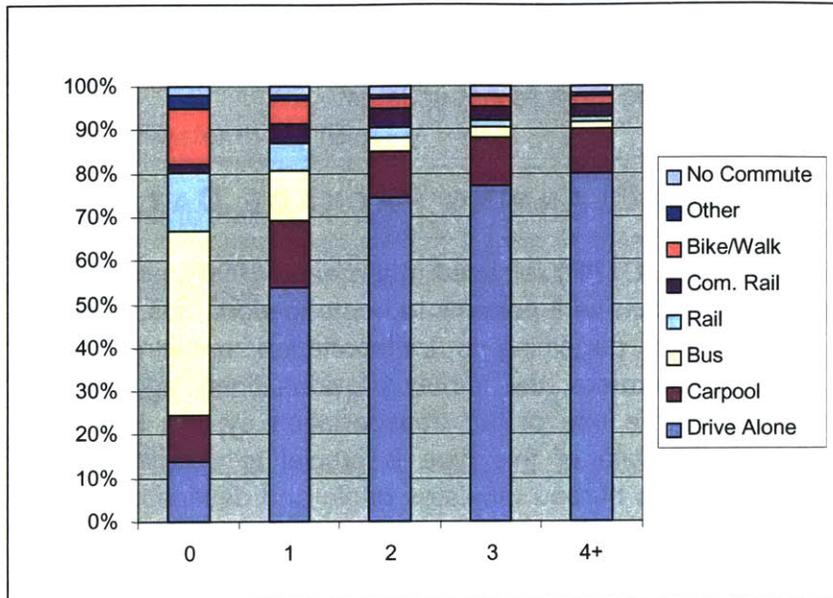
The CTA, Metra and PACE are funded through an umbrella agency, the RTA, which is responsible for regional transit coordination and planning. The political and economic implications of this arrangement have been the subject of a number of theses and dissertations. Allen (1996) provides a comprehensive historic review of transit service in Chicago, with Kirschbaum (2004) and Schofield (2004) providing more recent updates.

2.7 CENSUS TRANSPORTATION PLANNING PACKAGE DATA

The Census Transportation Planning Package (CTPP) released in the early 1990's provides a wealth of information on the transportation system as it pertains to home-to-work trips. One in six households responds to the census form pertaining to transportation, resulting in an extremely large national sample size. Furthermore, the survey provides finely aggregated socioeconomic characteristics that influence the use of the transportation system including household income and vehicle ownership. Data of this type is crucial to estimating trip generation and mode split models. The census bureau tabulates origin and destination flows based on the residential and workplace locations. These flows are valuable in understanding commuting patterns and estimating trip distribution functions and represent the primary market for transit. Finally, because this extensive data is collected at regular, albeit long, intervals it is possible to observe changing travel trends.

Figure 2-2 shows one example of the census data being used to understand how the market share of transit is impacted by vehicle ownership in the Chicago metropolitan region. The chart holds some interesting insight; commuter rail mode share, for example does not drop substantially with increasing vehicle ownership levels. An important lesson for transit operators is also found in the mode split chart of households without vehicles. While these households are traditionally thought of as transit-dependent "captive riders," the data indicates that nearly one third of work trips made by these households are not by transit. The "captive rider" is really a myth as those without access to cars rely on a number of modes. This suggests an agency can increase ridership by providing competitive service even to markets with large numbers of autoless households.

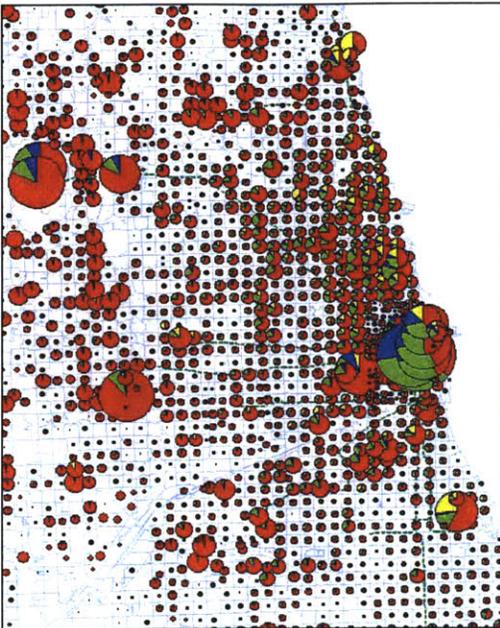
Figure 2-2. Mode Choice by Vehicles Available per Household



Source: 1990 CTP, Part 1 with additional calculations by author.²

Figure 2-3 displays mode split by destination in Chicago. The dominance of transit into the central business district is very clear. University campuses are revealed by the presence of a large number of walking-trip destinations. Major destinations like O'Hare International Airport and medical complexes reveal themselves as large pies.

² The presence of drive alone mode split for workers with zero cars available could be explained by borrowing vehicles from friends or relatives.

Figure 2-3. Mode Split at Work Destinations

red = auto, yellow = walk, blue = rail, and green = bus

The map underlines an important truth for the CTA: maintaining employment concentrations in the downtown is critical as transit plays less and less of a role in dispersed employment centers. The radial nature of the rail network is also evident with the vast majority of rail trips destined for a very concentrated number of locations. Rail extensions further into the suburbs will reinforce this pattern. Rail proposals, like the Circle Line, may help distribute rail passengers over a wider area and increase the number of destinations reachable by high-quality rail transit.

2.8 DEMOGRAPHIC AND TRANSPORTATION CHANGES SINCE 1990

The delayed release of updated data from the 2000 Census at the disaggregate level required by the method developed in this thesis clearly has an adverse impact on the accuracy of the results. It will be argued, however, that despite the economic and social changes that have taken place in the last fourteen years these results are still relevant. As more up-to-date data becomes available the analysis should be repeated to understand the impact of the changing spatial patterns on the transit system.

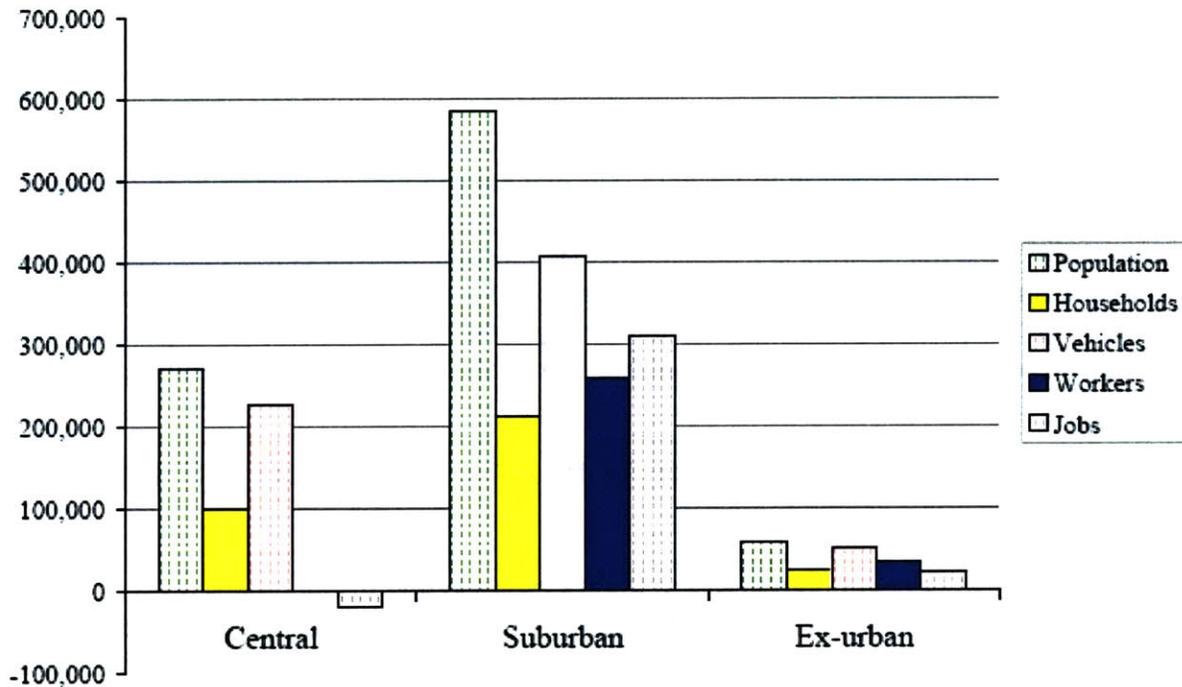
This section attempts to identify the important demographic and transportation changes since the 1990 census at a macroscopic level. The implications of these changes on the findings in this thesis are discussed briefly here and elaborated on in Chapter 5.

The most important change to the transit system since 1990 was the opening, in 1994, of the Orange Line providing service from the elevated loop southwest to Midway Airport. Several

renewal efforts, including the reconstruction of the elevated Green Line and the Douglas Branch of the Blue Line have improved speeds on the rail system.

Chicago is a medium-growth, mid-western city with a traditional development pattern of a strong central core and historic development along rail/transit lines. Population growth in central Cook County has outpaced job growth, much of it coming from new migration. Nearly a million people were added to the Chicago Metropolitan Statistical Area (MSA) between 1990 and 2000 (917,720) and, unlike many central counties throughout the country, Cook County continued to grow in population. Cook County is one of the most highly populated counties in the nation, and is the place of residence for 59 percent of the Chicago MSA population. However, between 1990 and 2000 Cook County accounted for only about one-third of the added population, and only kept its number of workers and actually lost jobs (Journey to Work Trends in the US, 2004). The growth in population, vehicles, workers and jobs was not even across the region as shown in Figure 2-4.

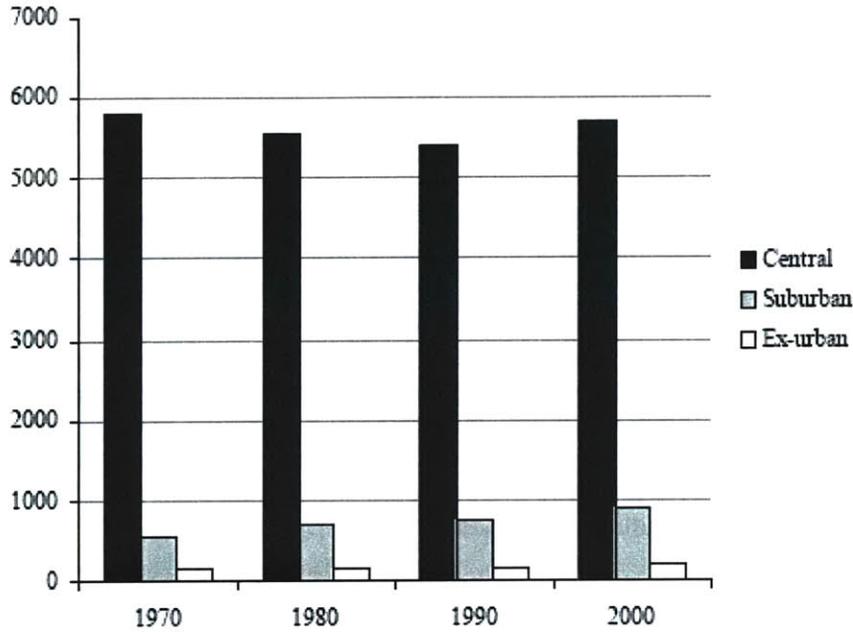
Figure 2-4. Added Population, Vehicles, Workers, and Jobs in Chicago MSA: 1990-2000



Source: Journey to Work Trends in the United States and its Major Metropolitan Areas: 1960-2000.

Population density in the Chicago MSA shown in Figure 2-5 shows a reversal in the trend of declining density in central Cook County. This is evidence of the renewal of urban neighborhoods. The rapid growth in the suburbs shown in Figure 2-4 has translated to steadily increased density shown in Figure 2-5, but not at the levels easily served by transit.

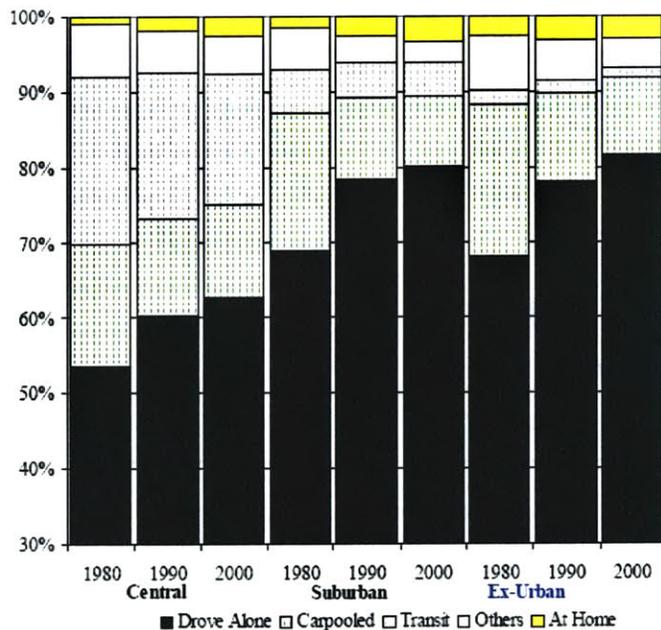
Figure 2-5. Population Density: 1970-2000



Source: Journey to Work Trends in the United States and its Major Metropolitan Areas: 1960-2000.

As shown in Figure 2-6, the percent of workers driving alone to work increased irrespective of location of residence from 1980 to 2000. Despite this shift, more than one-fifth of the central county workers still use transit. From 1980 to 2000, carpooling from suburban and ex-urban areas declined substantially perhaps due in part to the conspicuous absence of high-occupancy vehicle lanes in Northeastern Illinois.

Figure 2-6. Means of Transportation To Work: 1980-2000



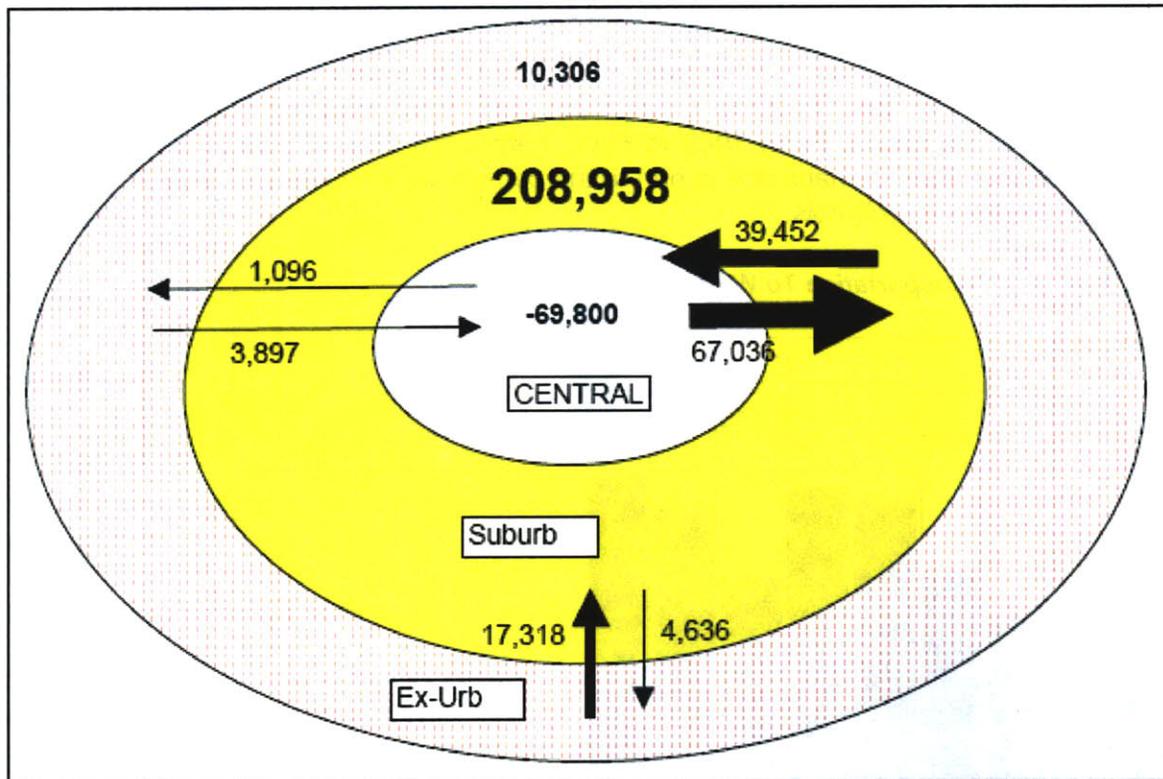
Source: Journey to Work Trends in the United States and its Major Metropolitan Areas: 1960-1990.

Relative to population growth, there was little job growth in Chicago during the last decade with the suburban counties accounting for 99 percent of the added jobs area-wide. Chicago gained over 270,000 people but only added only 1,500 workers (Journey to Work Trends in the US, 2004). A possible explanation is that the population in Cook County is aging and leaving the labor force, and immigrants to the city are younger and have children.

The last decade experienced continued dispersion of employment. Commutes to suburban jobs increased by 275,000 workers. The traditional movement from suburban counties to the central county gained just 43,000 commuters--39,432 from suburban counties and 3,897 from more distant ex-urban counties (Journey to Work Trends in the US, 2004).

Chicago had a traditional pattern of people who both lived and worked in the central county until the late 1970s. Later decades saw a shift to more suburban-to-suburban and reverse commutes. In 2000, both DuPage and Lake County attract more commuters than they generate defying the traditional notion of a suburb. The changes in flows over the last decade are shown in Figure 2-7 with suburb-to-suburb travel capturing the largest share of the growth.

Figure 2-7. Changes in Journey-To-Work Flows Between Central-Suburban-Ex-urban Areas: 1990-2000



Source: Journey to Work Trends in the United States and its Major Metropolitan Areas: 1960-2000. Font sizes and thickness of arrows are approximately sized to represent the magnitude in change of commuter flows.

The commuting trends in the last decade are likely to have mixed results for the Chicago Transit Authority. Increasing reverse and suburb-to-suburb commuting with its dispersed origins and destinations is difficult to serve by transit, particularly for the CTA with a statutory service boundary entirely within the central county. On the other hand, the city of Chicago appears to be reversing a long decline in population mostly through the arrival of new immigrants. These new city residents along with others returning to the city are revitalizing neighborhoods and often relying on CTA service for much of their mobility.

One such neighborhood of note is along the Lakeshore north of the Loop. In this neighborhood, incomes are high and transit's mode share is also high indicating a large concentration of choice riders. The service levels and neighborhood characteristics of this part of the city of Chicago should be considered a success story for transit in Chicago and an example for regenerating neighborhoods across the city. It raises important questions for public policy makers and planners concerning whether or not current zoning and transportation investment strategies encourage, or even allow, neighborhoods with characteristics like the North Lakeshore to form.

2.9 CONCLUSION

This chapter reviewed the literature and practices which influenced this thesis including assessment of transit investment benefits, the FTA planning process, accessibility modeling, graphic visualization, GIS, demographic data sources and trends.

The Chicago Transit Authority is at a unique time in its history for application of the planning tool developed in the following chapters. In recent years it has been successful at securing state and federal funding for renewal of its century-old elevated rail system. With the system approaching a state of good repair, it is turning its attention to expansion. Analysis of these expansion plans can benefit from the growing synthesis between GIS and transportation planning software. Unsatisfied with planning tools which rely on a "black box" a transparent and intuitive model for understanding impacts of major investments is presented in the next chapter.

3. ACCESSIBILITY MODEL AND METHODOLOGY

This chapter describes the framework used for selecting a measure of transit accessibility. Once the appropriate measure is selected, the details of its implementation are presented including estimation of a travel impedance curve and calculation of the generalized cost of travel.

3.1 FRAMEWORK FOR SELECTING A MEASURE

The framework for selecting an appropriate measure to evaluate changes to a transit network can be characterized as a search for a mathematical representation of the CTA's customer-focused mission statement. That is, "The CTA's mission is to deliver quality, affordable transit services that link people, jobs, and communities" (CTA Service Standards, 2001).

An ideal metric contains the following attributes:

- Easy to interpret. The units of the metric should be familiar and easy to compare geographically and across populations
- Transparency in the calculation. A widespread criticism of planning models is the perception of a "black box" understood only by model developers, often dependent on "fudge factors" to replicate actual behavior.
- Easy to present to the public / non-technical audience. Abstract concepts like transportation system user benefits, utility, and multidimensional variables are difficult to communicate to persons outside the transportation profession.
- Utilizes existing data sources. Travel behavior and socio-economic data is expensive to collect and is increasingly so at highly disaggregate levels. A metric which makes use of census, or other widely available data sources, can be implemented broadly.
- Flexible. Transportation investments have a variety of goals ranging from mobility improvements to economic development to environmental justice. Moreover, impacts vary across populations and travel purposes.
- Usable by in-house planning staff. The accessibility model is not intended to replace more sophisticated travel demand forecasting rather it is intended to support system planning and to prioritize proposals for more intensive study.

Figure 3-1 shows a qualitative evaluation of the three dominate accessibility metrics from the literature according to the criteria identified above.

Table 3-1. Metric Evaluation

Metric/Attribute	Isochrone	Gravity	Logsum
Easy to Interpret	Good	Fair	Poor
Transparent	Good	Good	Fair
Present to Public	Good	Fair	Fair
Data Available	Good	Good	Poor
Flexible	Poor	Fair	Good
Usable In-House	Good	Good	Fair
Accurate	Poor	Good	Good

The gravity model most closely matches for the ideal metric criteria. The utility-based measure is the most state-of-the-art and flexible to a variety of policy variables but relies on disaggregate data that is not widely available for Chicago and its results are difficult to interpret. The simple isochrone accessibility model is easy to interpret and to present to non-technical audiences with results like “the number of jobs within one hour by transit” but it is insensitive to differences in travel times within the selected travel-time boundary. Furthermore, its results can be strongly influenced by which boundary is selected for evaluation.

The gravity model uses existing data sources and has units which are easily interpreted. For example, employment access results in a score of weighted jobs reachable by transit. This can be compared to the total jobs in the region to gain a sense of the relative utility of the location in question. Changes in access score are measured in units of “new jobs accessible” a number which is easy to relate to both by the public and by decision makers.

3.2 IMPLEMENTATION OF THE GRAVITY MODEL

CTA market research indicates 64% of CTA customers use the system to commute to work or school (Northwest Research Group, 2003) a disproportionately large share, as work trips generally represent less than one-fifth of all trip making across all modes. This suggests that a home-based-work accessibility metric is appropriate for many planning applications because transit is most successful at serving work trip purposes.

Table 3-2. CTA Customer Trip Purposes in 2003

Primary Trip Purpose	Percentage of Customers
To/From Work	50%
To/From School	14%
Personal Business	9%
Shopping	8%
Visiting/Recreation	7%
Medical	5%
Other	7%

Source: Chicago Transit Authority 2003 Customer Satisfaction Survey, Northwest Research Group, June 2004.

Employment distribution can also be thought of as a proxy for the distribution of services in the region since retail and other services also generate employment.³ Consequently, the metric may also capture some of the benefits of transit service for shopping trips which, when added to work and school trips, total 72% of all transit trips.

The adoption of a home-based-work-trip accessibility metric for project evaluation is a reasonable choice, but it is acknowledged that transit also serves other important trip purposes. Cohen (2004) highlights the important function of transit in serving non-work trips and stresses that having transit service available for non-work trips is likely a crucial factor in household auto ownership decisions. An intuitive argument is advanced that high quality transit service for non-work trip purposes may facilitate owning fewer automobiles or foregoing automobile ownership altogether. Cohen cites a lack of survey and other data as the principal obstacle to more effective non-work transit planning and it is the same lack of data which prevents a more detailed analysis of transit service for non-work purposes in this thesis.

The accessibility model's ability to evaluate access to medical and other specialized services as well as the variety of other needs fulfilled by transit requires more careful consideration. Application of the gravity model for other trip purposes is not advanced in this thesis beyond one simple example of access to air transportation. With appropriate data on spatial distribution of non-work trip attractions its implementation would be very straightforward. One can envision an evaluation of a transit proposal on access to recreation using acres of parkland in a TAZ as the

³ For an example of this proxy implemented in the Urban Economics literature see (Bento, et al, 2002).

“opportunity” in the model. The only additional information required would be an estimate of the shape of the impedance function for the trip type under evaluation. Intuition suggests the impedance for work trips may be significantly different than for social, shopping and recreational trips and to specialized destinations like airports, regional hospitals, or special events.

Impedance Function Estimation

The gravity model relies on an impedance curve 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. In the case of a home-based-work model, for example, a job which is fifteen minutes away is considered more accessible than a job which is thirty minutes away.

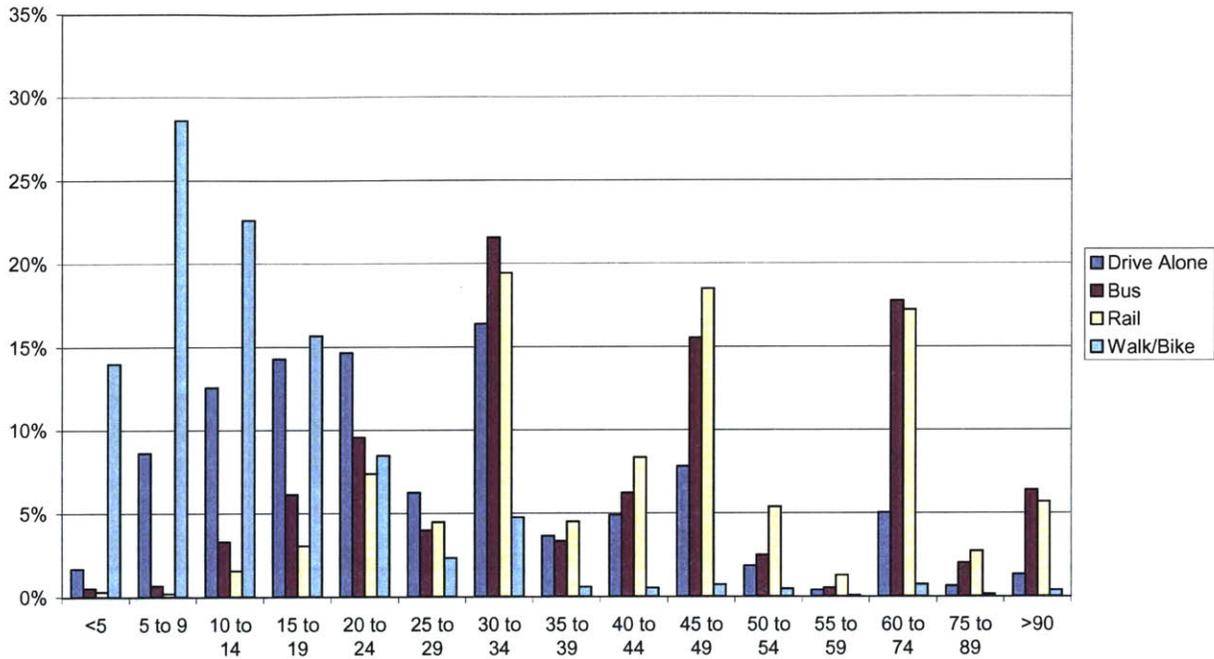
The Census Transportation Planning Package contains detailed information on trip lengths (in minutes) by mode, origin and destination. The overall mobility distribution for the six-county Chicagoland region is presented in Figure 3-1.

The shape of the distribution of trip length by mode is intuitive. Walk and bike trips to work are the shortest peaking at 5 to 9 minutes of travel time and with very few trips longer than 30 minutes. Auto trips are shorter than trips by transit with more than half the trips being shorter than 30 minutes. Bus and rail⁴ trips are longer, with most commuters traveling for longer than half an hour and a quarter traveling for an hour or more each way by transit. It is also important to point out that very few short trips are taken by transit. It is likely that the combination of aversion to waiting for the transit vehicle and paying a fare discourages trips of less than 10 minutes. Moreover, walking is likely a reasonable alternative for these short trips. This is not observed for auto trips with more than a quarter of trips less than 15 minutes in length.

The shape of this distribution is strongly influenced by the nature of the data collection process. The census long form is a survey and there appears to be a strong tendency of respondents to report their trip lengths at quarter-hour intervals with spikes at 30, 45 and 60 minutes for auto, bus, and rail. The actual distribution of trip lengths is likely to be much smoother.

⁴ In this discussion the mode rail is the “Streetcar, Trolley Car, Subway, or Elevated” option in the CTPP long form. In the case of Chicago, respondents are most likely to select this option if they use CTA heavy rail. METRA commuter rail passengers are likely to have selected “Railroad” as their journey to work mode and their response is not plotted here.

Figure 3-1. Frequency of Trips by Mode versus Travel Time

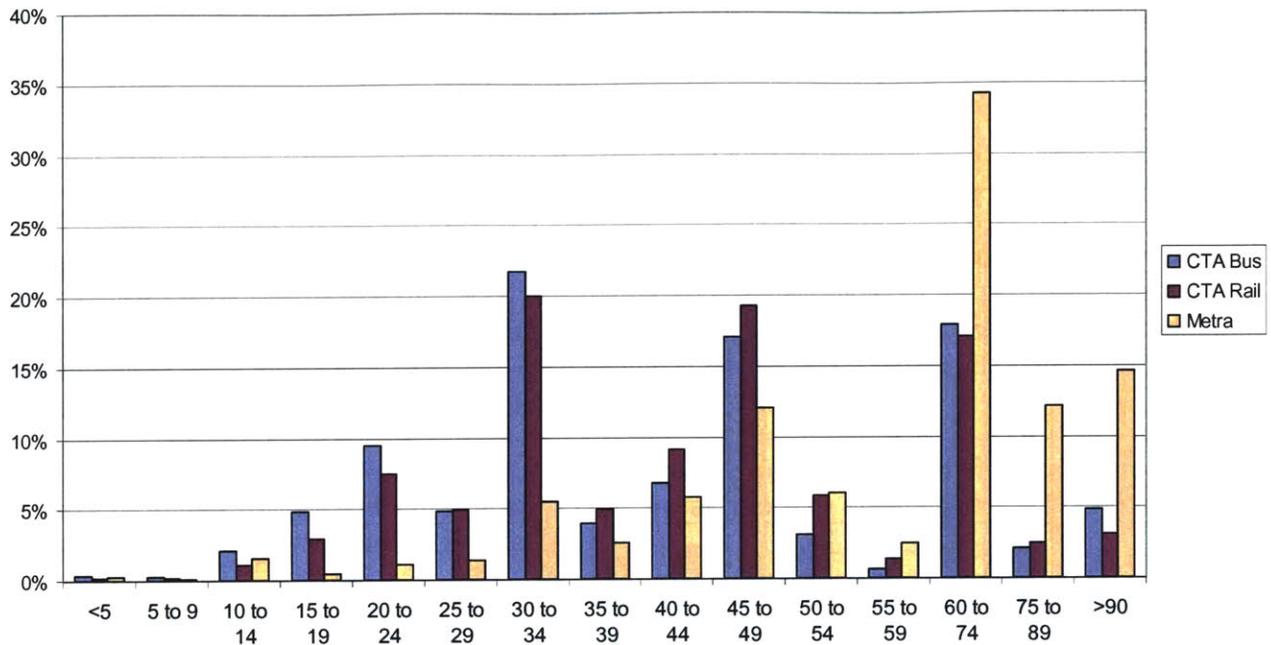


Source: 1990 CTP Part 1, Calculations by author. Trips for the entire six-county metro area are included

The shape of the metro-wide travel time distribution is dominated by suburban travel. Less than two-thirds of trips in the Chicagoland have their journey-to-work trip destination in central Cook County (McGuckin & Srinivasan, 2003).

To eliminate suburban auto-oriented trip bias from the analysis of the CTA service area a smaller region was selected. Only transit trips destined to an area within a two-mile radius of the center of the Loop⁵ were analyzed. Most transit trips have their AM-peak trip destinations within this radius and this sub-region is the most transit-competitive region in greater Chicago. Figure 3-2 shows the travel time distribution by transit mode for the Chicago Central Area.

⁵ The intersection of State Street and Madison Avenue is considered the center of the Loop as it is the 0 N/S and 0 E/W origin of the Chicago's grid address system.

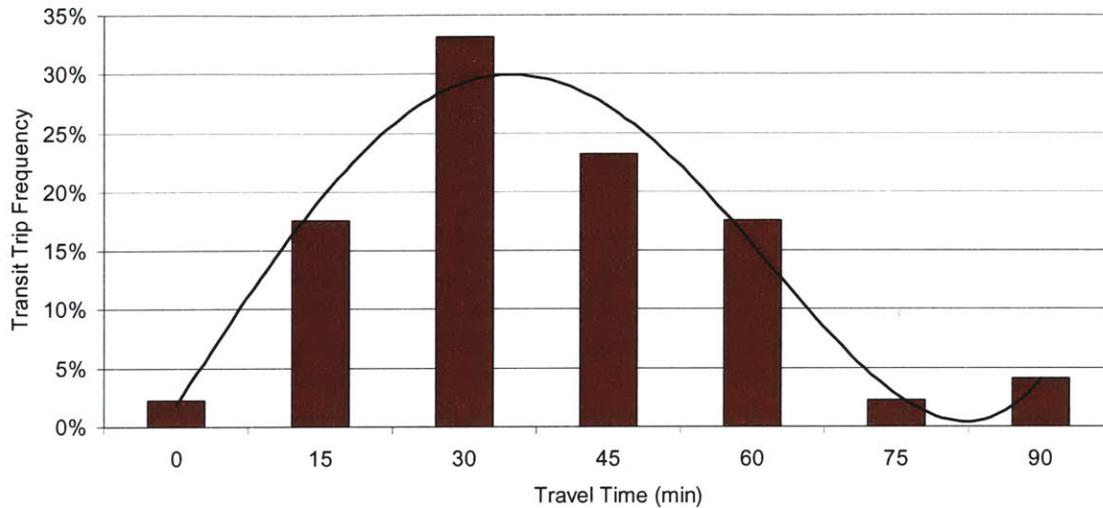
Figure 3-2. Central Area Transit Travel Time Distribution

Source: 1990 CTPP, Part 2, Frequency of transit trips by mode for trips destined to zones within a 2 mi radius of State and Madison. GIS analysis in TransCAD

It is important to note the similarities in travel time frequency on CTA bus and rail. This implies it is appropriate to estimate a travel time impedance function on the combination of these two modes. Metra commuter passengers, however, have much longer commute times. The reason for this is obvious: commuter rail serves distant suburban locations and most trips are destined for the city center. However, the travel time impedance function for commuter rail passengers is likely to be different from CTA transit passengers. Amenities on commuter rail trains are high. For example, service policy calls for every passenger to have a seat except those boarding just outside the downtown terminals, trains are equipped with bathrooms, and passengers are allowed to consume alcoholic beverages, among other concessions which make long trip times more tolerable.

These amenities are not available to city bus and rapid-transit riders. As such, trips on commuter rail were excluded from the estimation of a travel time impedance curve. Furthermore, to address the obvious bias in reporting times - which were rounded in multiples of fifteen minutes by survey respondents - the census categories were aggregated into fifteen minute intervals. The trip frequency graph for CTA bus and rail passengers destined to the central area is presented in Figure 3-3. The analysis below uses aggregated fifteen-minute intervals to eliminate the error due to rounding by respondents and to facilitate the estimation of a travel time distribution curve.

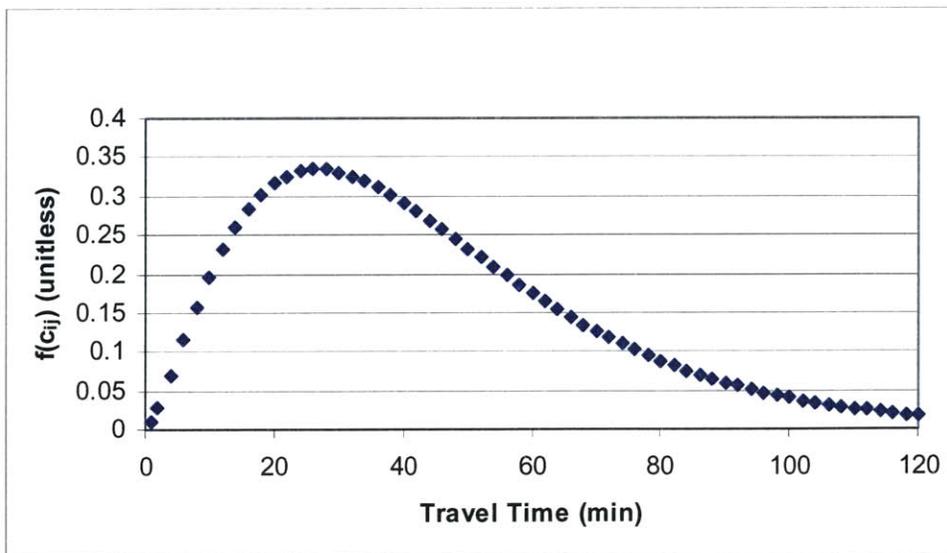
Figure 3-3. Aggregated Central Area Transit Travel Time Distribution



Source: 1990 CTPP, Part 2, Frequency of transit trips by mode for trips destined to zones within a 2 mi radius of State and Madison. GIS analysis in TransCAD. Choices “Bus and Trolley Bus” and “Streetcar, Trolley Car, Subway, or Elevated” are combined.

The shape of this curve is familiar to transportation planners as it appears regularly in the distribution step of the four step model. The functional form used to describe this curve is the Gamma Function, given as $f(t_{ij}) = a \cdot t_{ij}^{b-1} \exp(-c \cdot t_{ij})$ where a , b , and c are estimated parameters. a , b , and c were fitted to the data with the results shown in Figure 3-4.

Figure 3-4. Estimated Travel Impedance Curve



Gamma Function:

$$f(t_{ij}) = a \cdot t_{ij} - b \exp(-c \cdot t_{ij})$$

$$a = 0.01125$$

$$b = -1.48431$$

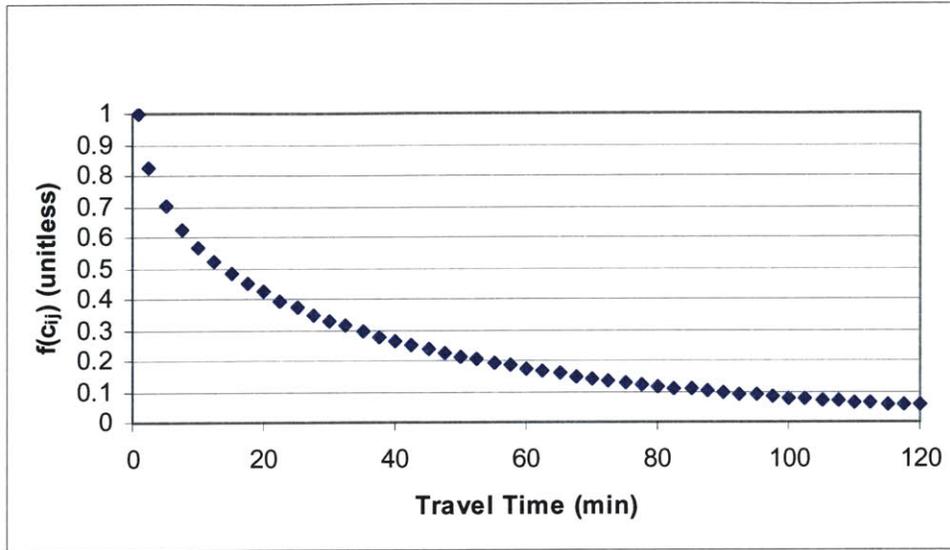
$$c = 0.05554$$

While grounded in actual user behavior this curve represents the combined effects of user preference for short trips and the reality of spatial separation of residences and employment. While there may be an underlying behavioral preference for a short travel time between residences and work, the spatial structure of the city prevents this with housing and jobs located in different districts. Moreover, other factors important to residential location such as affordability, school districts, and segregation (voluntary or otherwise) result in a separation of residence from job location that permits few short commute trips. The absence of these trips from the data does not imply that they have a lower utility than longer trips, it more likely indicates they are not possible.

This function cannot, however, be used in accessibility analysis because the impedance function must be continuously declining. This is particularly important in assessing relative change in access from improved transit travel time. Without a continuously decreasing impedance function, any improvement in transit access time below the maximum point would appear as a counter-intuitive decrease in transit accessibility.

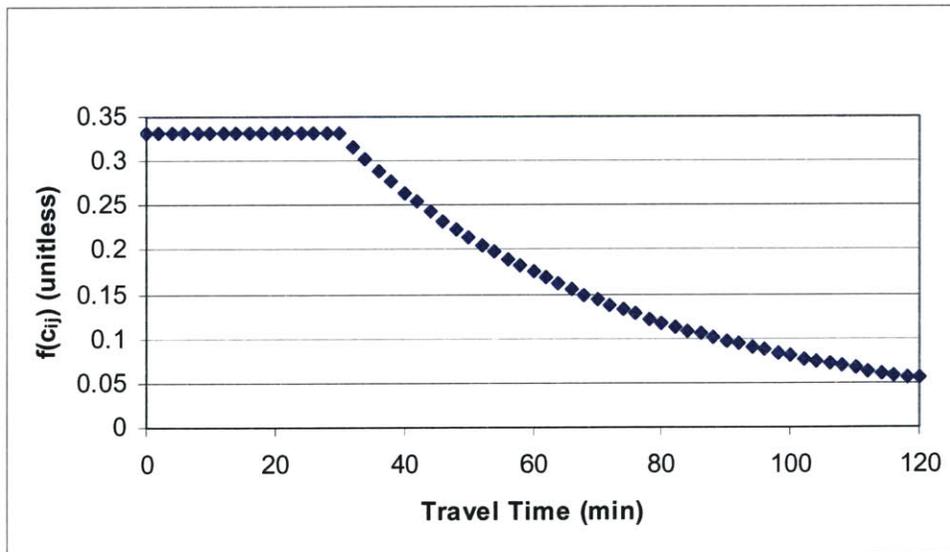
The challenge is to specify an impedance curve which is continuously decreasing, grounded in actual travel behavior, and useful in making comparisons. One such curve, shown in Figure 3-5, is the same exponential as estimated above with the positive linear term removed. This specification captures travel behavior well on the tail of the function. This specification was ultimately rejected because, when comparing relative accessibility changes, the most dramatic increases or decreases in the accessibility score occur in the range of travel time where the walk mode is a serious competitor with transit. Thus, the expected ridership gain, and user benefit from improved service is likely to be overestimated.

Figure 3-5. Exponential Impedance Curve



To remedy this inconsistency, the function shown in Figure 3-6 was also considered. In this case, the transit impedance is defined as a decreasing exponential function to the right of the most frequently reported trip length and constant to the left. While this functional form solves the problem of large accessibility changes resulting from small reductions in already-short transit trips, it was also rejected because it does not capture the benefit of shortening transit trip lengths below 30 minutes. Clearly, there is some benefit to shortening trip lengths of short transit trips and a credible impedance curve should capture these benefits.

Figure 3-6. Proposed Impedance Curve: Exponential with Cut-off at Maximum



Finally, the cumulative travel-time distribution curve shown in Figure 3-7 was selected for use in the gravity model. The curve 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. When considering changes in overall trip time, trips in the region of twenty to sixty minutes will experience the largest shift in access score. This is appropriate because very short transit trips are likely to have strong competition from walking and be relatively insensitive to travel time changes. Similarly, very long trips are not likely to attract riders even with large reductions in travel times.

Figure 3-7. Proposed Impedance Curve: Cumulative Distribution

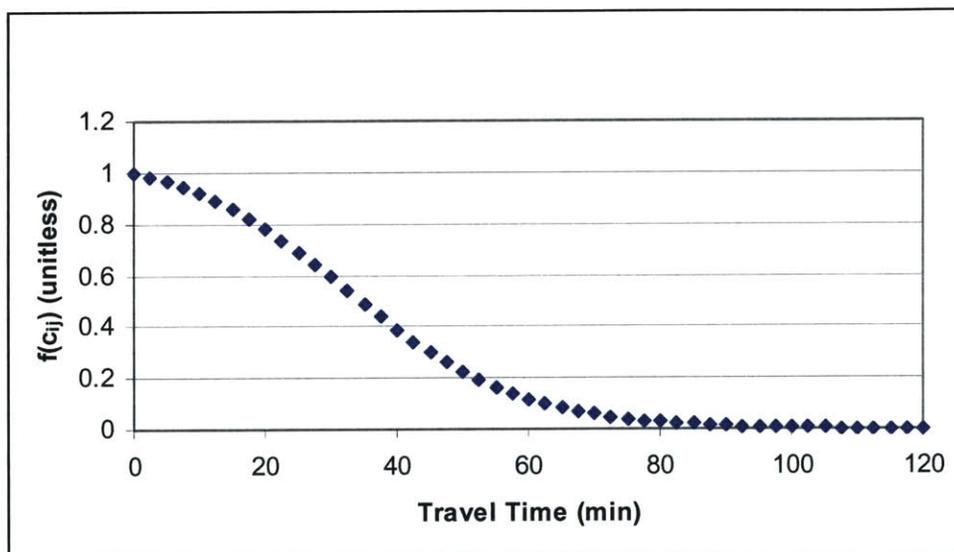
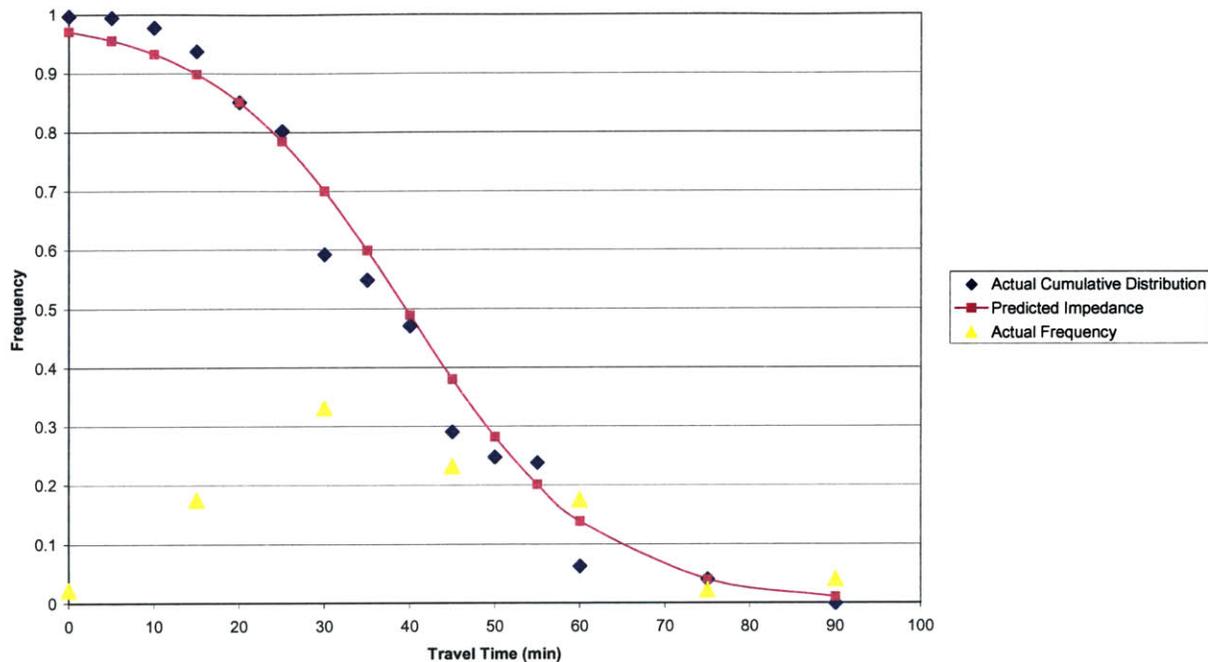


Figure 3-8 plots the actual cumulative travel-time distribution, the travel-time frequency curve and the fitted line. The fitted line deviates from the data at short trip lengths as the intercept is constrained to be unity.

Figure 3-8. Actual Frequency, Cumulative Distribution, & Fitted Impedance



$$\text{Impedance} = 1.08438 / [1 + 0.08438 \exp(0.076223 * TT)]$$

Generalized Travel Cost

It is widely recognized that users perceive the different travel time components of a transit trip differently. NCHRP 365 “Travel Estimation Techniques for Urban Planning” provides a comprehensive review of the various factors (or weights) which have been estimated for a number of regions world-wide. Weights for the trip components are generally estimated from discrete choice models and rely on revealed preference survey data. The weights vary across studies but generally indicate that time spent in the vehicle is less onerous than initial transit wait time which is less onerous than time spent walking to (and from) transit. Coefficients on service-level variables can never be compared directly because model specifications differ, but the ratios of the coefficients can be compared across studies.

The Chicago Area Transportation Study (the designated MPO for the Chicago Metropolitan Region) conducted a personal home travel survey in 1990 and estimated a mode choice model for use in the Shared Path 2030 Regional Transportation Plan for Northeastern Illinois. The coefficients of the estimated model are presented in Table 3-3.

Table 3-3. CATS Mode Choice Model Coefficients

	Home Based Work		Non-Work
	Non-CBD Dest.	CBD Dest.	All Dest.
In Vehicle Time (min)	0.0186	0.0159	0.0114
Initial Wait Time (min)	0.0811	0.0173	0.0610
Transfer Time (min)	0.0399	0.0290	0.0589
Walk Time (min)	0.0584	0.0468	0.0663
Cost (cents)	0.0072	0.0085	0.0329
Modal Coefficient	0.4983	0.6059	0.2726 home-other 0.8072 non-home

Source: Chicago Area Transportation Study. 2020 RTP Conformity Analysis Documentation, Appendix B. November, 1997

The mode choice model used for travel demand forecasting in Chicago is segmented by trip purpose (home-based-work versus non-work) and by work trip destination (CBD-trips versus non-CBD trips). In general, the coefficients appear reasonable but the model does raise some concerns. First, there is no segmentation by income, although one would expect at least the travel cost coefficient and perhaps other coefficients to be influenced by income level. A low-income person may be willing to trade longer travel times for a lower fare or lower toll option. This phenomenon may be particularly relevant in Chicago where METRA commuter rail offers higher-fare, higher-speed service in the same corridors as lower-fare, lower-speed CTA rail and bus service.

The implied value of time from the CATS model is the marginal rate of substitution for the trip attributes with respect to cost. It is calculated as the ratio of the time coefficient and the cost coefficient with the units converted to dollars per hour.

Table 3-4. Implied Value of Time (Dollars per Hour)

	Home Based Work		Non-Work
	Non-CBD Dest.	CBD Dest.	(All Dest.)
In Vehicle Time	\$1.55	\$1.12	\$0.21
Initial Wait Time	\$6.76	\$1.22	\$1.11
Transfer Time	\$3.33	\$2.05	\$1.07
Walk Time	\$4.87	\$3.30	\$1.21

Source: Chicago Area Transportation Study. 2020 RTP Conformity Analysis Documentation, Appendix B. November, 1997. Additional calculations by author.

The values of time implied by the CATS model are very low compared with other mode-split models. The reason for this is not entirely obvious, although the lack of income segmentation may be a factor. These very low values of time are problematic for transit modeling purposes because they imply decision makers will trade very long walks or journey times to avoid paying a transit fare. The model implies, for example, that a decision maker making a home-based-work trip to the CBD will trade 54 minutes of in-vehicle time for a \$1 reduction in travel cost. Moreover, that same decision maker would be willing to walk 27 minutes to forego the CTA's 1990 base fare of \$1.50 according to the implied values of time in the CATS model.

In response to the uncertainty of the value of time for transit riders the decision was made to omit fares from the accessibility analysis. The implication of this assumption is that more, short zone-to-zone pairs will involve a transit trip instead of a walk only trip resulting in lower travel time. Moreover, in corridors where METRA service and CTA service overlap, more zones will be connected by METRA which, in most cases, offers faster service at a higher fare.

It is acknowledged that fares are a very important factor in mode choice decisions and, as is the case in Chicago where fares are not unified, can be an important factor in route choice even after transit is the selected mode. Omitting fares is not fatal for the accessibility model, as it is concerned with the relative ease of travel between origin-destination pairs once transit is the selected mode. It is, nonetheless, recommended that further analysis of the Circle Line project, which is introduced in Chapter 5, address the issue of the money value of time and the impact of fares on trip patterns. This will ultimately have important impacts on ridership as, at present, there is no fare integration between the Metra commuter rail network and the CTA's bus and rapid rail network which certainly influences path choice for customers with both services available, and a primary motivation of the Circle Line is to provide transfers between systems.

Another means of interpreting the CATS model coefficients is to consider the marginal trade off in travel components relative to a minute of in-vehicle time. These ratios are presented in Table 3-5.

Table 3-5. Implied Travel Time Weights

	Home Based Work		Non-Work (All Dest.)
	Non-CBD Dest.	CBD Dest.	
In Vehicle Time	1.00	1.00	1.00
Initial Wait Time	4.36	1.09	5.35
Transfer Time	2.15	1.82	5.17
Walk Time	3.14	2.94	5.82

Source: Chicago Area Transportation Study. 2020 RTP Conformity Analysis Documentation, Appendix B. November, 1997. Additional calculations by author.

The implied travel time weights from the regional model do not distinguish transit modes, although experience suggests some bias in favor of rail even on paths which have time-competitive bus options.

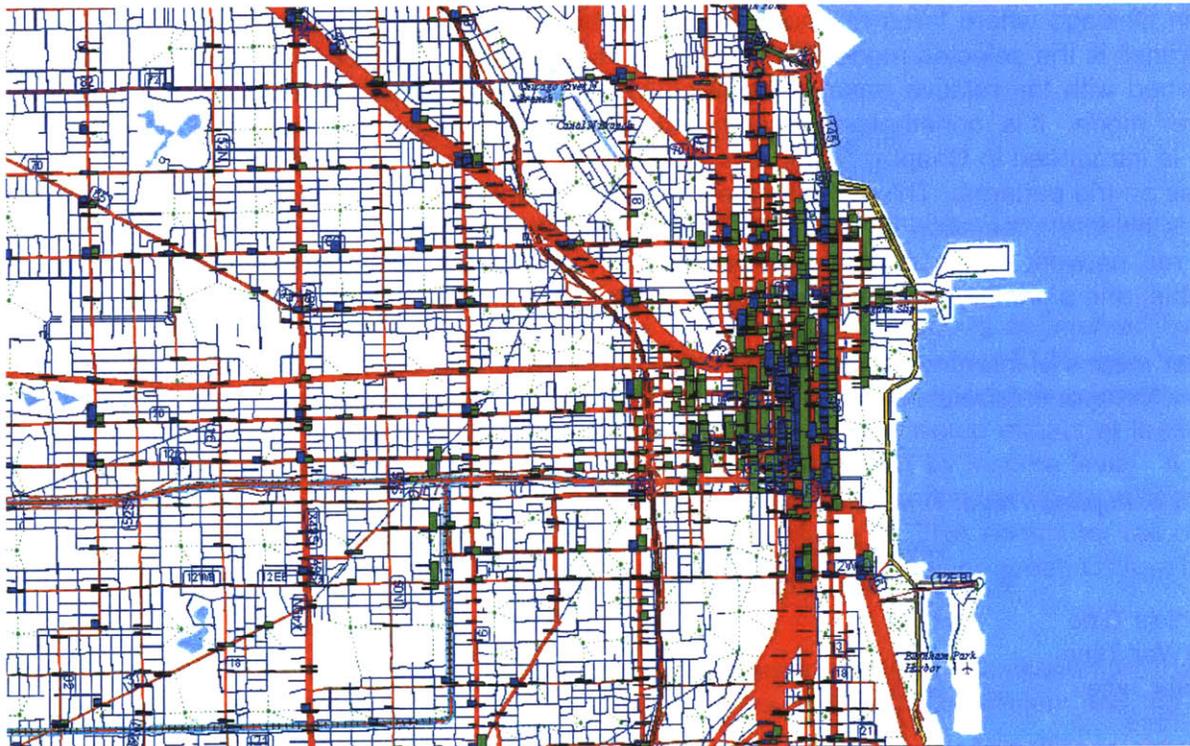
Ultimately, it was determined that the CATS mode split model coefficients were not adequate for calculating the generalized cost of transit in the network model. Instead the coefficients were adjusted according to FTA guidance for New Starts travel demand forecasting⁶ and roughly calibrated in an iterative process.

The iterative calibration of the travel time weights involved assigning the census journey-to-work flows to the transit network and comparing the relative mode split between bus and rail. A graphical image of the output of this assignment is presented in Figure 3-9. When the CATS

⁶ The FTA recommended mode split coefficients were presented in a Transportation Research Board session, January, 2004. Attempts by the author to locate a document supporting this presentation were not successful. Nonetheless, the values of these coefficients are well known in the transportation planning community and are widely used on projects subject to FTA review.

coefficients were used without distinguishing between bus and rail mode the resulting assignment totals significantly overestimated the number of bus trips. It was obvious from this process that bus and rail ought to be treated as different modes with different associated trip time weights.

Figure 3-9. Results of Assignment of 1990 Journey-to-Work Flows



Line thickness is proportional to one-way ridership by route. The height of the green and blue bars is proportional to boardings and alightings respectively.

The weights ultimately selected to estimate the generalized cost of travel are given in Table 3-6.

Table 3-6. Generalized Cost Weights

Mode	In-Vehicle Travel Time	Waiting Time	Transfer Time	Walk Time	Access
Rapid Rail	1.0	2.0	2.0	3.0	
Bus	1.5	3.0	3.0	3.0	
Commuter Rail	1.0	2.0	2.0	3.0	

3.3 CONCLUSION

The accessibility model can be used to estimate the relative accessibility of destinations across the region. It requires a calculation of generalized cost between origin-destination pairs. The development of the network model which performs this calculation is discussed in the next chapter.

4. TRANSIT NETWORK MODEL

The transit network model developed for the CTA was not developed exclusively for use in this thesis. Rather, it was a collaborative effort among participants in the CTA-MIT research effort. The development approach adopted was one of incremental improvement as data became available and time for model development allowed. Emphasis was placed on developing an understanding of the performance of the transit system in Chicago early in the development of the model to encourage participation in the collaborative effort. Consequently, early versions relied on a number of simplifying assumptions which were relaxed as the model evolved.

In this chapter, the work completed to build the transit network model is documented and data sources identified so that the work done here can be carried forward by future researchers or similar models developed for other transit systems. The model remains a work in progress, and a number of suggested refinements are suggested throughout the chapter.

4.1 MODEL STRUCTURE AND SCOPE

The planning model constructed for Chicago was designed with the objective of understanding the impact of system-level changes to the transit network including new rail service, bus and rail re-routing, limited stop bus service, and changes in frequency. To adequately capture the regional impacts of transit investments the model boundary was kept large as practical in light of computational resources. A larger number of analysis zones require more computation time and storage but are necessary where transit service and access modes vary substantially over a small area. Where the transit network is dense, the resolution of the traffic analysis zones is small to capture the tradeoffs between routes and more accurately describe access conditions.

The maximum extent of the CTA's bus and rail network is approximately 15 miles from the Loop. To capture the impact of changes to this transit network on the larger region, an area was selected extending 25 miles from the Loop. The urbanized area extends beyond this 25 mile boundary, but it was assumed that the impacts of changes to the CTA network would be small at great distances from the city center. Expressways, major arterials and commuter rail within a 50 mile radius of the Loop were retained to represent origins and destinations outside the modeled travel area.

The model is intended to be flexible and able to serve as a foundation for implementation of a full four-step travel demand model. As a consequence, data on roadway classification and a fine network of streets were maintained. Roadway speeds were initially estimated based on their functional classification as defined by the Caliper Transportation Data CD.

4.2 TRANSPORTATION ANALYSIS ZONES DEFINITION

Chicago has very extensive transit service; the area within a fifteen-minute walk of a Chicago Transit Authority bus or rail route covers more than 315 square miles. The statutory service area of the Chicago Transit Authority is much larger encompassing nearly all of Cook County. The Chicagoland Urbanized Area as defined by the Census Bureau is 1748 square miles. For analysis purposes this large region was partitioned into travel analysis zones (TAZs). To

facilitate importation of data from the census the model retains the traffic analysis zone definitions provided by the Census Bureau. In general, these zones are ½ mile by ½ mile square within a 25 mi radius of loop. In the dense Central Area the analysis zones are as small as a few city blocks.

The fundamental assumption used by most transportation planning functions is that travel analysis zones are small enough to represent the variability of transportation options available at that location. In this way, the socioeconomic characteristics and travel demand data for a zone can be stored in the TAZ centroid – a node which can be linked to the transportation network through a centroid connector. This assumption can pose challenges for transit planning as the quality of the walk access, station or stop location and other important factors in mode and route choice are likely to vary at a scale smaller than the size of the analysis zone. This is, nonetheless, a necessary simplification to keep data and computational requirements manageable in a regional model. One refinement that is often implemented is the sub-area analysis in which the outputs of a larger regional model are fed into a microsimulation model in a region of particular interest. Microsimulation models are capable, among other things, of representing very dense route choices in a dynamic and stochastic environment on a smaller scale.

4.3 STREET AND RAIL INFRASTRUCTURE LAYER

The transportation network is modeled as interconnected nodes and links. The GIS feature in TransCAD allows the importation of this infrastructure geometry from a variety of sources. Then the entire transportation network including walk access, drive access, streets for buses, and railways are represented in a single infrastructure layer. They are classified according to their functional class in a database. The following section provides details on the function and data source for the various link types.

Centroid Connectors

Centroid connectors are specialized links which connect the TAZ centroid – where all trips start or end - to the transportation network. Centroid connectors are not physical links, but are a simplified representation of the access to the road and transit network. When calculating the path between an origin-destination pair connectors are only used at the beginning and end of the path with the rest being confined to the physical transportation network. The travel time for a centroid connector is calculated using the average access speed which is defined in the model as 3 mph for walk access and 20 mph for drive access.

Road Infrastructure Links

Caliper Transportation Data CD provides roadway geometry and a functional classification for every public street in the United States. The original source for this data is the Census Bureau's Tiger Files.

There is a tradeoff between accurate description of access links to transit along actual streets and keeping the size of the walk-access network small for computational simplicity. Not all local

streets are included in the transit access network. A selection of links within a quarter mile of CTA bus/rail stop is used to describe walk access to transit. This decision sharply reduced the number of links in the walk access network and kept the computation and memory requirements low. Functional classification is provided by the dataset and was used to estimate free flow speed. A major weakness in the existing dataset is the lack of information on roadway capacity (i.e. the number of lanes by direction). This limits the model's ability to capture congestion on the highway network. Additional data on the location of signalized and stop-controlled intersections would also be useful in describing the performance of the highway network.

Rail Infrastructure Links

Shape-files describing the rail geometry and station data were provided by CTA planning GIS database. Station-to-station running times were queried from the Hastus scheduling software used at the CTA. Link travel times were entered as door-open to door-open minus 40 seconds of dwell. Whereas street link travel times were estimated by assuming a free flow speed and calculating a corresponding travel time, rail link travel times were entered manually and the corresponding speed inferred.

The assumption of 40 seconds of dwell time per station includes train acceleration and deceleration. It is recognized that not all stations on a route have the same dwell time as assumed. This can be modeled by adding running time to neighboring links. Assuming a constant dwell time was important because it allowed express trains, such as the Purple Line, to share the same links as the Red Line local trains.

Rail links are excluded from the set of links which allow drive or walk access. Rail stations are connected to the rest of the transportation network using short pedestrian-only links called station-access links. Pedestrian access links are also used to link stations on different lines where it is possible to transfer. Where data is available, the transfer time on a station-access link is entered according to field measurement without respect to the physical length of the link. In other cases, the links were assigned an arbitrary travel cost of one minute to represent the cost of accessing the station platform from the rest of the transportation network. This was considered more accurate than assuming a walk speed and computing the travel time across the link given the length of the station-access link. Accessing the station platform is, in general, considerably more difficult than walking down a sidewalk and often requires traveling up or down stairs so it is unrealistic to rely on straight-line distances to calculate the access time to a station.

Summary of Geographic Layer Types Included in the Model

Table 4-1 summarizes the links included in the CTA network model and their important properties.

Table 4-1 Geographic Line Layer: Types of Elements and Properties

Function Type	Number of Elements	Name	Driving Speed	Transit Speed	Walk	Drive
1	3,048	Expressways	55	44	N	Y
2	4,443	Major Arterials	45	36	N	Y
3	6,913	Minor Arterials	40	32	Y	Y
4	2,287	Ramps	40	32	Y	Y
5	81,885	Local Streets	30	24	Y	Y
6		(unassigned)				
7	151	CTA Rail Lines	N/A	Variable	N	N
8	210	CTA Station Access	N/A	N/A	Y	N
9	265	Metra Station Access	N/A	N/A	Y	N
10	19,698	Centroid Links	20	N/A	Y	Y
11	460	Metra Rail Lines	N/A	Variable	N	N
111	4	Circle Line Phase 1	N/A	40	N	N
222	4	Circle Line Phase 2	N/A	40	N	N
333	18	Circle Line Phase 3	N/A	40	N	N

Note: Walk speed is 3mph for all links where walk-access is permitted.

Some combinations utilized in the model:

Drive Links: 1,2,3,4,5,10 A total of 118,274 links

Walk Links: 3,4,5,8,9,10 A total of 111,271 links

Non rail links 118,762

Figure 4-1 shows a small section of the network as modeled. TAZ centroids are connected to the transportation network with green-dotted centroid connectors. The different functional classifications of the road network are also shown with thin local streets and thicker arterials in grey, expressways in red, and ramps in black. Note that many of the local streets have been omitted from the model but are retained within ¼ mile of a transit stop.

Figure 4-1. Road and Street Network as Modeled



4.4 TRANSIT ROUTE LAYER

Bus, rapid rail and commuter rail transit services are combined in a single transit route system. Modes are distinguished by a tracking variable which comprises one attribute of the transit route system. Other attributes of each route are:

- Route name and ID
- Headway in the AM Peak, PM Peak, Midday, and Owl periods
- Dwell time
- Fare
- Maximum and minimum wait time
- Layover time at terminal points

The route system defines the specific direction and links in the infrastructure layer utilized by a particular route. Stops, by direction, are recorded at their physical location by the integrated GIS database. When a transit network is created for calculating travel times and shortest paths, stops are consolidated at the nearest node in the infrastructure layer.

A mode table and mode-transfer-cost table are used to store variables which are common among modes including the weights for the various travel-time components of a transit journey. The transfer-cost table allows for the definition of global transfer penalties from one route to another as well as tailored transfer penalties at specific transfer locations. For example, the difference in perceived disutility between a cross-platform transfer and a subway-to-elevated train transfer can be captured at a single node. This consolidation implies boardings and alightings may not be available at the stop level if there is more than one physical stop per block.

The outlying Pace bus service was excluded from the model development due to marginal impact on CTA system. Pace primarily provides mobility in the suburbs for those without access to an automobile. Much of the suburban service is focused on feeding Metra commuter rail stations and CTA terminals. This same access is provided by park and ride and, as such, this access mode option should be sufficient for capturing the impact of Pace on the CTA transit system and vice versa. Drive access to transit is discussed in more detail later in this chapter.

Changes to the transit route system can be explored by defining scenarios. New routes can be added to a single layer and are “turned on and off” using the select by condition feature. This database tool allows any combination of routes to be combined for analysis.

An important limitation of the link between the transit routes layer and the underlying infrastructure layer – and a warning to future users of the model – is that links which are used by the transit layer cannot be changed in the infrastructure layer without corrupting the entire transit route network. At present, the only way to make changes to the infrastructure layer – adding an infill station on a link, for example – is to remove all the transit routes which use the link which is to be changed and to replace them after the change is made. Obviously, this has an adverse impact on the time required to evaluate multiple scenarios where changes are required to physical infrastructure, but this analysis can be done with enough time and care.

A tracking variable allows for classification of routes for visual display. For example, the CTA Blue Line consists of two branches – the Douglas and Congress which join west of the loop and continue northwest of the city to O’Hare Airport. In the model, this rail route is represented as four lines: O’Hare to Douglas, Douglas to O’Hare, O’Hare to Congress and Congress to O’Hare. Given the same tracking number these routes can all be displayed as a single blue line. While this is unimportant to the modeler, it is crucial in communicating to a non-technical or unfamiliar audience.

Headway values are stored at the route level. In the simplest case of a path served by one high frequency route, the wait time is assumed to be half the headway. For paths served by multiple routes where the passenger is indifferent to the choice of route, the wait time is half of the combined headway of the routes. Returning to the example of the Blue Line, a passenger at O’Hare traveling to the Loop is indifferent between a Congress or Douglas train and will board

the first train which arrives. Thus the wait time is half the combined headway of the branches. On the other hand, a traveler continuing on the Blue Line to one of the branches takes a specific train and waits, on average, half of the branch headway.

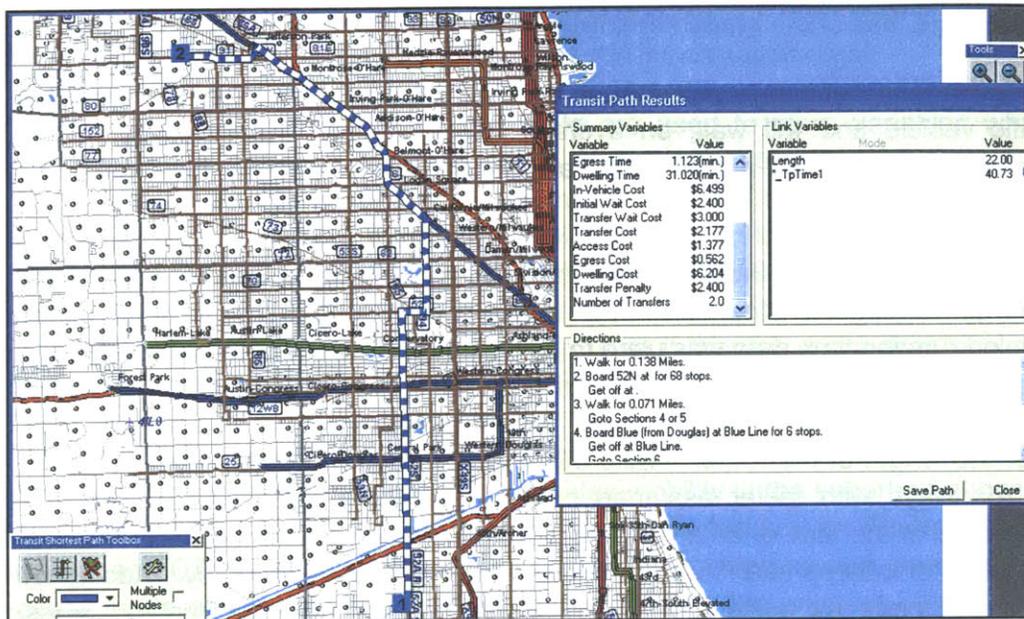
Passengers traveling on long headway routes, such as commuter rail, are likely to time their arrival for a specific vehicle and will wait, on average, less than half the headway. This phenomenon can be modeled through a maximum wait time parameter either at the route level or globally by mode.

Bus link travel times are a function of the underlying infrastructure layer link speed. This travel time was calibrated by varying the stop dwell time from an assumed 20 seconds per stop. Spring 2003 scheduled running time data was used to calculate the average travel speed for the day for the entire line. Adjustments to the assumed 0.33 minute dwell time allowed for the running time of the bus to match the scheduled time. It is acknowledged that bus running time is not constant over the length of the route. While this is partly captured in the case of routes which travel over roadways with faster assumed speeds (based on their classification), a shortcoming of the model is the lack of data on the spatial distribution of running time. As this data becomes available its incorporation into the model can improve its accuracy. Additional accuracy gains can be made by assigning automobile traffic and adjusting running times downward on congested links.

4.5 SHORTEST PATH OPTIONS

The fundamental variables underlying the calculation of transit accessibility are the travel-time costs associated with a path from origin to destination. The network model was constructed to allow the calculation of these costs. Three methods are available for their calculation. In each case, the various travel-time parameters are calculated from a set of origins to a set of destinations and stored in matrices known as skims. An example of a shortest path calculation and some of the stored values is shown in Figure 4-2.

Figure 4-2. Example of a Shortest Path Calculation



Shortest Path Method

The least sophisticated path finding method is referred to in TransCAD as the shortest path method. “This method assumes that all passengers traveling from an origin to a destination choose one itinerary that minimizes the total generalized travel cost. On any path segment only one transit line will be chosen, even when the segment is served by several transit lines with similar travel times” (Caliper, 2002). In addition to being faster to compute than other methods, the principal benefit of this method is that for each origin-destination pair there is only one value of travel cost which simplifies subsequent calculations. This is also the principle weakness of this method. Transit networks, particularly dense networks, offer a variety of paths between origin-destination pairs. Stochasticity and other difficult to measure factors will influence the route selected by passengers. This is particularly important when assigning passenger flows to transit routes. The shortest path method assigns all passengers to the route with the minimum generalized cost even if another route is just seconds longer. Obviously, this leads to unrealistic assignments with some routes overloaded and parallel routes without traffic.

Method of Optimal Strategies

“The concept of an optimal strategy may be considered as a generalization of the concept of a single path. Based on the assumption that passengers only have the information of which transit line arrives next at a given stop, a strategy is defined as a set of rules that allow the passenger to travel from origin to destination. A line segment going out of a stop will be used only if its addition to the optimal strategy will reduce the total expected travel cost from that stop to the destination. Unlike the path created by the shortest path method, paths corresponding to the optimal strategies have branches...This method returns only a matrix of skimmed values and not a specific path” (Caliper, 2002). This path calculation method more closely matches

transit passenger behavior recognizing that multiple paths exist and routes become more or less attractive as passengers pass stops along their route.

Pathfinder Method

Pathfinder is the most sophisticated shortest path calculation available in TransCAD. “This method is a generalization of the old UTPS and other methods, in which multiple paths are utilized between a single O-D pair. Similar service characteristics are combined into common trunk links, even in hard cases characterized by: different transit travel times for route segments; different stopping patterns; different route layouts; paths over transfer points. The Pathfinder method computes the reduced first wait associated with the fact that different routes could be used to reach a destination because of overlapping service. The algorithm preprocesses the transit network and builds trunk links...In order for transit links to be combined into a common trunk link, their impedance has to be similar (but not identical) and less than a user-defined threshold, which cannot exceed 25% of the best path impedance. Once it has preprocessed the network, Pathfinder builds vines on the combined network” (Caliper, 2002).

Experience suggests this pathfinding method is the preferred method for analysis, particularly the assignment step of the four-step model. This pathing method is particularly powerful in dense transit networks where many routes offer competitive service. As this is the case in Chicago, the pathfinder method was originally selected for use in the accessibility analysis. Unfortunately, several bugs were encountered with this “state of the art” method. TransCAD recorded inconsistent travel times between origin destination pairs under identical scenarios. This inconsistency translated into a change in accessibility – sometimes a large change – where none was expected. As a result, the analysis was conducted using the simpler shortest path method.

4.6 PARK AND RIDE

The large Chicago region modeled has dense transit service in the core with walk-access being the primary access mode, but as one moves away from the CTA service area fixed route transit service becomes sparser and access times to stops increases. To adequately capture the impact of major transit investments on much of the region, the provision was made for a drive-access mode to outlying commuter rail and rapid transit stations with park-and-ride lots.

Importance to METRA

A recent Chicago Tribune article highlights the importance of park and ride access to Metra commuter rail stations. “The feeder bus service provided by Pace to commuter train stations in the suburbs has been an abysmal failure, serving only 3 percent of Metra riders. Fifty-eight percent of Metra customers get to the train by driving. In the outer-ring suburbs, up to 90 percent of Metra riders drive to the stations.”

“Metra officials are well aware that growth in train ridership is directly tied to the availability of parking spaces. This year, 14 suburbs have requested additional parking that would cost \$26 million, and Metra is trying to fulfill as much as it can. But the strong focus on increasing parking

capacity--Metra estimates 35,000 more spaces will be needed by 2010--threatens to hold back any potential increases in bus-to-rail commuting, which has been one of the more difficult transit markets to serve." (Hilkevitch, 2004).

As shown in Table 4-2, a combination of walk and drive access accounts for 94% of trips on Metra, thus the decision to exclude Pace feeder buses from the regional model is not a serious limitation. Moreover, a regional model without provision for drive access would not have captured the impacts to a large portion of the region which does not have convenient access to train stations.

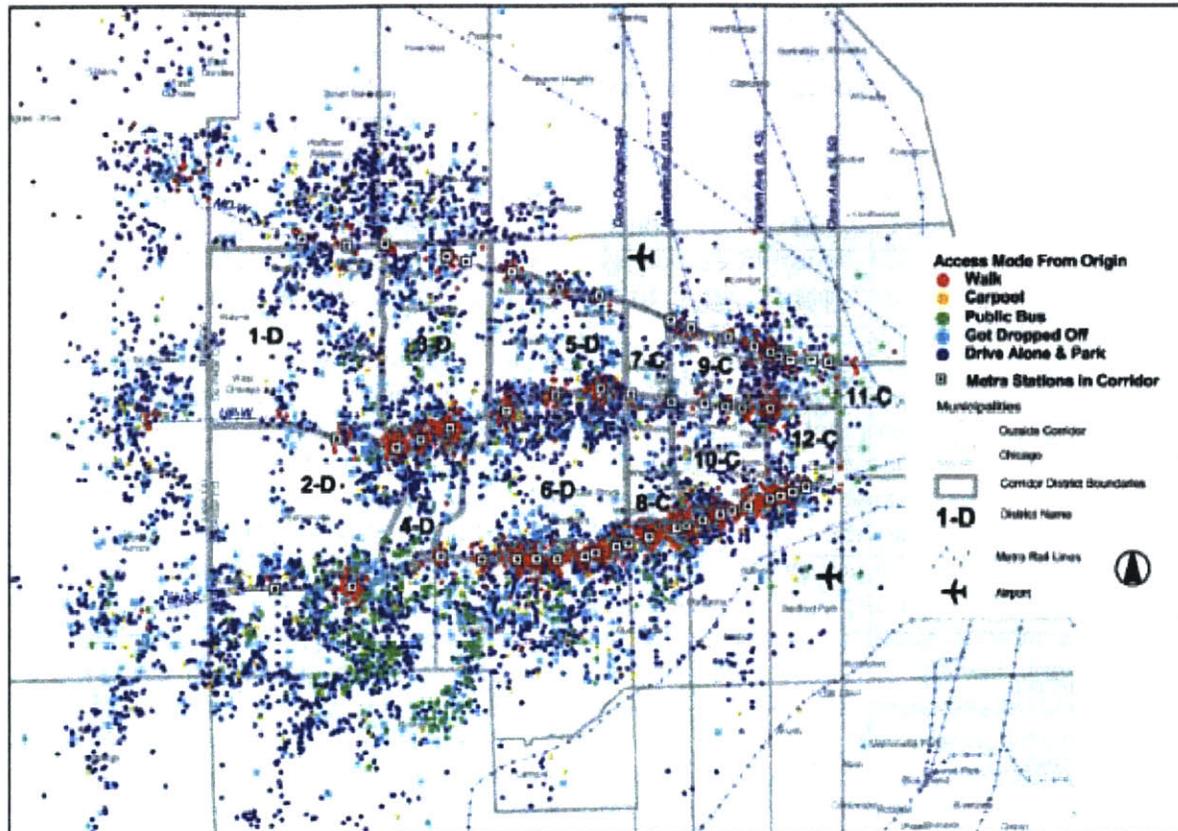
Table 4-2. Metra Access Mode

Walk	Bike	Drive Alone	Carpool	Dropped Off	Taxi	Rapid Transit	Bus	Other
21%	1%	53%	4%	14%	1%	1%	3%	1%

Source: Metra Fall 2002 Origin-Destination Survey, Cook-DuPage Corridor Travel Market Analysis Study, 2004.

A separate onboard survey of Metra passengers was analyzed as part of a study of transportation options in the western portion of Chicagoland. Passengers were asked to identify their access mode and provide their home address. The results of the survey were geocoded and are presented in Figure 4-3. The map makes clear the dominance of drive access to commuter rail stations beyond a short walking distance. Bus access, at least in the corridors shown here, does not appear to be a dominant access mode except in the southwest. The accessibility maps presented in Chapter 5. show a similar access profile.

Figure 4-3. Metra Customer Origins by Access Mode



Source: Cook-DuPage Corridor Travel Market Analysis Study, RTA, 2004

Limited Importance to CTA

The Chicago Transit Authority maintains nearly 5800 park and ride spaces, which represent a very small percentage of the more than half-million rail trips taken each weekday. Drive access to the rail system is a very minor contribution to overall ridership levels. At present, customers are charged between \$1.50 and \$1.75 per day for park-and-ride access. Half the lots do not fill to capacity as shown in Table 4-3, a testimony to the high levels of service on feeder bus routes.

The exceptions are the large lots on the Blue Line extension to O'Hare. In addition to being utilized by suburbanites commuting radially inward, they are also an option for air passengers who use the Blue Line to continue on to O'Hare. The pricing schemes at Cumberland specifically make this option attractive. The park and ride fees are a minor but important source of revenue for the authority.

Table 4-3. CTA Park and Ride Facilities

Rail Line	Station	Spaces	Occupancy
Blue	Rosemont	797	107%
Blue	Cumberland	1633	91%
Blue	Forest Park	1051	90%
Blue	54 th /Cermak	82	21%
Brown	Kimball	73	120%
Brown	Kedzie/Lawrence	50	106%
Green	Ashland/63 rd	235	55%
Green	Garfield	117	N/A
Orange	Midway	299	130%
Orange	Pulaski/51 st	390	110%
Orange	Kedzie/48 th	160	99%
Orange	Western/49 th	200	104%
Orange	35 th /Archer	69	101%
Orange	Halsted/Archer	31	84%
Purple	Linden	328	54%
Red	Howard	328	107%
Yellow	Skokie	750	78%

Source: CTA System Map, 2003. Occupancy from internal CTA planning data. Occupancies larger than 100% represent turnover of spaces over the course of the day.

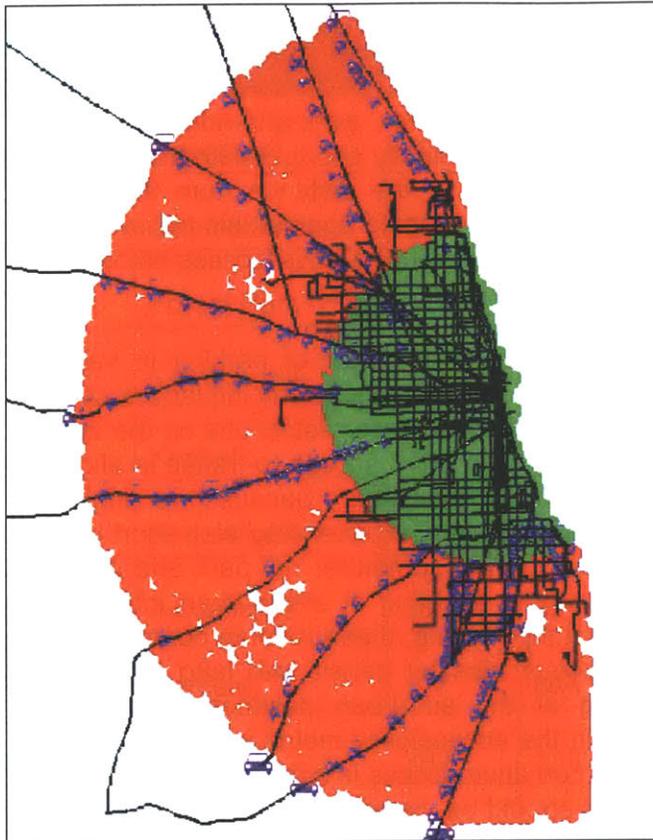
Modeling Drive Access to Transit

Modeling park-and-ride access is challenging because it is asymmetric – a vehicle is available on the access end of a transit trip but not on the egress end. Furthermore, the model, in its current state, does not contain information on congested travel times. Consequently, drive times are almost always faster than travel by transit. Moreover, park-and-ride capacity is unconstrained to simplify calculations. As a result, computing strictly shortest path transit travel times can result in the unrealistic behavior of driving most of the distance from the origin, parking, and taking a short transit trip to the destination. To mitigate against this behavior and more accurately capture the true impact of drive access to transit, the drive access times were limited to 15 minutes and weighted heavily in the generalized cost function.

The network model was developed without reliable data on the cost of parking in various locations. Parking cost is a primary determinant of mode choice and similarly influences choice of access mode to transit. The absence of parking cost data requires restrictions on the zones where drive access to transit is permissible. Specifically, no drive-access-to-transit is allowed within 10 miles of the downtown loop. This restriction was necessary because we originally encountered a counterintuitive phenomenon. Urban origins were experiencing very short transit travel times to suburban job centers by driving to an outlying commuter rail park and ride lot, boarding an outbound commuter rail train for a stop and alighting at a suburban job center. While undoubtedly, some Chicagoans engage in such trip making, these reverse commute trips are often acknowledged as some of the most onerous trips by transit with long headways, hostile pedestrian environments and free parking at the suburban destinations. It was considered unrealistic to weight these trips heavily in the accessibility metric when they are so rarely taken in reality. The ten mile radius prohibition on drive access is admittedly arbitrary and the value of accessibility on the border of this radius should be viewed with some suspicion. A more realistic description of the park-and-ride access mode was simply not warranted given the limited impact of this mode on the CTA service area.

Figure 4-4 illustrates the zones where drive access is allowed and those where transit access is confined only to walk-access. This is admittedly an arbitrary cut-off, but without more data on parking costs, lot capacity, and vehicle availability throughout the region, it is necessary. The figure also identifies the stations which were defined to have park and ride lots available.

Figure 4-4. Park and Ride Locations and Catchment Area



Analysis zone centroids eligible for drive access to transit are shown in red. Those centroids within a 10-mile radius of the Loop are limited to walk-only access to transit and are shown in green. Stations with park and ride available are shown in purple.

4.7 CONCLUSION

Considerable effort was expended in developing a transit network representation that could be sensitive to changes in the CTA transit network. It must be considered a work in progress as its accuracy can certainly be improved with more data. In the next chapter the impacts of changes to the transit network will be explored using the outputs of the network model.

5. FINDINGS AND ANALYSIS

This Chapter applies the accessibility model to the Chicago Transit Authority illustrating the potential for the methodology to be used as an in-house planning tool that screens alternatives in a simple, fast and transparent process

By measuring the change in transit access to jobs and residents the accessibility analysis highlights development opportunities for residential and commercial development resulting from a project.

The first project analyzed in detail is the Circle Line – a major transit expansion to connect the radial lines of the CTA heavy rail system and Metra commuter rail. The second application of the model is assisting the design of a project by evaluating potential intermediate stations on express trains between the Loop and two major airports.

5.1 INTERPRETING THE ACCESSIBILITY ANALYSIS

The output of the transit shortest path calculation from the network model is a travel time matrix, comprised of several components, which is summed to give the total transit travel time between origin destination pairs. The path selected as the shortest depends on the generalized cost weights discussed in the previous Chapter. The travel time between centroids is converted into an impedance score which ranges between zero and one using the function estimated in Chapter 4. Impedance values start at one for a very short travel time and decrease asymptotically toward zero as travel time increases. The accessibility between OD pairs is then calculated as the impedance multiplied by the opportunities at the origin or destination. Opportunities refer to a variety of variables; this thesis measures access to employment, residents, and flights in addition to suggesting other applications.

Two basic interpretations of the scores are available from each analysis. One is the ease of getting to a destination to satisfy a need, the other is the ease of traveling from an origin. In the case of access to employment, the calculation involves measuring the ease of traveling from an origin and is weighted by the number of jobs at a destination. For an access-to-residents calculation, the calculation measures the ease of traveling to a destination weighted by the number of residents at an origin. The access score of a particular zone is the sum of scores to all accessible pairs.

In general, the model uses walk access to transit to calculate accessibility if it is a viable option. Drive access to transit is only an option if the origin is outside of a 10-mile radius of the loop and there is no path to a transit stop with a walk access time of less than 20 minutes. This was necessary to limit trips with very long and unrealistic drive access components (ie radially outward drive-access-to-transit trips) and remove errors in the shortest path calculations which were caused by bugs in the software. This crude limitation on drive access to transit results in accessibility scores which are not continuous across space. Sharp changes occur at the boundary between drive and walk access modes in the suburbs. This is not a problem in the CTA service area where drive access is not permitted and bus service is extensive.

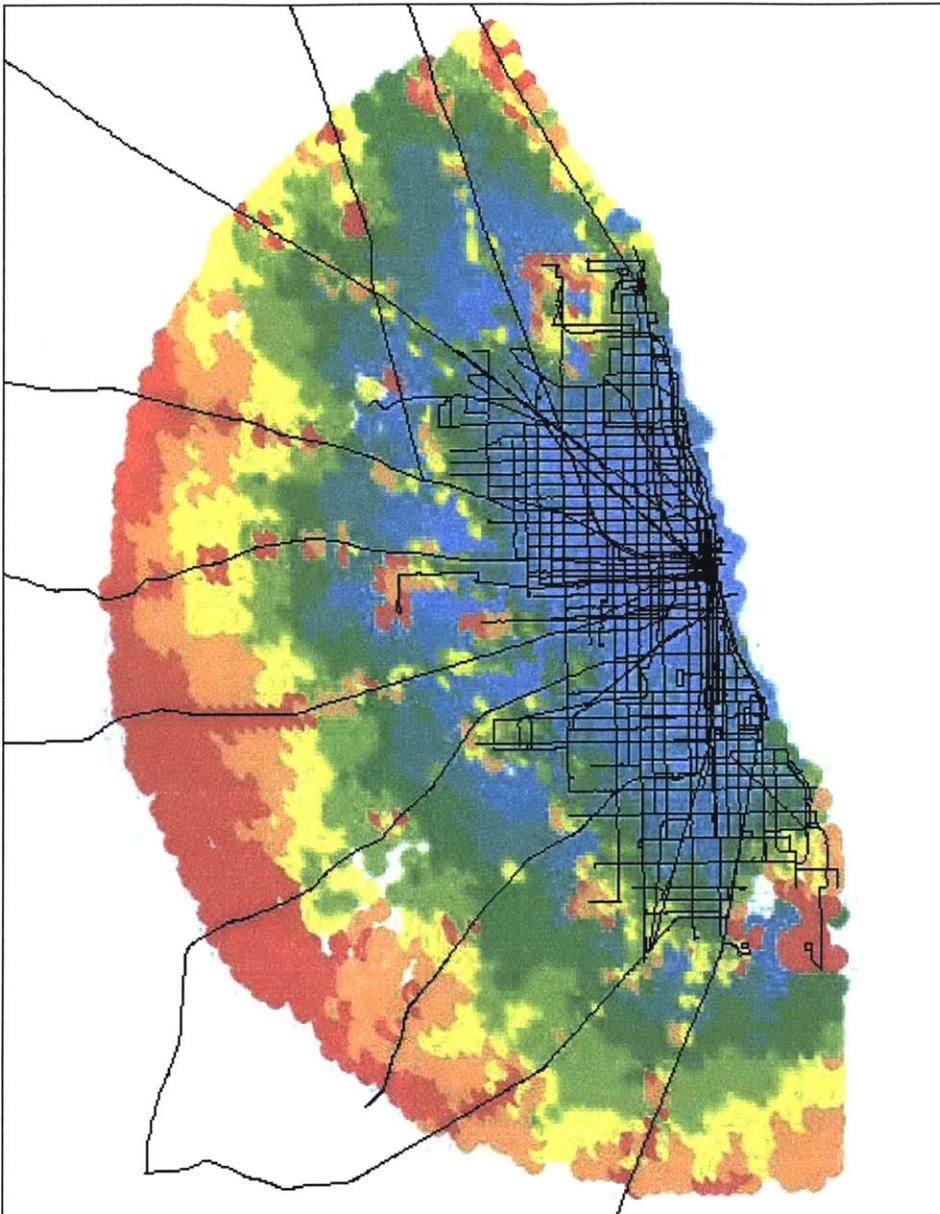
Additional discontinuities are introduced because total trip lengths are limited to two hours of travel time by transit. As a result, many of the more than sixteen million origin-destination pairs are not connected by transit and do not contribute to the accessibility score. It would have been preferable to include very long transit trips in the evaluation as the impedance function would have converted them into very small values, but the calculation time and storage space precluded saving these trips.

As a result of drive access, egress, and total trip length cutoffs, boundary effects are noticeable and accessibility is not continuous from zone to zone. This is a shortfall of the model which requires careful analysis and interpretation of the results. These boundary effects are particularly pronounced because of reliance on the shortest path calculation algorithm (software bugs were detected in the more sophisticated pathfinder method). When evaluating changes to the transit network, a small change in the generalized cost may result in a radically different path being selected to connect an OD pair. This, in turn, reveals itself in a change in travel time and hence accessibility. In the course of this research a pattern emerged in which these large changes in accessibility, seemingly unrelated to the network changes being evaluated, occurred near the boundary between walk and drive access and near stations which are park and ride lots. For this reason, caution is advised when attempting to explain a change in accessibility at a particular node in these regions. Generally, the accessibility change maps are best used for identifying corridors of change rather than change at a specific node as discontinuities in the means of calculating transit travel time inevitably results in outliers.

Unweighted Transit Travel Time Image

The sum of travel times to all destinations is presented in Figure 5-1. That is, each point represents the sum of travel time from the zone shown to all other zones. Cool colors on the scale represent shorter aggregate travel time and warm colors are long aggregate times. The image is generally what one might expect, the further the origin from the center of the transit network - and from the center of the analysis area - the longer the trips by transit and thus the larger sum of travel time to all possible destinations. Note the higher travel times near Metra commuter rail stations and at the periphery of the CTA bus network. These long travel times relative to their neighbors are because drive access to transit is not available to zones where walk access to transit is available and these nodes are near the boundary of the walk access radius.

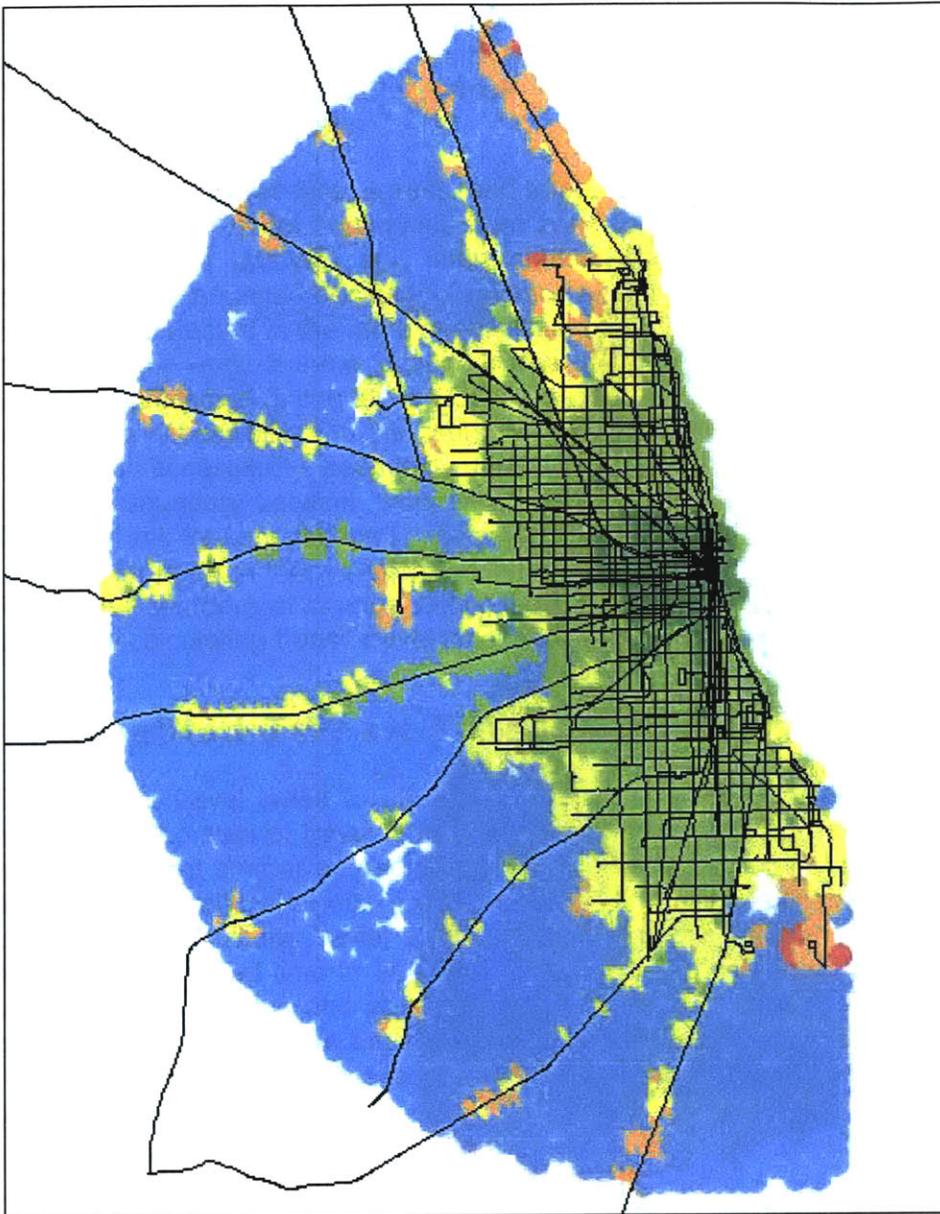
Figure 5-1. Sum of Travel Time at Origin



Travel time sums are shown from low to high using cool to warm colors, respectively

The sum of travel times to destinations is presented in Figure 5-2. Notice that it is impossible to take transit to a wide area of the city as indicated in blue. In this case, cool colors are very low aggregate travel times because they are beyond the service area of transit. The only interchanges connected in this region are served by walk trips. In the far suburbs, only zones located close to Metra stations are within walking distance and thus appear accessible. Inside the CTA service area, as we would expect, trips to the center of the transit system are shorter than to the periphery. The longest trips (indicated in red) are to the far south and north sides of the city.

Figure 5-2. Sum of Travel Time at Destination



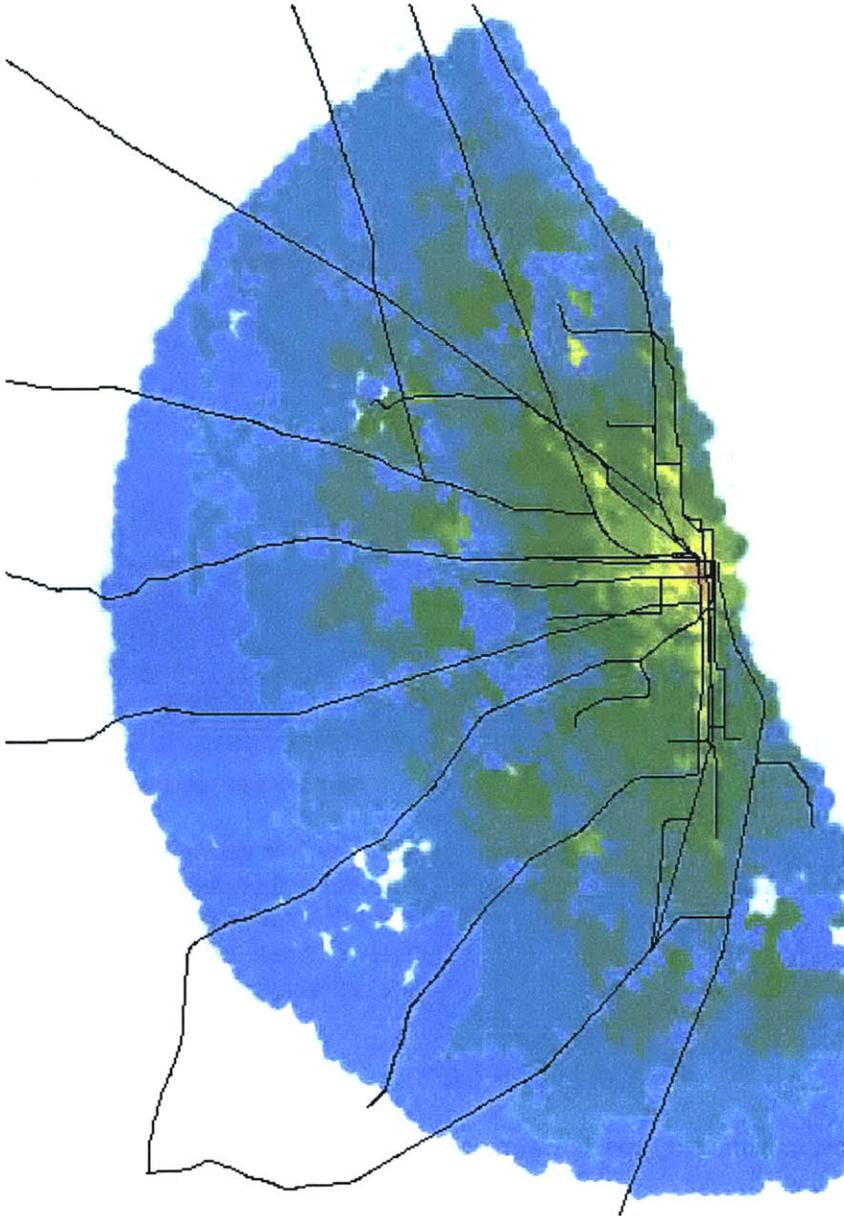
Travel time sums are shown from low to high using cool to warm colors, respectively

Impedance Image

Travel times between origin-destination pairs are converted into impedances using the function estimated in Chapter 4. The sum of impedances to all destinations plotted at the origins is the inverse of the travel time images. Travel time plots show how long trips will be, impedance plots show how many places are accessible. Very many places are accessible from the center and fewer places are accessible from the periphery. Boundary effects from the drive access restrictions are very visible in Figure 5-3. Zones with drive access can reach many more places

than those confined to walk access which is why blue zones exist next to green at a distance from the city center.

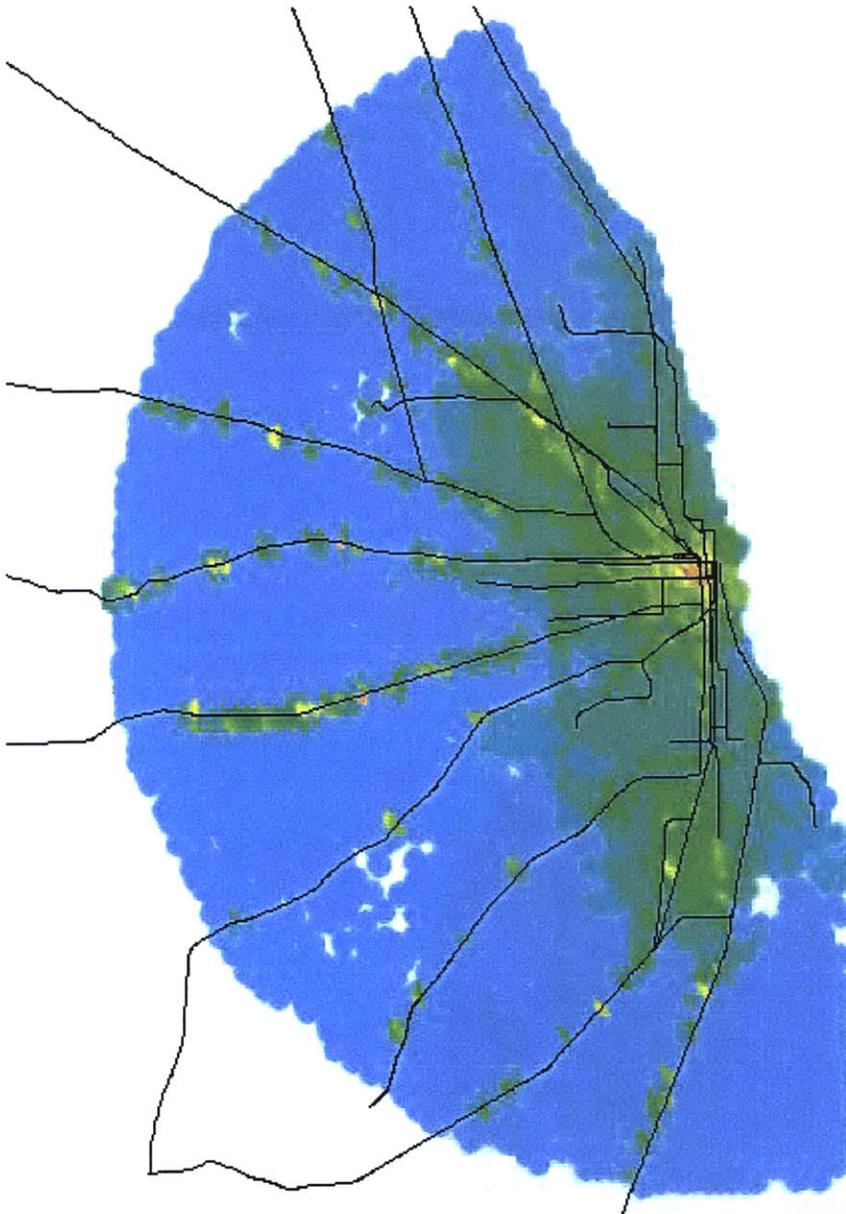
Figure 5-3. Sum of Impedance at Origin



Impedance scores are shown from low to high using cool to warm colors, respectively

The sum of impedance at the destination of transit trips is shown in Figure 5-4. Similar to Figure 5-2 the suburban locations beyond the walking distance of commuter rail stations have very low impedance sums because zones beyond walking distance cannot reach these destinations. As you might expect, zones near the center of the transit network and along rail lines are relatively easier to access by transit and have high impedance sums.

Figure 5-4. Sum of Impedance at Destination

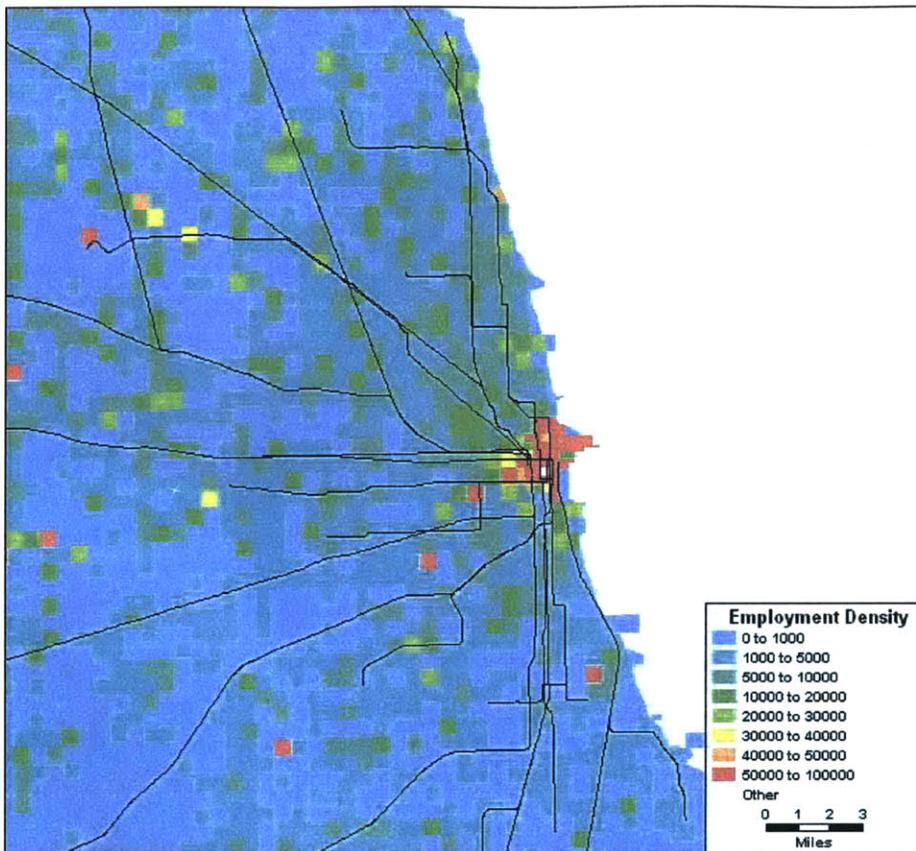


Impedance scores are shown from low to high using cool to warm colors, respectively

Employment and Residents Map

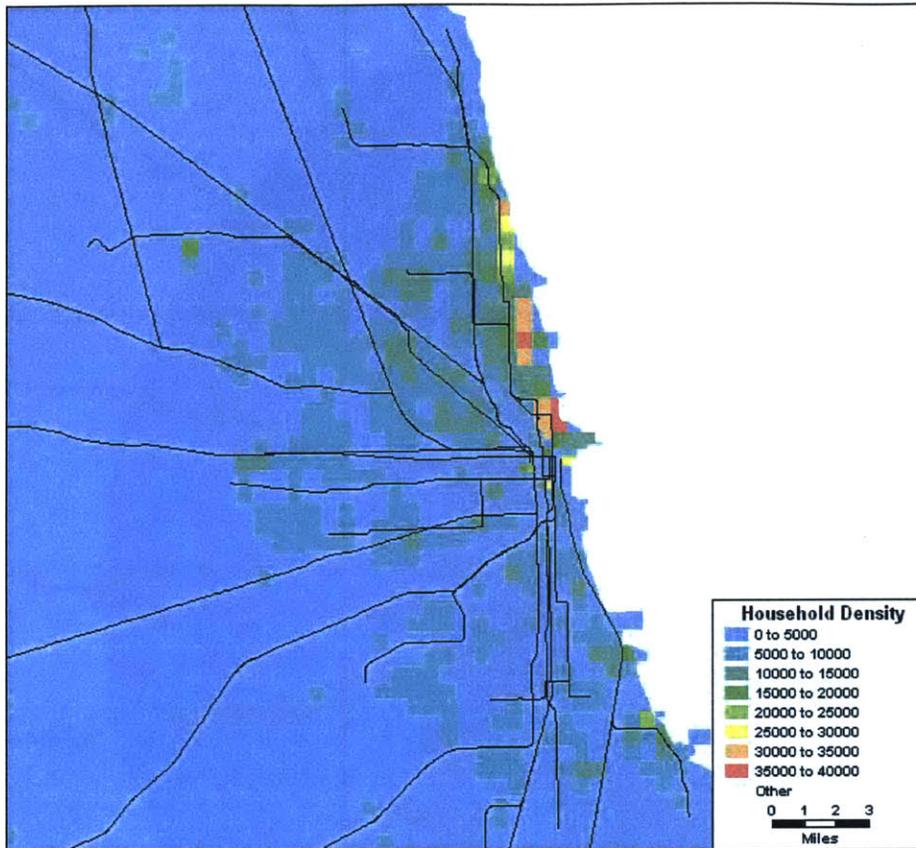
Impedance between OD pairs is multiplied by employment at the destination or residents at the origin to calculate employment accessibility and resident accessibility respectively.

Employment density for the Chicago region is plotted in Figure 5-5. Note that much of the employment in the city is concentrated in the CBD although, O'Hare, the Medical Center, and the University of Chicago also stand out. Transit service which reduces travel time to these regions of high employment will rate better than others in an access to employment score.

Figure 5-5. Employment Density

Units are jobs per square mile

Residential density in the Chicago region is plotted in Figure 5-6. Chicago has a high density concentration along the Lakefront extending north from the CBD. The low residential density to the West and South of the CBD is a result of redevelopment of the high rise public housing projects. Transit service which results in shorter trips to the northern lakefront and other concentrations of population will result in higher customer/employee access scores.

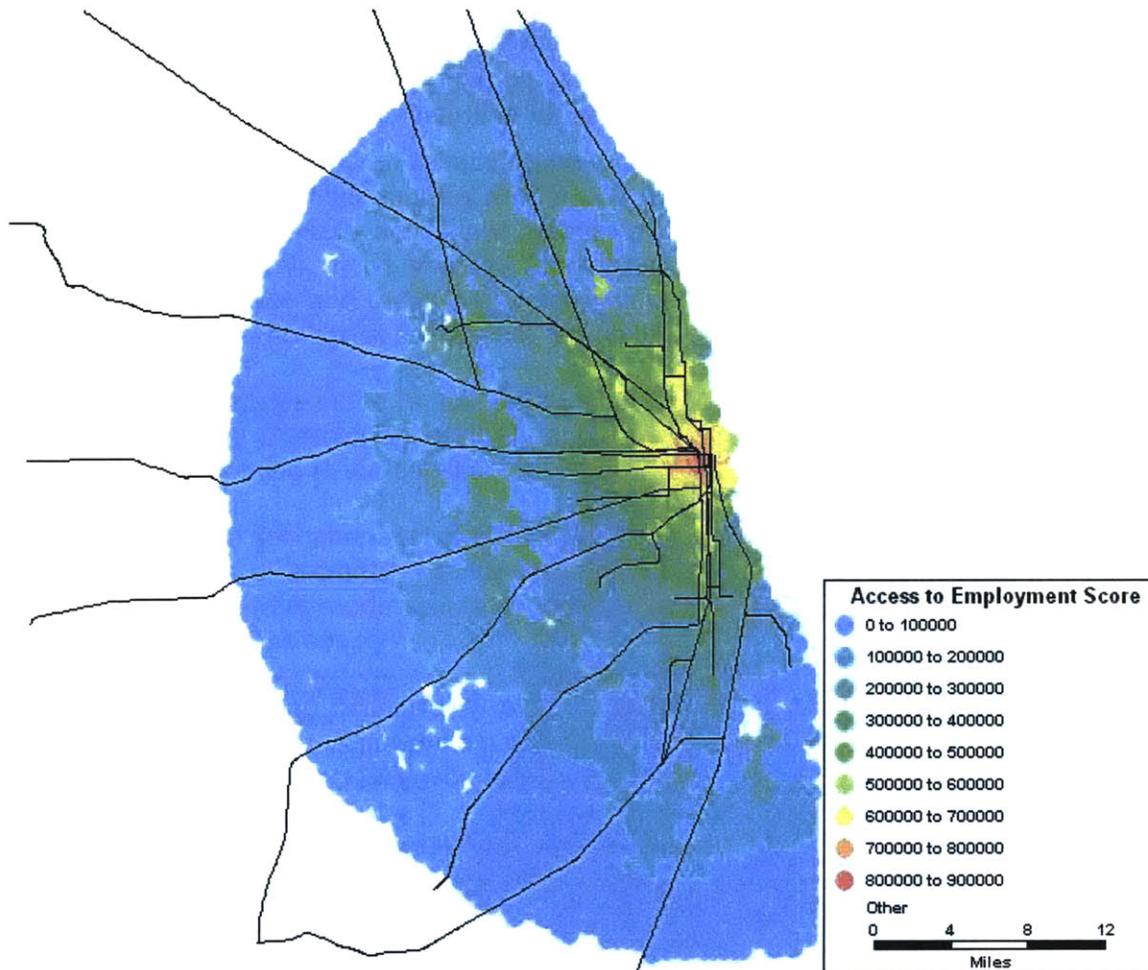
Figure 5-6. Residential Density

Units are households per square mile

5.2 BASE ACCESSIBILITY FOR CHICAGO

The geographic distribution of transit access to jobs for the Chicago region is presented in Figure 5-7. The interpretation of this map can best be summarized as it provides an answer to the question: Where should I locate my residence if I want high transit access to employment? The answer, according to the map, is along the rail lines and close to the CBD. Transit access, as you would expect, falls off in the periphery. This map can be conceived of as a two dimensional representation of the transit level of service at the origin of a trip.

The units of the accessibility score in Figure 5-7 are “weighted jobs accessible by transit” *from* this location. The units of the accessibility score shown in Figure 5-8, conversely, are “weighted residents accessible by transit” *to* this location. When interpreting the magnitude of the scores it may be useful to note the total population and employment in the study area is 5,273,009 and 2,744,456, respectively.

Figure 5-7. Transit Access to Employment

The units of the Employment Accessibility Score are “weighted jobs accessible by transit”

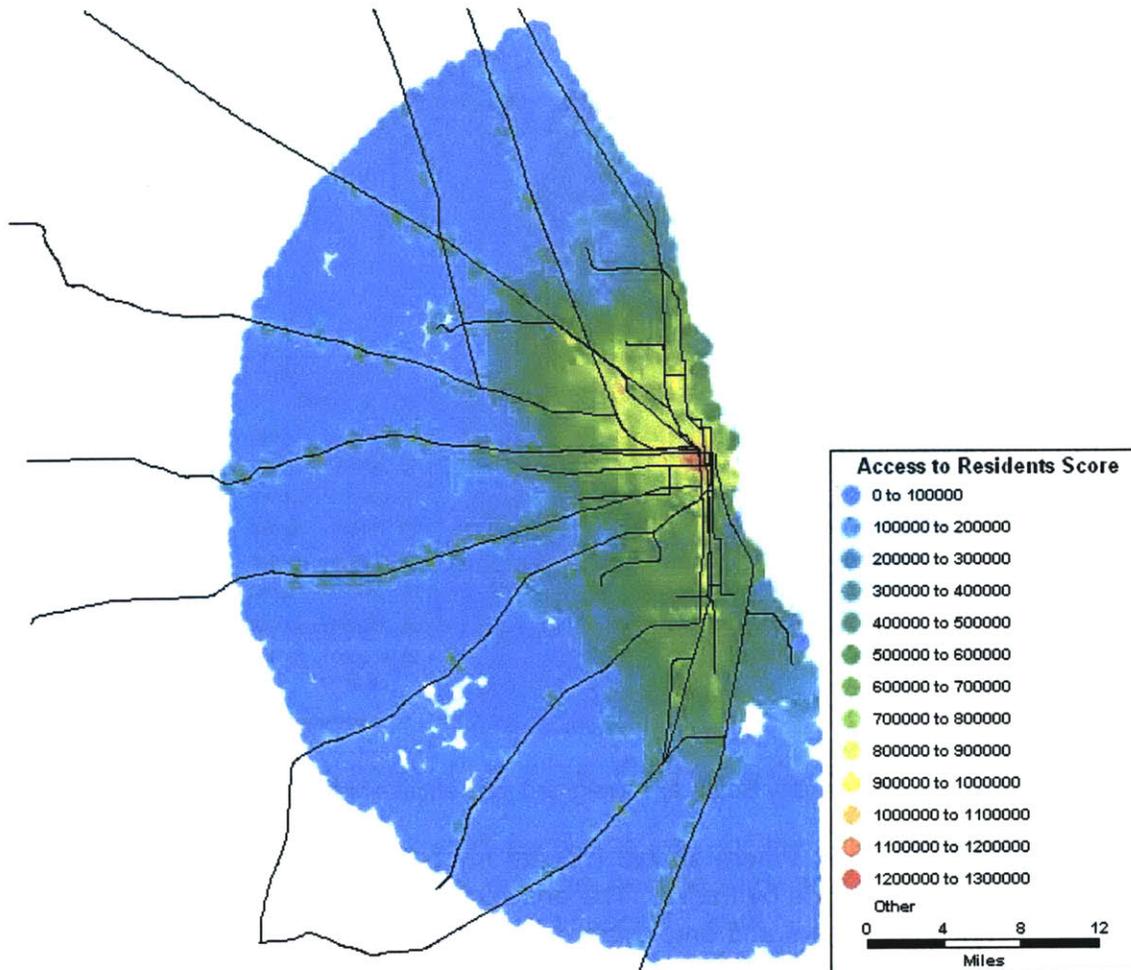
Figure 5-8 answers the question: Where should I locate my business so that customers and employees have high access to me by transit. The answer is more diffuse than in the case of residential location since customers and employees are spread more uniformly throughout the region and not concentrated in the CBD like employment. The CBD is a very accessible place to locate a business, however, as are the rail lines to the northwest. In the suburbs it is absolutely necessary to locate within walking distance of commuter rail stations if one wants employees or customers to access a business by transit. The northwest quadrant generally has high accessibility because of cross-town service to the heavily populated lakeshore corridor.

Figure 5-8 is also an indication of commercial development potential because it is a measure of the ease of reaching a destination as weighted by the number of people in its proximity. The accessibility model captures the interaction between transportation and land use by linking attributes of the transit system with land use variables.

While there is little evidence that transit investments lead to overall regional growth, enhanced transit access is likely to foster some redistribution of regional growth. The accessibility model

provides a means of measuring the enhanced transit access but it does not intend to quantify the amount of land use change or assess its benefits. A large number of factors influence economic development and there are difficulties inherent in all economic forecasting that makes land use changes difficult to predict. Nevertheless, corridors which have enhanced transit access can reasonably be expected to be candidates for land-use change.

Figure 5-8. Transit Access to Residents



The units of the Residents Score is “weighted residents accessible by transit” which can be interpreted as the number of employees or customers who can reach the site by transit.

5.3 ACCESSIBILITY AND JOURNEY-TO-WORK MODE SPLIT CORRELATION

One advantage of the accessibility metric is that its performance can be quantitatively assessed against observed behavior. The accessibility score was designed to reflect the attractiveness of transit service for work trips across space. The underlying assumption is that zones with high transit accessibility scores should have high transit ridership. If this relationship holds then it can be argued that changes to the transit network which increase accessibility are associated

with increase benefits of transit as measured by an increase in transit mode split. Without this argument it is more difficult to argue for using change in accessibility to evaluate transit proposals. There is a difficulty in establishing causality in this correlation between transit supply and transit demand. They will always be correlated because a transit agency will adjust service up or down in response to changing demand.

The correlation coefficient was calculated between the accessibility score and the zonal transit mode split as reported in the Journey to Work Census tables. Walking trips were included in the calculation of transit mode split since intensive transit service contributes to quality urban spaces with higher walk mode shares. Analytically, the network model allows all-walking trips between nearby zones and these paths are included the accessibility score. For this reason, suburban areas with no transit service are still have an accessibility score.

2470 of the 4000 zones in the region were included in the analysis. Zones which were omitted either did not have a transit accessibility score or were not the origin or destination for more than five trips according to the census.

One expects mode split and level of transit service to be positively correlated. One of the basic planning functions of a transit agency is to match the service supplied with the demand for transit. Journey-to-work mode split is an indicator of transit demand and the accessibility score is an indicator of transit supply.

The correlation between accessibility scores and mode split are given in Table 5-1 for both origins and destinations. A correlation coefficient of one indicates perfect linear correlation and a value of zero implies no relationship or randomness.

Table 5-1. Accessibility Score and Mode Split Correlation Matrix

	Transit + Walk Mode Split at Origin	Transit + Walk Mode Split at Destination
Access to Employment Score	0.708	
Access to Residents Score		0.501

The two correlations are positive, as expected, and high considering a measure of automobile competition is missing entirely from the analysis. The correlation with mode split by destination is lower because suburban zones near Metra stations generally have high accessibility scores and low transit mode splits because parking in these locations is free and transit use low. The absence of a measure of parking cost impacts the performance of the accessibility metric throughout the analysis. It can hardly be contested that high transit mode split to destinations in the CBD is due to high parking costs. Similarly, reverse commute trips to suburban employment centers have a lower mode split because parking is free.

A refinement on the correlation analysis is a multivariate regression. The census offers few variables for inputs into a regression model. Somewhat surprisingly, average auto ownership at an origin was not found to be significant predictor of transit mode split at that origin. A possible explanation can be found in Figure 2-2 which showed a large number of transit trips in Chicago

are made by people with a vehicle available. A more important determinant of mode split from a zone is likely to be parking cost at the destination.

Median income, however, was found to be significant as indicated by the large magnitude of the t-statistic. It has an expected negative sign. That is, as the median income of a zone goes up, transit mode split goes down, all other things being equal. High income travelers are likely to have a higher value of time and may be willing to pay a premium in terms of reduced travel time and higher parking costs.

The author cautions that the analysis did not control for colinearity between transit supply and transit demand. More sophisticated statistical techniques to address this deficiency are not the subject of this research. Furthermore, this colinearity makes it impossible to prove causality although the strong correlation is a validation of the accessibility metric.

Table 5-2. Transit Access Score Regression Analysis Results

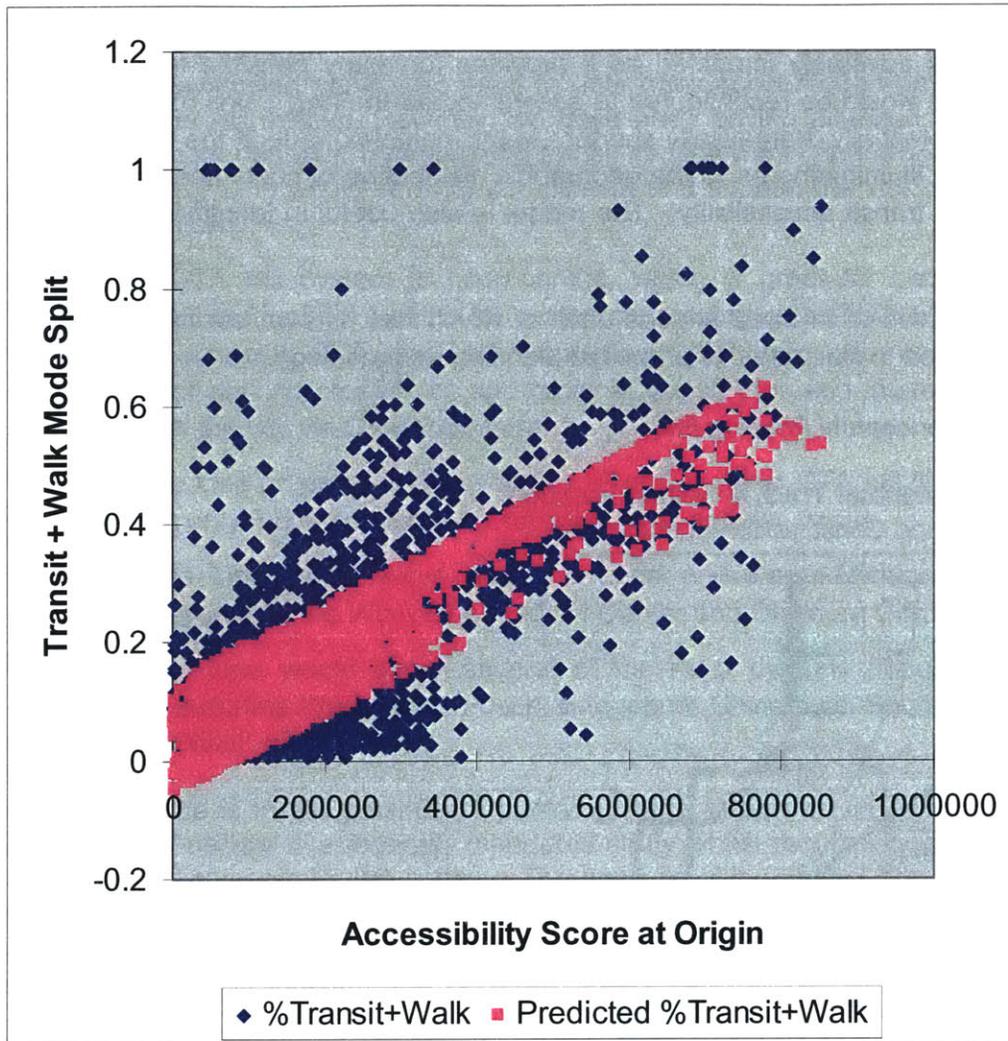
<i>Regression Statistics</i>				
Multiple R		0.76011094		
R Square		0.577768642		
Adjusted R Square		0.577426338		
Standard Error		0.117166686		
Observations		2470		

<i>ANOVA</i>				
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>
Regression	2	46.34265602	23.17133	1687.884
Residual	2467	33.86705543	0.013728	
Total	2469	80.20971145		

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	0.135224354	0.006691958	20.20699	3.8E-84
IncPercentile	-0.187495259	0.008901803	-21.0626	1.06E-90
AccessScore	6.40907E-07	1.55283E-08	41.27357	1.4E-283

Combined, the two simple measures of income percentile and accessibility score only explain 58% of transit mode split. Again, this is due to an absence of data on parking cost at the destination and competitive position of the auto for similar trips. Figure 5-9 shows the wide variation in observed mode split and the relatively narrow explanation offered by the metric. Nevertheless, the trend is clear – transit mode splits increase with increasing accessibility scores.

Figure 5-9. Accessibility Score Line Fit Plot



5.4 DESCRIPTION OF THE PROPOSED CIRCLE LINE

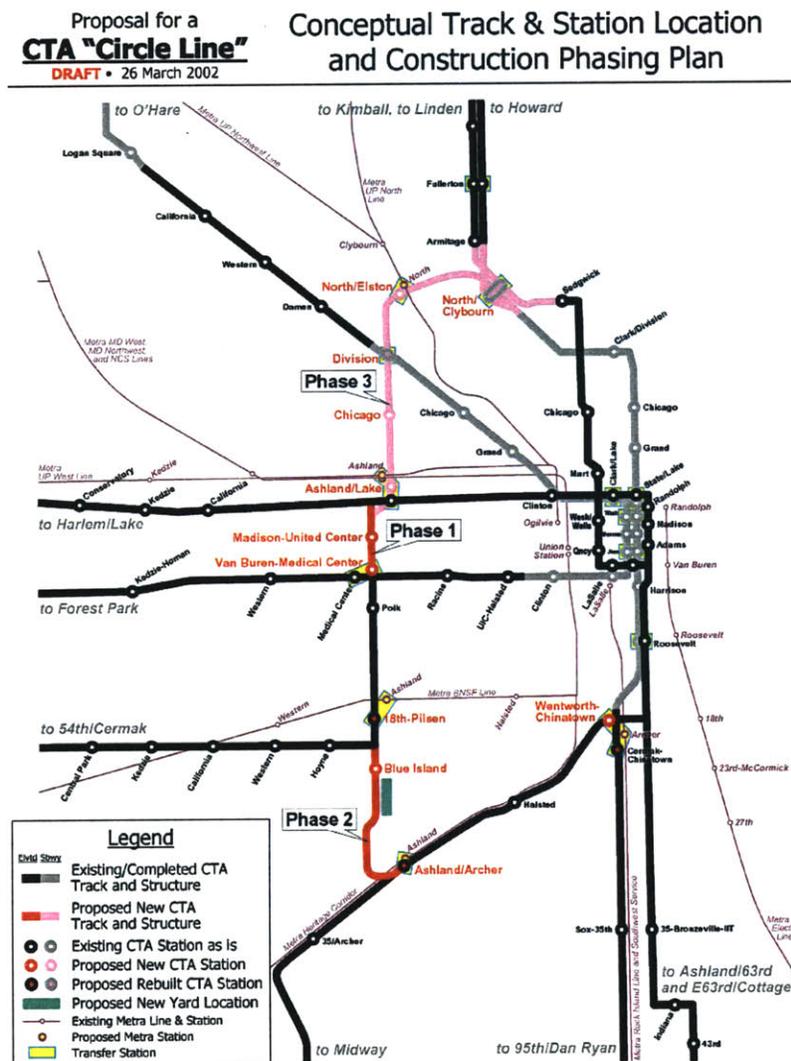
Traditional system planning at the CTA, like many transit properties, has focused on radial extensions which extend the network but maintain the focus on the downtown. The extension of the Orange Line from the Loop to the Southwest Side in the mid-nineties is an example of this focus. Expansion proposals currently under consideration include extending the Orange Line south to Ford City, the Yellow Line north to Old Orchard, the Red Line south to 130th Street and the Blue Line west to DuPage County. The Circle Line is a departure from this thinking. The Circle Line, as it is conceived, would connect the radial CTA lines outside the downtown core. Additionally, the proposal would intercept Metra Commuter Rail corridors enhancing access to the CTA system for commuter rail passengers.

With expansion proposals on the periphery of a system it is easy to conceive of the potential project beneficiaries. Rail extensions generally reduce travel times toward the city center and

the benefits accrue along the corridor. If the extension involves bus network restructuring from line-haul routes to feeder routes, some areas of the corridor may experience inconvenience as a one seat ride requires a transfer. The Circle Line is a more complicated project to conceptualize who benefits and who is adversely impacted as it provides for many possible trip routings. Existing rapid transit lines would be reconfigured to accommodate the new trains making some trips longer and others potentially dramatically shorter. In this complex tradeoff the accessibility model can be particularly illuminating as to the geographic distribution of costs and benefits as measured by changes in transit accessibility. The model is also useful in identifying potential development corridors.

The Circle Line is conceived of in three phases each of which has its own set of anticipated benefits which are analyzed to illustrate this proposed planning methodology.

Figure 5-10. Circle Line Conceptual Phasing Plan



Source: www.chicago-l.org

The CTA motivation for the Circle Line project are articulated in a draft planning summary of system expansion proposals generously shared with the author by Jeff Shriver. The project conception is as follows:

“Many CTA expansion plans discussed to date have concentrated on extensions to the outer reaches of the rail system. Recently, we have been paying attention to expansion plans that improve our core capacity. By improving transit service within and around the Central Area, the proposed Circle Line would strongly compliment and support the vision and goals in the City’s Central Area Plan.

- Today’s CTA rail system is Loop-centric, which is great for Loop-bound trips, but this network means indirect service for customers making cross-town trips. Creating a new rail line that connects CTA and Metra outside of the Loop will improve CTA’s competitive position for serving cross-town and regional transit trips and improve access between the region and the city via CTA and Metra
- The Circle Line proposal is a way to link all of Chicago’s CTA rail lines, and all of the Metra lines, with only 6.6 miles of new or rebuilt “L” and subway tracks
- The Circle Line would serve both the Loop and North Michigan Avenue employment centers, as well as the West Side Medical Center and Clybourn Corridor areas.
- The Circle Line would serve several of the most densely populated neighborhoods in Chicago, including West Town, Pilsen, Bridgeport, Chinatown, South Loop, River North, and the Gold Coast” (CTA, 2004).

The Circle Line is in the preliminary planning stage known as an Alternatives Analysis. The Alternatives Analysis is a federally mandated study which requires consideration of a range of modes and alignments for the corridor. The analysis of the project completed to date has been concerned with feasibility of a heavy rail alignment along Ashland Avenue. The descriptions of anticipated project benefits represent current thinking which is likely to change as the analysis advances.

The source for proposed alignments, operating plans, and train routings are internal CTA documents prepared during the feasibility study. Anticipated benefits of each phase were summarized from the CTA System Expansion CD. For the purposes of this thesis, we will concentrate on the alignment, mode, and operating plan considered in the feasibility study. The reader is cautioned that these plans are considered by the CTA to be conceptual in nature and the planning documents referenced herein are marked as draft.

5.5 CIRCLE LINE CHANGE IN ACCESSIBILITY

Region-wide Accessibility Changes

A system wide assessment of the benefits of the Circle Line project is a measure of the aggregate change in accessibility across the region. The three phases were modeled and run to evaluate the change in regional accessibility as summarized in Table 5-3.

Table 5-3. Circle Line Aggregate Accessibility Analysis Results

	Employment Access Score	Change from Base	Change from Previous	Resident Access Score	Change from Base	Change from Previous
Today	669,579,061			784,599,996		
Phase 1	679,917,067	1.54%	1.54%	795,502,678	1.39%	1.39%
Phase 2	681,731,258	1.81%	0.27%	797,401,380	1.63%	0.24%
Phase 3	683,365,996	2.06%	0.24%	798,774,985	1.81%	0.17%

The regional change in accessibility score looks promising for the Circle Line. Each phase increases access to employment implying potential ridership gains and increased access to customers and employees implying development potential. The percent changes may appear small because the project represents a local change to a mature transit network the impact of which is felt only on OD pairs which have their trip shortened or lengthened by the new investment.

If the Circle Line project were being evaluated in a systems planning effort with the goal of ranking this project against other proposals the analysis could stop here. Other proposals could be evaluated and their accessibility change compared to that of the Circle Line. It may be appropriate to rank projects on the simple ratio of estimated cost over accessibility change. The Circle Line project holds great promise for improving transit in Chicago and has become the CTA's top priority for expansion of the system. Accordingly, the remainder of this analysis examines the geographic distribution of the accessibility change and the incremental change resulting from each project phase.

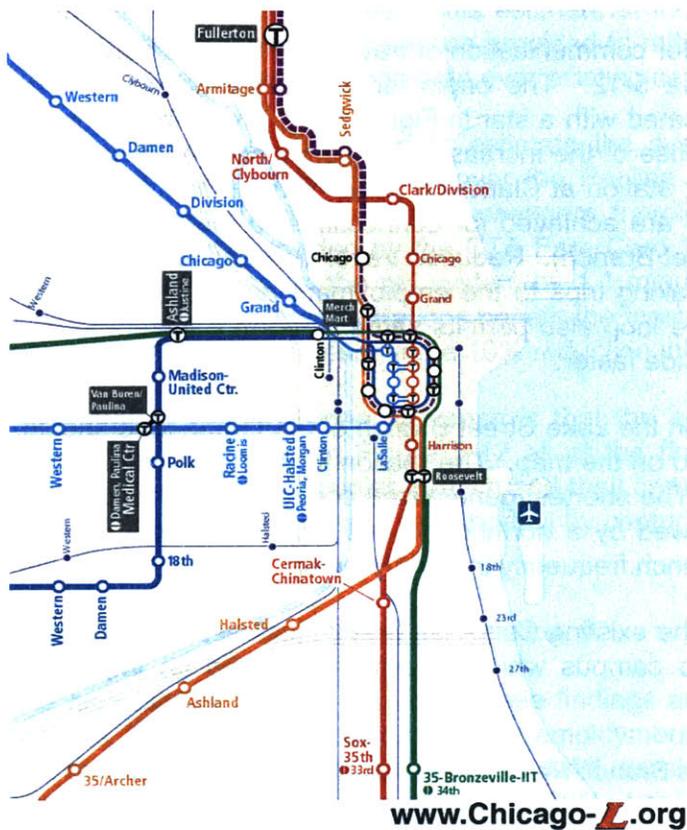
Circle Line Phase I

Phase 1 calls for restoring the 0.75 mile 107-year old "Paulina Connector" between the Blue and Green Lines. The Paulina Connector is a section of track that has not been used for passenger service since 1958, but was maintained because it is the only link between the Blue Line and the rest of the system. Figure 5-11 depicts a conceptual routing plan for Circle Line Phase 1.

The current branching configuration of the Blue Line limits the maximum service frequency to either of the Western branches because the common O'Hare branch is operating at its minimum headway in the peak period and does not require additional off-peak service. If the southern Douglas branch operated independent of the rest of the Blue Line, additional service could be provided on the Congress Branch and frequency increased on the Douglas Branch. The Paulina Connector provides an opportunity to do just this.

This analysis assumes a 10 minute headway on the re-routed Douglas Branch and a 7.5 minute headway on the Congress Branch of the Blue Line. All other headways remain the same as in the base case.

Figure 5-11. Circle Line Phase 1 Routing



Source: www.chicago-l.org

Phase 1 Anticipated Benefits

- Increased operational flexibility and improved service levels.
- The newly restored Douglas branch could be operated as an independent line to the Loop:
- Significantly improved service levels on both the Douglas and Congress Branches, benefiting the entire west side.
- CTA rail connections to the West Side Medical Center from both the Loop Elevated and Dearborn Street subway (CTA, 2004).

Phase 1 Analysis

Phase 1 primarily impacts the Douglas Branch, which is undergoing a complete rebuild which is nearing completion. This phase was subject to additional analysis because it is nearing completion and public hearings are being held to assess the environmental impacts of using the Paulina Connector to route Douglas Branch trains to the Loop.

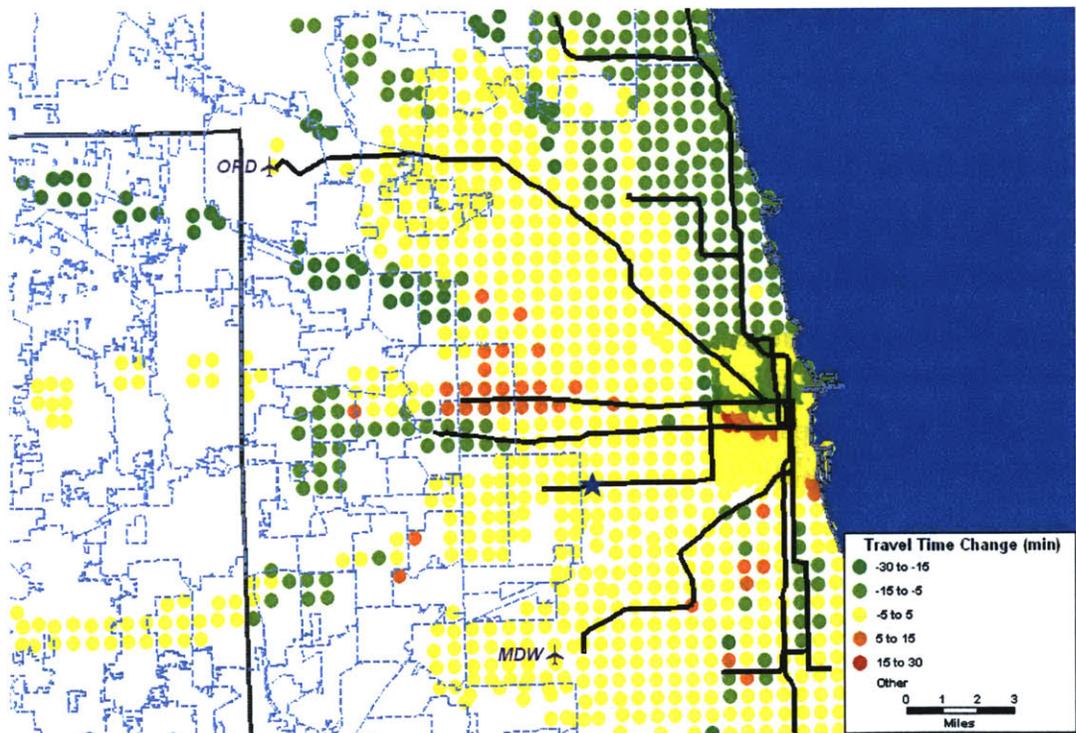
Isochrone Analysis

A simple isochrone analysis was developed for communication of travel time savings during the public outreach process, as shown in Figure 5-12. The origin for the isochrone analysis is Kostner Station on the Douglas Branch indicated with a star in Figure 5-12. From the Douglas Branch, travel times generally improve because of the increased frequency on the branch and faster travel times to the major Loop transfer station at Clark and Lake. Very impressive travel time reductions - in excess of 20 minutes - are achieved for connections to Metra at Ogilvie Station (adjacent to Clinton on the Lake Street Branch). Reduced travel time to Clark and Lake permits connections to northbound trains making trips to the employment and population rich North Side significantly faster. Access to the loop also permits same platform transfers to the Green Line making some trips to the South Side faster.

Intuitively one would expect outbound trips on the Lake Street Branch of the Green Line should also be faster although they do not appear so on the map. The reason for this is specific to the station selected for the isochrone analysis. The shortest generalized cost path from the station selected involves an outbound rail trip followed by a northbound bus trip which takes slightly longer due to reduced outbound Douglas Branch frequency in the AM peak.

Most adverse impacts are concentrated on the existing Congress Branch just west of the Loop. This is the University of Illinois at Chicago campus which is perceived to be an important destination for Douglas Branch customers.

Figure 5-12. Travel Time Change from Douglas Branch Rerouting



Travel time changes are from the Kostner Station on the Douglas Branch

A CTA Market Research survey indicates 5% of Douglas Branch riders access these three adversely impacted stations. Using the network model to calculate the change in travel time

resulting from the re-routing, it was estimated that the average trip length for these customers will increase by 10.9 minutes. This estimate of increased travel time is important because it suggests that additional bus service provided to mitigate against this impact should offer travel time savings of the same magnitude over existing service.

The network model was used to estimate the system-wide change in travel time from the rerouting of the Douglas Branch over the Paulina Connector. This travel time change was weighted by the number of rail passengers traveling between station pairs using an origin destination matrix provided by the CTA Fare Card Model.⁷ System wide, the reroute reduces average travel times on the rail system by 1.1 minutes from 36.5 to 35.4 minutes. Rail riders who board Douglas Branch stations benefit the most from the re-route saving an average of 3.2 minutes per trip and representing a 10% reduction in passenger-minutes of travel.

A shortfall of the isochrone approach is that the analysis is dependent on the specific zone selected for analysis. In Figure 5-12 all of the findings are specific to travel time from the Kostner station on the Douglas Branch and they cannot be generalized across the system. The accessibility model addresses this shortfall by capturing the change in travel time for all possible interchanges.

Accessibility Analysis of Phase 1

The accessibility analysis supports these findings and validates CTA expectations of Phase 1 benefits. Region wide, transit access to employment increases 1.5% and access of customers and employees to workplaces improves 1.4% as shown previously in Table 5-3. Figure 5-13 shows the incremental change in accessibility from Phase 1 of the Circle Line over the base case. Geographically, the benefits are concentrated on the West side and along the O'Hare Branch. This is primarily a result of the increases in frequency permitted by uncoupling the branching lines. Note in Figure 5-13, the zones near UIC indicate a decrease in accessibility indicating the need for some degree of mitigation. The benefits from Phase 1 also extend into the northwest suburbs, mostly likely resulting from enhanced connectivity at Oglivie Station.

The concentration of adverse accessibility change in Evanston, north of the City are a result of decreased service at the Congress-Branch Clinton stop which is the rapid transit station which offers connections to Union Station, the downtown commuter rail terminal for the Metra District North Line. Explanation for the sporadic accessibility changes in the west and southwest is less clear and is likely a result of boundary effects.

⁷ The AFC Model is discussed in the concluding chapter 6.

Figure 5-13. Phase 1 Incremental Change in Access to Jobs

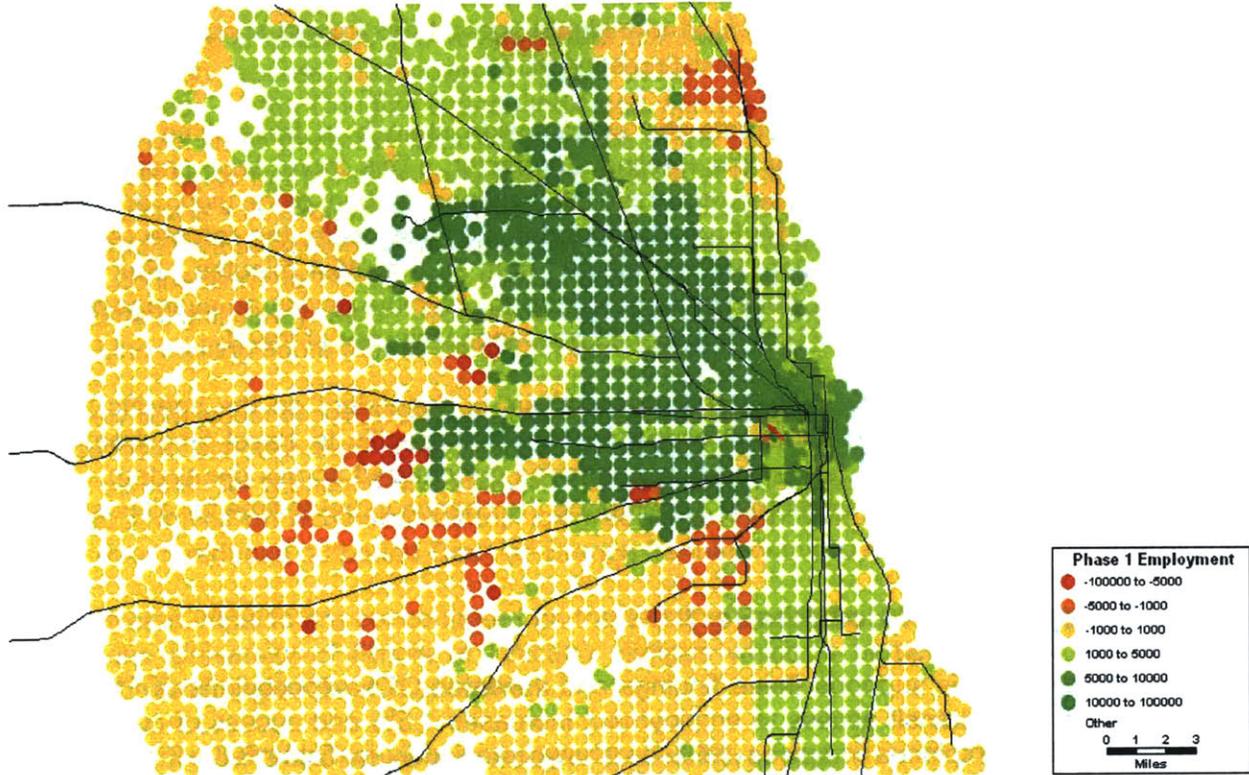
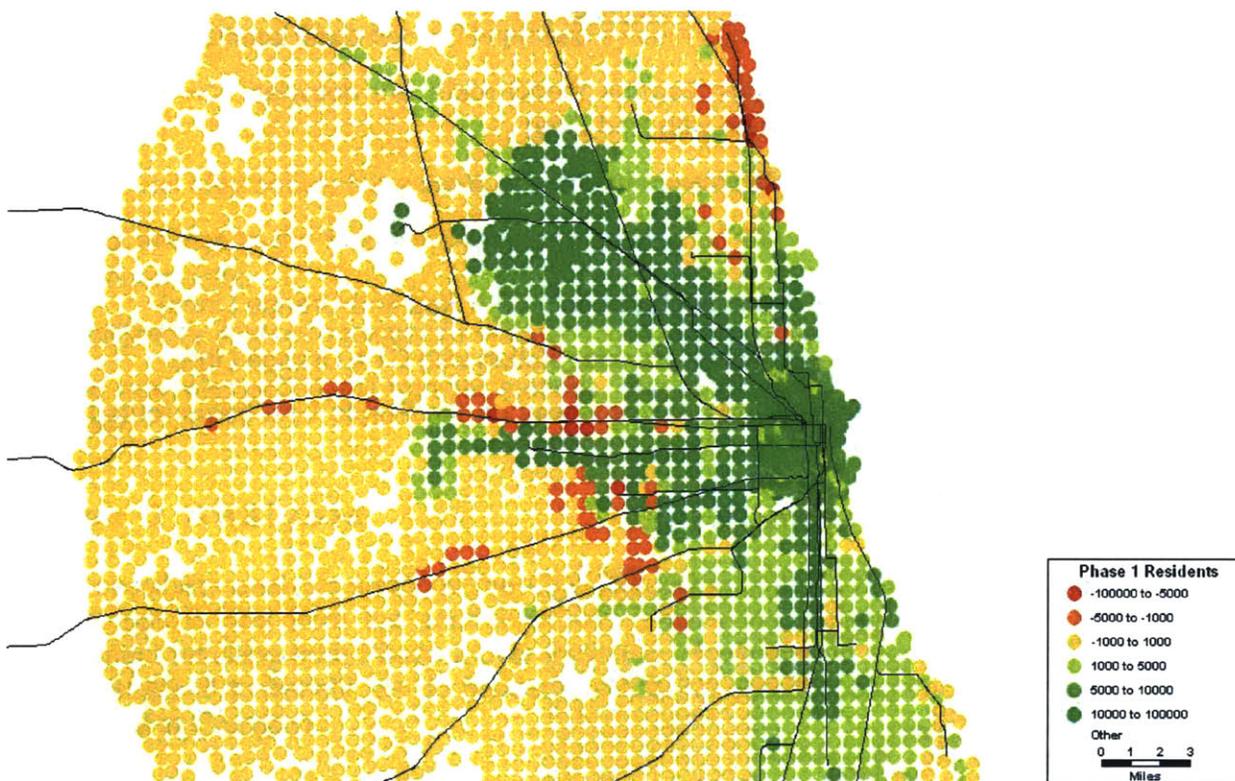


Figure 5-14 shows the incremental change in access to residents from Phase 1. Businesses along the Blue Line corridors to the west and northwest also benefit from the increased train frequencies which make it easier for employees and customers to reach those locations. Again, Evanston shows up as adversely impacted because transit access to Union Station is more circuitous.

Figure 5-14. Phase 1 Incremental Change in Access to Customers/Employees



To understand these results better, the reader is cautioned that the accessibility model takes proposed frequencies and train running times as given inputs. The majority of the benefits from this phase of the Circle Line come from increased service. This increased service is not accompanied by planned reductions elsewhere on the system. These plans were developed with knowledge that there would be enough rail cars available to operate the service called for as the CTA does not anticipate enlarging its fleet in the near future.

Moreover, the Loop elevated tracks are already intensely utilized by Brown, Purple, Green and Orange Line trains. Routing Douglas Branch trains through the loop may stretch the limits of its capacity especially at the two at-grade junctions in the northwest and southeast corners. The analysis presented here assumes running times remain the same as in the base case and thus the reroute can occur without congestion and delay. This should be carefully analyzed and confirmed before the plan is finalized.

Circle Line Phase 2

Phase 2

Phase 2 calls for building 1.5 miles of new elevated track, the Cermak-Archer Connector, connecting the Douglas Branch and the Orange Line. Figure 5-15 shows a conceptual routing plan for Phase 2.

Phase 2 Anticipated Benefits:

- Added operational flexibility and improved system connectivity.
- Direct service between the State Street subway and the near southwest and near west sides.
- Faster rail trips between the south, southwest, and west sides.
- Direct access to the Medical Center and the United Center from south and southwest side neighborhoods.
- Significantly improved access to Midway Airport from the west side.
- Two new Metra-CTA rail transfer stations, one in Chinatown and one in Bridgeport (CTA, 2004).

Phase 2 Analysis

The accessibility analysis supports the CTA expectations that Phase 2 of the Circle Line will shorten trips to and from the southwest side. shows the incremental change in access to employment resulting from Phase 2 over Phase 1. Residents on along the Orange Line to the southwest stand to benefit, as do residents along the Phase 2 alignment, along the Douglas Branch and in Evanston.

Evanston residents are benefiting because Phase 2 calls for the Purple Line to be routed through the State Street Subway out to the Orange Line and terminating at a new station near the United Center on the Paulina Connector. This rerouting improves connectivity from the north, south and southwest. The reduction in frequency formerly provided by the Purple Line on the elevated tracks north of the Loop is reflected in the reduction in access to work in zones just to the north of downtown.

Phase 2 also calls for increase Metra connectivity and there is some evidence of increased access to jobs along the lightly used Heritage Line to the southwest which could imply increase ridership and potential for increased transit-oriented residential development.

Figure 5-16. Phase 2 Incremental Change in Access to Employment

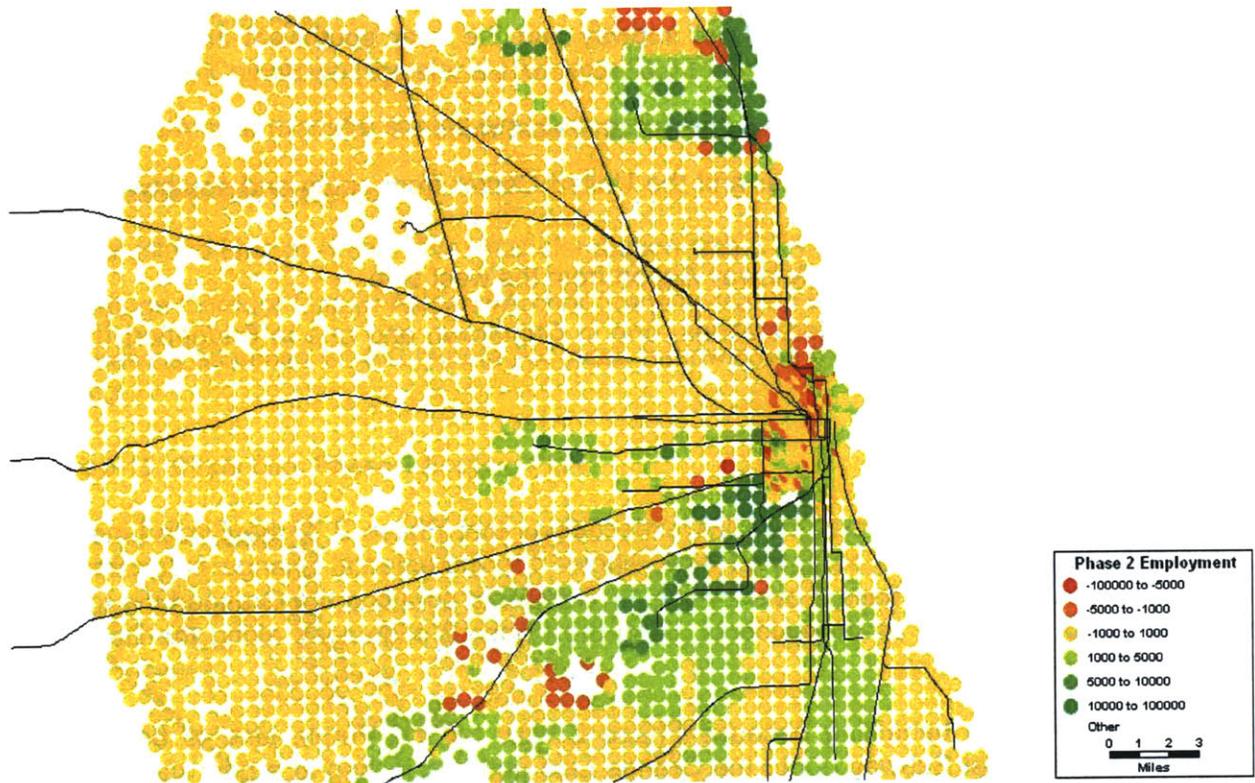
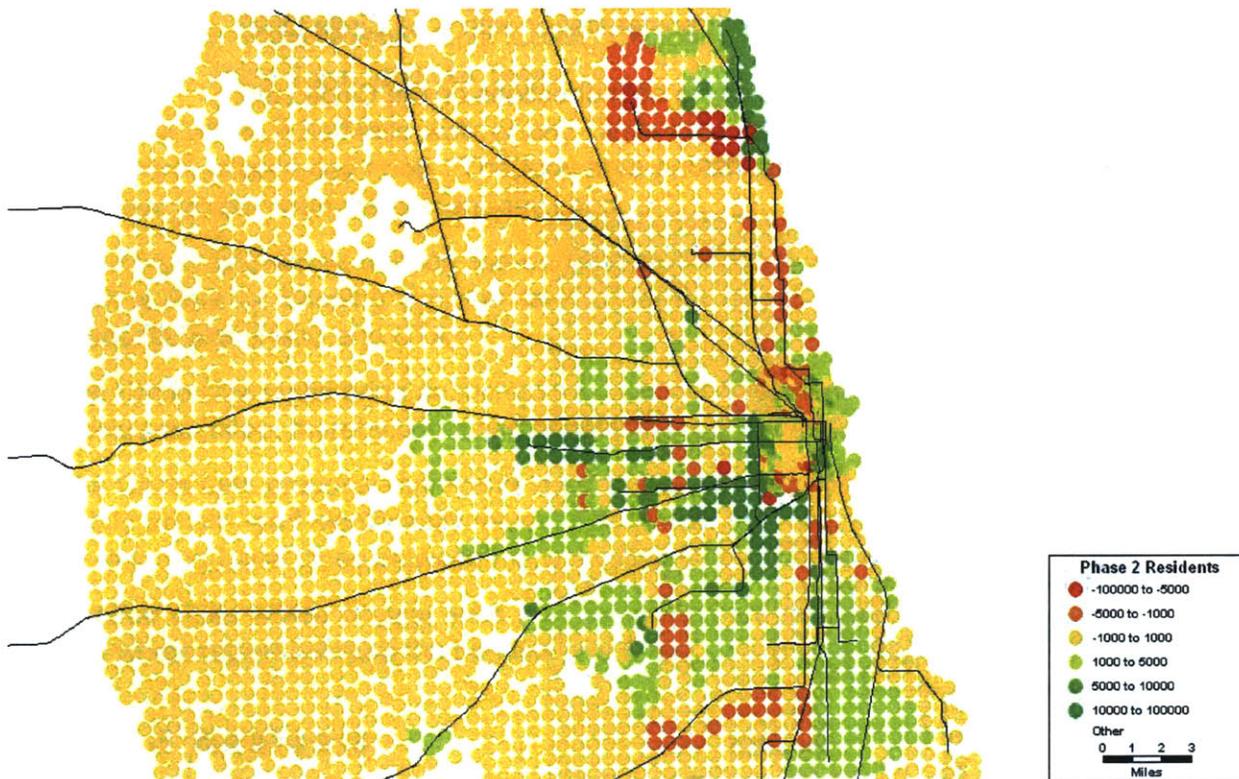


Figure 5-17 shows the incremental change in transit access to residents from Phase 1 to Phase 2. The strongest potential for increased commercial development resulting from Phase 2 is along the Ashland corridor and in the South Loop. These neighborhoods experience strong increases in customer and employee transit access. There is a concentration of reduced accessibility along the Yellow Line to Skokie perhaps a result of the realignment of the Purple Line. This corridor is not anticipated to have much commercial development so the impacts of reduced transit service are minimal.

Figure 5-17. Phase 2 Incremental Change in Access to Customers/Employees



Circle Line Phase 3

Phase 3 calls for construction of 3.35 miles of new track linking the Paulina Connector with the Red Line at North/Clybourn, via the Blue/O'Hare Line at Division preferably in subway to minimize neighborhood impact.

The existing elevated Brown Line could be re-routed into a new one mile tunnel between Sedgwick and Armitage stations to serve a new "super station" with the Red and Circle Lines at North/Clybourn. The conceptual routing plan is shown in Figure 5-18.

The project will require construction of five new or rebuilt CTA stations:

- Ashland/Lake (transfer station with Green Line)
- Chicago/Ashland
- Division/Milwaukee (transfer station with Blue Line/O'Hare)
- North/Elston
- North/Clybourn (transfer station with Red and Brown Lines)

And two new Metra stations:

- Milwaukee District, UP-West, and

- North Central Service at Ashland (transfer station with CTA Green and Circle Lines)
- UP-North and UP-NW at North/Elston (transfer station with CTA Circle Line)

This analysis assumes a 7 minute headway in both directions on the Circle Line.

Figure 5-18. Circle Line Phase 3 Routing Plan



Source: www.chicago-l.org

Phase 3 Anticipated Benefits

- An entirely new CTA route—the “Circle Line”—could begin service in both directions, using all three new track segments as well as parts of the existing Red Line, Orange Line, and Douglas Branch.
- The Circle Line would connect nearly all of Chicago’s major employment and special event destinations with every existing CTA and Metra rail line.
- Increased system connectivity and simplicity would reduce transit travel times across the city and region.

- Circle Line destinations would include: the Loop, North Michigan Avenue, the Medical Center, United Center, Grant Park, Millennium Park, Museum Campus, Soldier Field, River North, South Loop, Pilsen, Gold Coast, Clybourn Corridor, Near West Side, Bridgeport, Chinatown, West Town, and Old Town.
- The area within a half-mile walk of any Circle Line station would be six times greater than that of the present-day Loop. The total area encompassed within the Circle Line would be 28 times greater than the present-day Loop.
- The Circle Line would support the ongoing revitalization of neighborhoods adjacent to the Central Area by bringing a higher level of transit access and operating flexibility to these areas (by both Metra and CTA).
- The Circle Line could bring an increased customer base and variety of urban destinations to Metra's doorstep, thereby spreading benefits throughout the entire Chicago region.
- The Circle Line proposal represents a unique opportunity to transform how Chicagoans use public transit—and significantly increase the value of CTA's existing transit infrastructure—by reducing travel times between many existing CTA rail stations.
- In other cities where circular lines now exist, they are the backbone of the transit system. The whole region will reap the benefits of a Circle Line in Chicago (CTA, 2004).

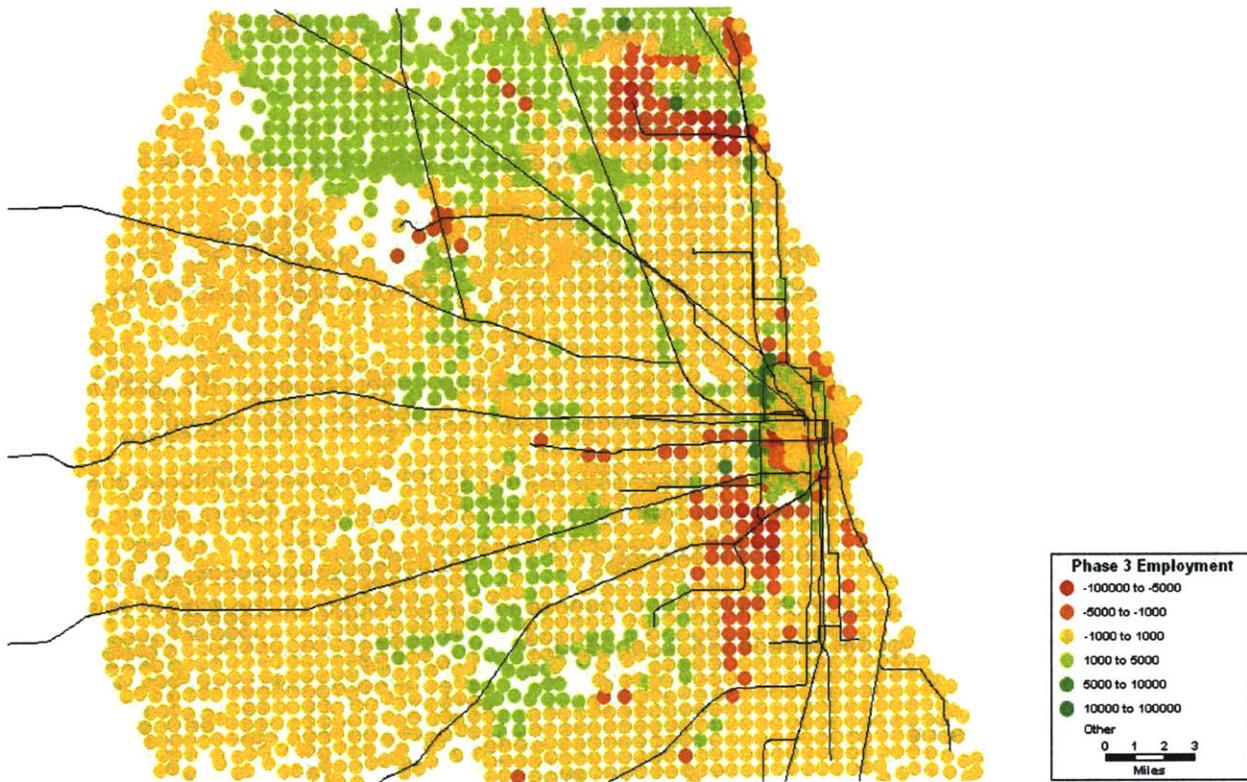
Phase 3 Analysis

Phase 3 is the most ambitious and expensive phase of the Circle Line. Completion of the final phase will permit operation of an entirely new CTA line which loops the Loop. The incremental increase in accessibility from the previous phases is not large in aggregate, but there is increased connectivity between Metra and CTA. As shown in Figure 5-19, access to employment scores increase in the northwest suburbs, the far west and the southwestern suburbs along Metra lines. The change is not extremely large, on the order of 1000 to 5000 new jobs accessible per zone. A wide swath of the northwest suburbs benefiting from Phase 3 indicates some Metra passengers may transfer to the Circle Line to access North Michigan Avenue as anticipated by the CTA.

Much of the increased access to employment is along the Circle Line alignment and points north supporting the CTA perception that the project will enhance transit service between the Northside and the Medical District.

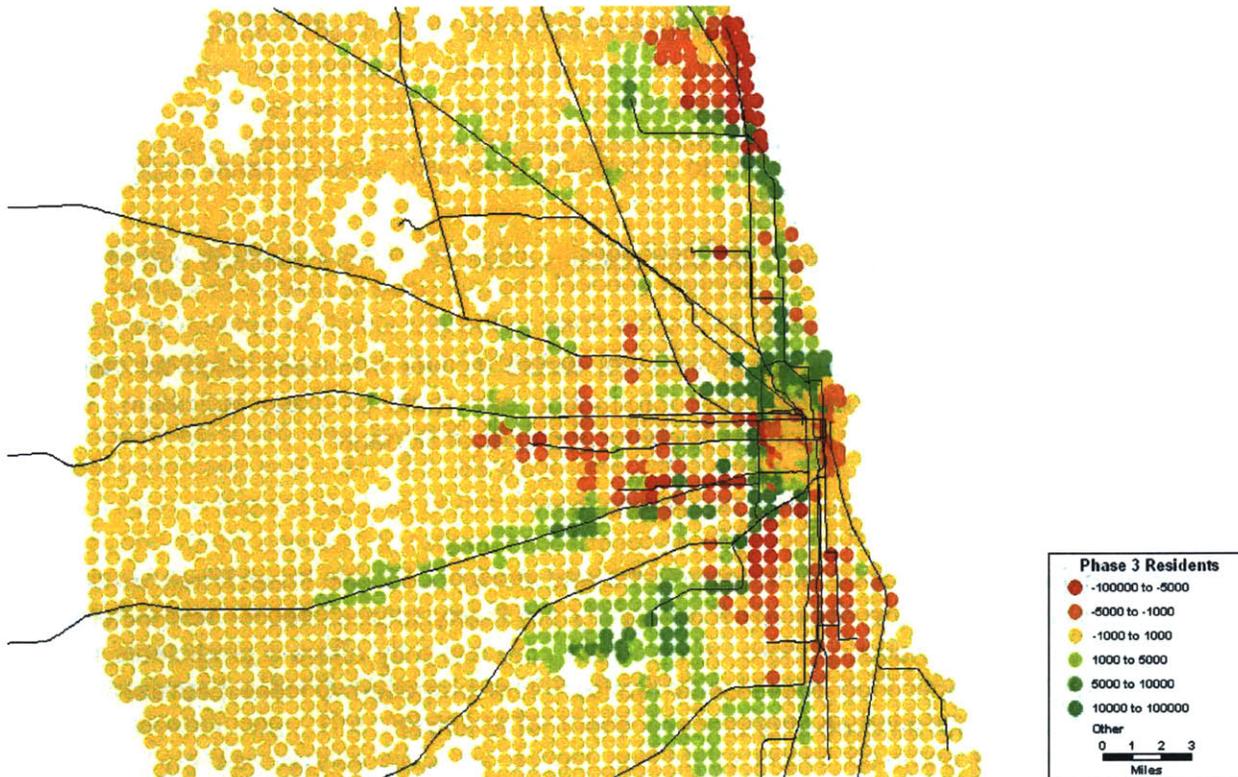
Compared to Phase 2, the Circle Line routing requires an additional transfer to reach the employment-rich north side from the southwest. This may explain some of the incremental reduction in access to employment in this area.

Figure 5-19. Phase 3 Change in Access to Employment



Perhaps the most promising evidence supporting the CTA perception of the benefits of the Circle Line is the strong development potential along the Ashland Corridor and near some Metra Stations radiating out from the city shown in Figure 5-20. This is the first supporting evidence that the project could be an economic development catalyst. Serious efforts to coordinate planning for this corridor with City officials should be a focus of planning for the new transit investment to best leverage this increase transit access along the corridor.

Figure 5-20. Phase 3 Change in Access to Customers/Employees



5.6 DESCRIPTION OF PROPOSED AIRPORT EXPRESS TRAIN

Project Description

CTA's Airport Express Train proposal would connect both O'Hare and Midway Airport to Chicago's Loop with new high speed trains.

- O'Hare Express service features under 30-min one-way travel time and 15 minute service headways in both directions, 5 AM to 10 PM, seven days a week. O'Hare Express trains will use existing Blue Line tracks and special new passing tracks at key locations to bypass intermediate stations.
- Midway Express service features under 25-min one-way travel time and 15 minute service headways in both directions, 5 AM to 10 PM, seven days a week. Midway Express trains will use existing Orange Line tracks and special new passing tracks at key locations to bypass intermediate stations.

Proposal calls for development of a downtown air terminal on Block 37, a joint development project located in the CBD between existing subway lines. The terminal is within a short walk or transfer to major hotels & conference centers, colleges & universities, and other central area attractions

The Downtown Air Terminal would have special amenities including:

- A full service air terminal with airline ticketing, passenger check-in, and checked baggage facilities including:
 - a street entrance at sidewalk level
 - escalators, elevators, and stairs down to a ticketing level with seating, retail facilities, car rental, washrooms, and airline offices
 - a platform level with two fully enclosed train loading areas for O’Hare Express and Midway Express customers

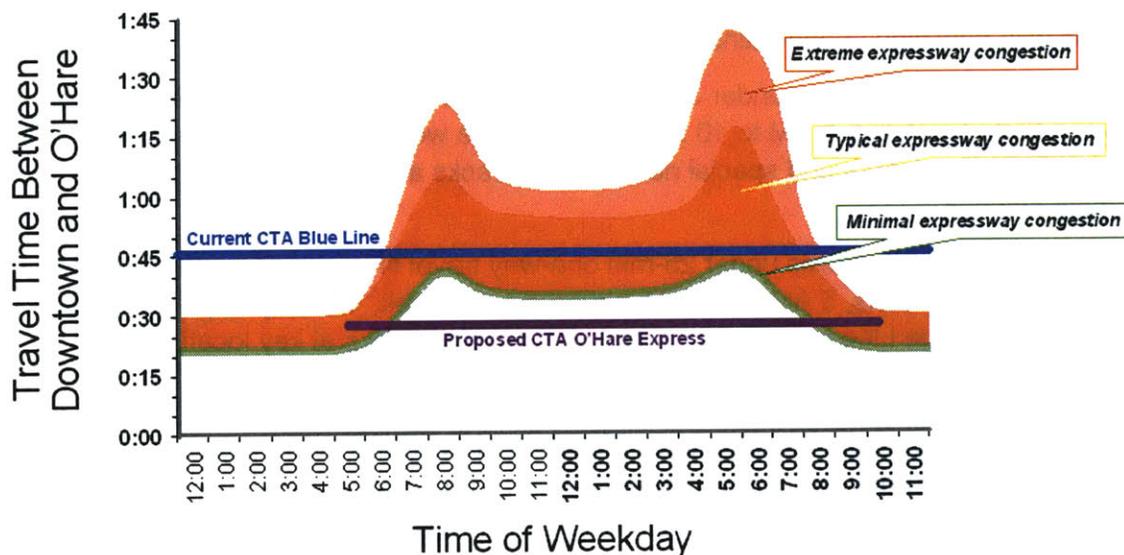
The interiors of the express trains, as envisioned, would include amenities such as custom designed coaches video monitors for travel information and route progress indication, 110V laptop power outlets, dedicated customer assistants and special signage.

The potential benefits, as described by CTA officials are:

“CTA’s O’Hare Express service would mean shorter and more predictable travel times for airport travellers. Travel times on the Kennedy Expressway are highly unpredictable—sometimes 30 minutes, sometimes 90 minutes or more. CTA’s Blue Line currently offers a predictable travel time, which is often faster than expressway travel. The proposed O’Hare Express would combine predictability with an even shorter travel time” (CTA, 2004).

Figure 5-21 graphically describes the project justification. Strictly considering in-vehicle time, the proposed CTA O’Hare Express would be a very time-competitive service and would be immune from expressway congestion.

Figure 5-21. Airport Access Times from the Loop by Mode and Time of Day



Source: CTA System Expansion Proposals CD

5.7 AIRPORT EXPRESS ACCESSIBILITY ANALYSIS

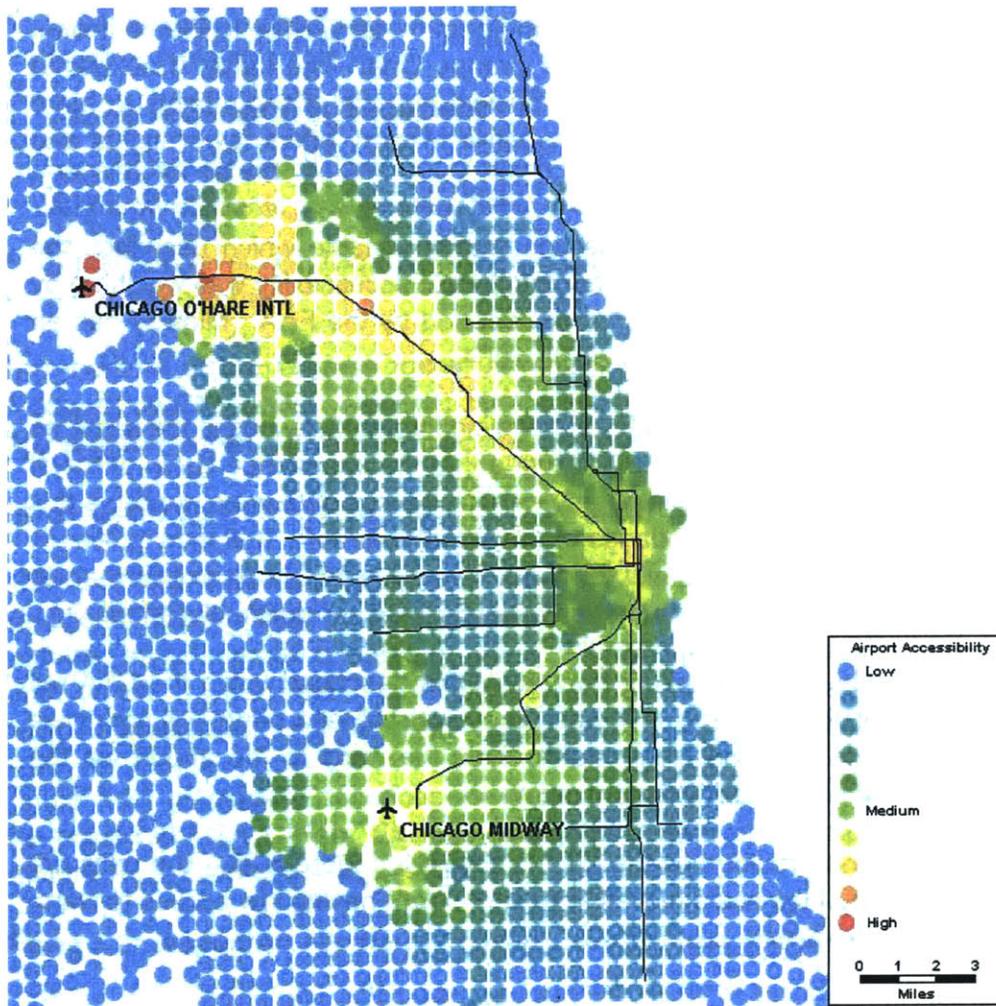
Chicago is fortunate to have rapid transit service to two major airports: O'Hare to the northwest via the Blue Line and Midway to the southwest via the Orange Line. The value of access to each airport is not equal; O'Hare is one of the world's busiest airports offering flights to more than a hundred domestic and international destinations while Midway offers fewer flights and destinations.

The flexibility of the accessibility metric allows selection of any variable which describes the relative benefit of access to each airport. For this analysis, transit accessibility was weighted by the average number of flights departing each airport as reported by the FAA. Midway has an average of 900 flights per day and O'Hare as 2552 (FAA, 2004).

The impedance curve used to describe the disutility of traveling longer distances is the same as the one estimated in Section 3.2, although one could argue that the impedance curve of travel to the airport is flatter than that of the daily commuter to work. If more data were available this function should be adjusted to reflect the impedance of travel to the airport. It stands to reason that transit passengers are likely willing to travel longer distances to reach an airport than to travel to work since it is an infrequent trip and requires travel to a very specialized location.

In this analysis, unlike the Circle Line analysis, transit access is described using the CTA rail and bus network only. The motivation for this is the assumption that Metra riders will not utilize the airport express service since for almost any Metra origin the route to the airport via the airport express would be too circuitous and time consuming.

The current level of airport access provided by the CTA is shown in Figure 5-22. The units are not shown, but the interpretation of the scale moves from cool colors having low access to warm colors with high airport access scores.

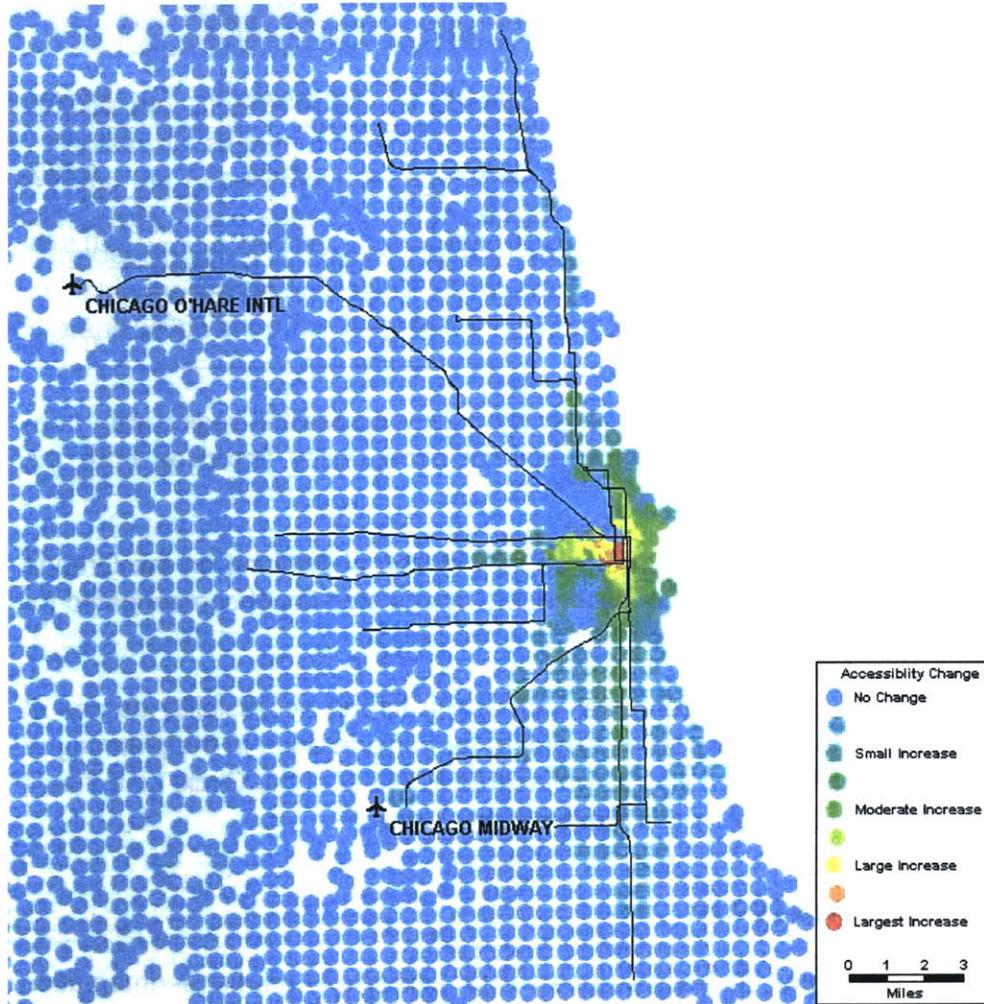
Figure 5-22. Airport Accessibility

The addition of Airport Express service corridor results in an increase in the airport access score as shown in Figure 5-23. As one might expect the largest magnitude access score increase is concentrated within a short walking distance of the downtown terminal for the trains. Moderate increases in scores radiate out along CTA rail lines as passengers transfer to CTA rail. The geographic distribution of the increased airport access oriented toward the south side of the city. Travelers from this part of the city experience the greatest reduction in travel time from non-stop service, particularly toward O'Hare.

There is no change in airport access in the northwestern quadrant of the city starting immediately outside the downtown area. This result suggests two things which should be important considerations as the project develops. First, it is not surprising that very few people will back track to board the Airport Express as the existing Blue Line service provides faster travel times. A more important observation is that there is very little increase in access to Midway from the express service. If there was, the northwest quadrant of the city should experience a net increase in airport access since trips to Midway via the loop should be shortened.

The reason the Midway Express does not improve accessibility is related to the specification of the generalized cost of transit travel. The savings offered by non-stop service are smaller than the increased wait time for that service relative to the existing Orange Line frequency if the wait time is weighted by 2.0 relative to in-vehicle time.

Figure 5-23. Incremental Increase in Airport Access



Intermediate Station Model Results

A total of five scenarios were considered for the Airport Express project. As evidence for the potential usefulness of the accessibility model for in-house project design, the total time required to prepare the transit routes layer and run the multiple shortest paths calculations was less than four hours for all five scenarios.

The first scenario established the base level of airport accessibility provided by the CTA today. Next, express trains without intermediate stops were modeled and the results visualized in Figure 5-23.

Three different intermediate station designs were considered with infill stations at Jefferson Park and Division on the Blue Line and at Ashland on the Orange Line. The aggregate accessibility results are summarized in Table 5-4.

Table 5-4. Summary of Intermediate Station Analysis

	Current Service Level	Non-Stop Airport Express	+ Jefferson Park	+ Jeff. Park + Ashland	+ Jeff. Park + Ashland + Division
Regional Air Access Totals	464296	502799	506088	505769	509160
% Change from Base		8.29%	9.00%	8.93%	9.66%
Incremental % Change		8.29%	0.65%	-0.06%	0.67%
Incremental Change from Jefferson Park					0.61%

The airport express trains increase airport accessibility by 8.29% across the region with non-stop service. The infill station analysis indicates regional accessibility improves from the addition of an infill station at Jefferson Park.

There is a net negative change in accessibility from an infill station at Ashland on the Orange line. This implies the additional delay to through passengers from a stop is not compensated for by the increased accessibility from an infill station.

An infill station at Division has a similar incremental increase in airport accessibility as one at Jefferson Park, indicating that it too, should be a candidate for consideration in the planning of the project. A station at Division station would also connect to Phase 3 of the Circle Line if built as planned further increasing the desirability of a station at this location.

Limitations of the Analysis

The author recognizes that the Airport Express proposal is an exercise in market segmentation for travel to the airports. A portion of the project's financing depends on some riders opting to pay a premium fare for a premium level of service offered by the non-stop service. Each added intermediate stop reduces the premium expresses passengers are likely to perceive above the existing rail service.

There is also stiff competition from point-to-point airport access modes including taxis, limousines, subscription shuttles and private car. The ability of the Airport Express train to compete with these modes may be compromised by additional stops. Competition from these other modes is likely to remain strong even after the introduction of the premium rail service. CTA planning documents have focused on comparing the station-to-station rail travel time achievable with express trains as compared to the congested travel time on city streets. This comparison omits time spent waiting for the train and egress from the downtown terminal which is known to be perceived more onerously than in-vehicle time. There is likely to be very little, if

any, wait and egress time for other modes. This should be an important consideration in future planning and ridership forecasting, especially since many large hotels and the convention center are not within easy walking distance of the downtown terminal and will require a transfer to reach them.

A final point to consider on the Airport Express proposal is whether or not its goal is to maximize transit access to the airports. Considering the project is conceived as a joint-development effort between the CTA and a private developer, a more important objective of the project may be economic development. Clearly, high-speed, reliable access to two international airports will enhance the Chicago CBD as a location for business and hotel development. Hotel and convention development over the last several decades have moved away from the downtown core and the Airport Express may be an attempt to reign in this decentralization. If this is the case, it may make sense not to maximize airport access across the City, but to concentrate it where development is desired. In this context, the accessibility model is a tool for quantitatively estimating the airport accessibility foregone by omitting intermediate stations and for highlighting the areas which are most likely to benefit from the enhanced access.

6. CONCLUSIONS

This chapter begins with an assessment of the performance of the accessibility model and then summarizes the main findings of the Circle Line and Airport Express analysis, the purpose of which is to illustrate the application of the accessibility methodology. Areas for future research are divided into two parts: future applications and refinements of the transit network model and applications of the accessibility metric.

6.1 ASSESSMENT OF THE ACCESSIBILITY METRIC

The accessibility metric makes use of well-known planning tools in a new way. Land use and socioeconomic data are combined with transit shortest path calculations to measure the performance of the transit system across space. The accessibility metric has two major benefits for transit planners:

- The analysis is rigorous, transparent and quick. Strategic planning efforts could be enhanced by knowing early in project development the magnitude and distribution of potential benefits of a project. The accessibility metric is not a complicated ridership forecasting model understood only by its developer but it is more sophisticated than a simple comparison of travel times from a few origin destination points. Transit networks are complex and assessing the impacts of changes can benefit from a tool that recognizes network effects. Planning efforts using this metric can use the results to generate new alternatives to solve identified transportation problems.
- The land use interaction is modeled explicitly suggesting corridors where enhanced transit service could lead to increased residential and commercial development. As discussed in Chapter 2, the positive urban development changes resulting from transit are a principle objective of transit investments and this methodology highlights a project's development potential.

6.2 IMPLICATIONS FOR CHICAGO

The accessibility analysis of the Circle Line and the Airport Express trains suggests some important issues for consideration by the CTA as the projects advance.

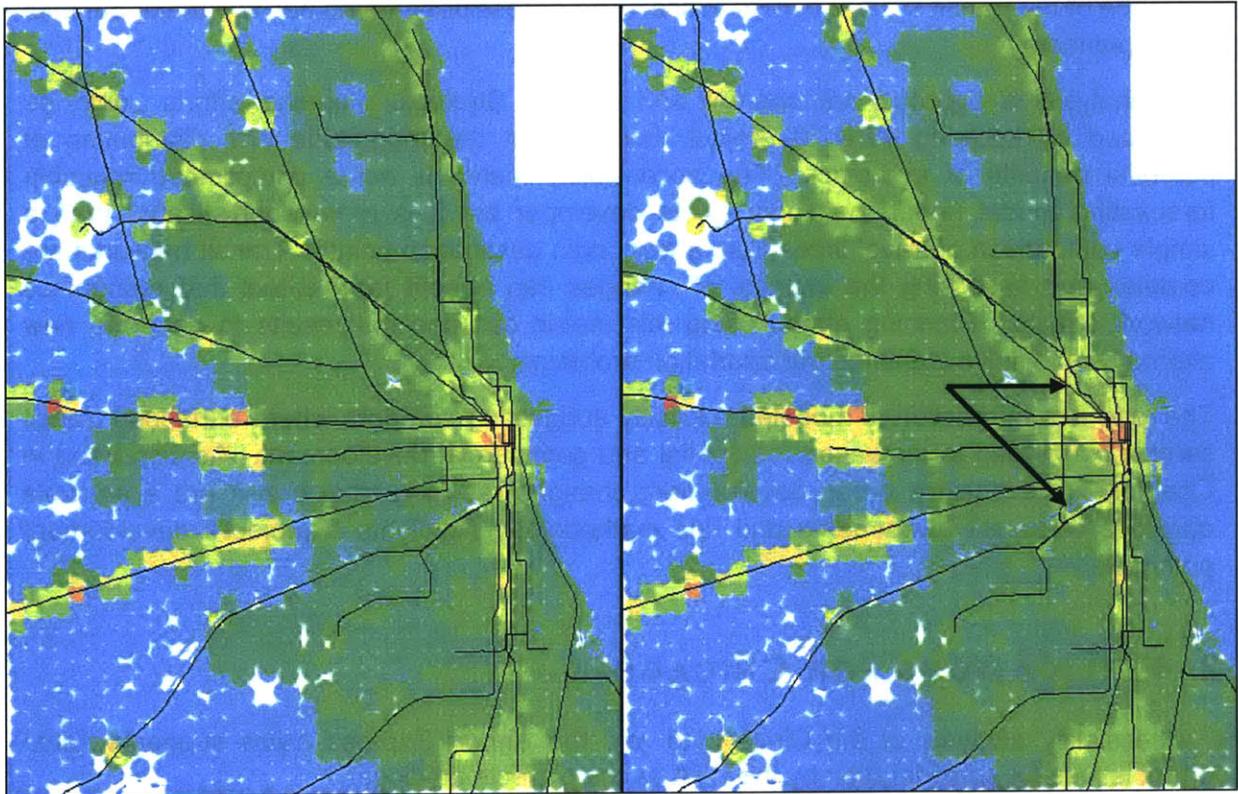
Significant Accessibility Benefits from the Circle Line Accrue in Phase 1

The majority of the benefits of the Circle Line project evaluated using the accessibility model are realized with the completion of Phase 1. This suggests the increased frequencies permitted by uncoupling the Blue Line branches to the west will offer significant reductions in travel times and should lead to increased ridership if implemented early next year.

Circle Line Enhances Commercial and Residential Development Potential of Ashland Corridor

The accessibility model shows the Circle Line will enhance transit access to employment sites along its alignment. This is perhaps best visualized in Figure 6-1 where the accessibility score before and after construction of the Circle Line are presented side by side. This enhanced transit access, if accompanied by transit-supportive zoning and development policies could lead to increased commercial development in the corridor. This development will be fueled by the lower land prices in the corridor as compared to the Loop. In effect, the Circle Line introduces a highly-transit-accessible location beyond the expensive downtown core. If development is allowed this major transit investment could encourage employment growth near transit in line with sustainable development practices.

Figure 6-1. Circle Line Commercial Development Potential



Access to customers and employees by rail transit score with warmer colors indicating increased access. Before the Circle Line on the left and after the Circle Line on the right.

The Circle Line also makes it easier for residents to travel to work by transit. This increased access, which is concentrated along the corridor, to the southwest and west may increase residential development. Some of the neighborhoods with enhanced transit access have experienced decades of population decline and this project could reverse the trend. In more vibrant neighborhoods, the increased transit access may facilitate a shift from auto travel and reduce congestion.

Benefits to Metra Passengers Are Real but Uncertain

The estimated increases in transit accessibility from the project are, as expected, not uniform across the region. There is some evidence of enhanced access in the suburbs but only in select corridors (namely, the northwest and southwest).

There are two important factors which will affect the impact of the Circle Line on Metra passengers that were not well modeled in the accessibility analysis. Fare integration between the CTA and Metra is a long-sought goal that has not yet been achieved primarily due in some part to difficulties in reconciling Metra's zone based fares with CTA's flat fares and developing an appropriate revenue sharing scheme.

The second factor that will influence the level of benefit to Metra passengers is the degree to which passengers are willing to transfer outside the downtown terminals. There was little available data on the transfer penalty between CTA rail and Metra. This transfer penalty has to be kept low if the Circle Line is to attract significant numbers of Metra riders.

There are a number of strategies available which could reduce the transfer penalty. Stations should be designed and constructed so as to make the transfer experience as short and pleasant as possible using cross platforms transfers, enclosed walkways and integrated fares. It is absolutely critical that high frequencies be maintained on the Circle Line, since otherwise much of the in-vehicle time savings could be eaten up by time spent waiting for trains. Maintenance of high headways may cause operational problems in the busy State Street Subway particularly if mixed train lengths are used during peak periods. This issue should be addressed very early in the project planning since current headway assumptions in the State Street Subway appear very ambitious compared to current operations.

Circle Line Does Not Offer Much Benefit to the Southeast Side

The Circle Line has strong political support from a broad range of constituencies because, as CTA project backers often cite, it "connects everything to everything." Conspicuously absent from these connections is the Metra service to the south lakeshore. The accessibility maps for all three phases show little impact along the South Lakeshore. This is a politically active constituency who, unlike other corridors, are not likely to perceive much benefit from the Circle Line and there is a valid argument that this corridor is deserving of the same type of economic development benefits which will accrue in the Ashland corridor.

A possible remedy is to combine the Circle Line project with a project that enhances service to the South Lakeshore. The underutilized Metra Electric service in this corridor is deserving of attention. If the Circle Line is to receive even broader support across the region, the issue of how to improve transit to the South Side should be addressed soon.

Airport Access Improves with Additional Stops on O'Hare Airport Express Train

It is clear from the accessibility analysis that the Airport Express proposal, as designed, will be a boon for airport access from the CBD. Some question remains as to the benefits to those who must make transfers from the downtown terminal to reach major hotel destinations along North Michigan Avenue and the convention complex on the South Lakeshore although Airport Express passengers arriving in the downtown terminal will be well positioned to utilize the existing rail infrastructure for the downtown distribution portion of their trip.

From the strict perspective of increasing accessibility to the City's two major airports the Airport Express trains would perform better by adding stops between the downtown terminus and the airports. These additional stops would cause some delay to through passengers, but greatly enhance access from city neighborhoods outside the loop. The accessibility model facilitates the quantitative assessment of this tradeoff and can be an important tool in the early planning of the project.

Benefits of an Express Train to Midway are Tenuous

Using the concept of the generalized cost of travel, the time savings offered by non-stop service to Midway are not large enough relative to the existing service to make waiting for a Midway Express train attractive. This attractiveness will be further diminished if, as is expected, a premium fare will be required for express service. Project backers may point to the enhanced amenities on the express trains such as baggage check-in, spacious seats and meeting facilities as a means of attracting passengers, however the effectiveness of these measures is uncertain and certainly beyond the scope of this analysis.

6.3 ENHANCING THE USEFULNESS OF THE TRANSIT NETWORK MODEL

The reader may question the necessity of developing a transit network model at a transit agency if a similar model is maintained by the regional transportation planning agency. The author does not advocate duplication of effort and encourages close cooperation between the transit agency and the regional planning agency on maintaining the data necessary for implementing network models. There are, however, unique applications of a transit network model which are beyond the level of detail available in a metropolitan context. In further developing the usefulness of the transit network model, the author recommends it become a repository of information for use in strategic and service planning at a transit agency. Some of the key information sources and applications are articulated in this section.

Integration with AVL and APC data

In an effort to meet American's with Disabilities Act requirements that stop announcements be made for the visually impaired, the CTA is implementing an Automatic Voice Annunciation System (AVAS). The benefits of the AVAS system extend beyond audible stop announcements

on buses. The Automatic Vehicle Location (AVL) technology enables automatic stop announcements. AVL data offers a wealth of information on vehicle running time and schedule adherence. Integrating AVL data into the network model would not only improve the accuracy of the model in describing travel time by bus, it could also help identify problem spots to service planners and operations staffs by displaying bus speeds.

Automatic Passenger Counting (APC) technology is also being installed on a fraction of the bus fleet. Again, integration of this data with the network model could be used to validate results of a transit OD matrix assignment and assist service planners in understanding the geographic distribution of boardings and alightings.

Passenger mile estimation and integration with AFC passenger origin-destination model

On the rail system, CTA Rail Operations Manager, Adam Rahbee and others are using Automatic Fare Collection (AFC) data to estimate station-to-station flows. The CTA has an entry-only fare collection system which records the entrance station and time of a fare card holder. Using a model documented in Rahbee and Czerwinski (2002) and Zhao (2004) one can infer the exit station of that passenger and build a station-to-station passenger flow matrix.

There has already been some integration of the AFC OD model data with the network model as discussed in section 5.5 where AFC flow data was used to estimate the weighted travel time change resulting from rerouting the Douglas Branch. This data could also be useful in validating a transit assignment.

The network model has also provided station-to-station travel lengths which, when combined with AFC OD flows, has allowed estimation of passenger miles of travel on the rail system for reporting purposes.

Zhao (2004) suggests many more analyses - including detailed assessment of path choice and transfer penalties - are possible using of the AFC OD data. The network model may facilitate those analyses by providing shortest path calculations data skims over the rail network.

6.4 FURTHER APPLICATIONS OF THE ACCESSIBILITY METRIC

Measuring the Impact of Fare Policy on Transit Accessibility

Fare policy was excluded from the analysis presented in Chapter 5. This is a shortcoming in Chicago where fares are not integrated between the commuter rail provider and the city transit provider. An important refinement of the accessibility metric is the incorporation of fares and assessment of the impact of fare policy on transit accessibility. This analysis could yield interesting results, particularly if the fare policy is found to be putting different geographic regions at a disadvantage.

Development of the Highway Network and Inclusion of a Measure of Auto Competitiveness

The accessibility model is limited to a transit supply-side model. To move toward a complete representation of transit demand requires more data on the highway network. Highway link capacity data – i.e. the number of lanes by direction – is missing from the network model and is crucial to modeling congestion. Moreover, a credible OD matrix for automobile trips is required for assessing congestion impacts. At a finer level of detail, the location of stop and signalized intersections would also improve the representation of the highway network.

Auto competitiveness is also a function of parking cost. Data on the cost of parking at a fine level of geographic detail is not widely available. Daily commercial garage rates differ significantly from hourly rates which differ from metered rates meaning parking cost varies by trip purpose. Accurate modeling of parking cost should include a terminal time required for searching for a space and egress from a garage in addition to the dollar cost. Many neighborhoods outside the CBD have a low dollar-value of parking cost, but supply is so constrained that a driver may circle for a long time looking for a space. This condition is often overlooked by modelers but can be an important explanation for high transit share.

This data must be available if the CTA or future researchers are to implement a full four-step demand model using the work completed so far. Perhaps the best way to make progress in this area is to develop a stronger relationship with CATS the regional travel demand forecasting agency for Chicago and other agencies.

Ridership Forecasting

A correlation has been established between journey-to-work mode split and accessibility metric. A better representation of parking cost and auto competitiveness could improve this correlation and may ultimately facilitate ridership forecasting by calculating the elasticity between a change in accessibility and a change in ridership. The recent restructuring of the Lake Shore Express routes changed the competitiveness of transit for certain trips and had a resulting ridership impact. This could provide the empirical data necessary for a more refined estimation of the ridership impact from a change in transit accessibility.

Ultimately, the network model described in Chapter 4 could be expanded to become a full travel demand forecasting model. This effort may serve important research needs as part of the collaborative research program and could also greatly improve strategic planning efforts inside the Authority.

Accessibility To Special Destinations

The analysis in this thesis concentrates on the use of the accessibility metric to assess the impacts on employment access, and development potential, and airport access. With sufficient data, the accessibility metric is flexible enough to assess access change to a variety of service planning objectives. Several objectives have been identified in past research for the CTA.

Shuey (2003) seeks to improve the relationship between transit agencies and large medical center complexes. The accessibility model could be used to assess the level of access to

medical facilities provided by the transit system. Shuey notes that due to the odd-hours worked by a number of Medical Center employees, night-owl service is perhaps the most important time to evaluate the value of the transit system to these employees. If the improved relationship between the Medical Centers and a transit agency calls for increased service, service planners could use the accessibility model to measure the effectiveness of the new routes in increasing access to and from the Medical Complex.

Cohen (2004) points to CTA market research which shows evidence of very long trips by transit dependents to malls and discount “big box” retail. This is particularly pronounced on the economically distressed South Side of Chicago. There are two applications for the accessibility metric in evaluating access to retail by transit captives. The first is to quantify the impact of service changes designed to improve access to retail including supermarkets, discount clothing stores, etc. The second application is to identify sites where retail access is low as potential economic development sites. Cohen suggests that the weekend level of service is more important than peak-hour service for these trips. The accessibility evaluation could be weighted by the number of autoless households at the origin.

Bent (2003) suggests means of improving transit service to open space and recreation sites in Chicago. A quantitative assessment of the transit accessibility provided to these locations using off-peak or weekend service levels could be a tool for evaluating service changes. A data set on the geographic distribution of the type and size of open space and recreation opportunities available would have to be identified.

Locating Sites for Transit Oriented Development and Infill Stations

Many transit agencies are using transit oriented development (TOD) to leverage the large investment in rail infrastructure and increase ridership. The accessibility model could be used as a TOD citing tool. TOD efforts should be targeted in zones which have high transit accessibility scores and available underutilized land.

Many community groups in the CTA service area have requested infill stations on existing rail lines. New stations represent large capital investments and should be planned with care. To date, the CTA has been unhappy with the techniques available to prioritize sites for infill station construction. The accessibility model could be used to rank potential station sites based on the increased access provided by a new station similar to the airport express analysis presented in Chapter 5. Access to employment correlated with transit mode split so planners can be confident that this prioritization scheme will result in overall system ridership gains.

Transit Supportive Zoning Changes

Minimum and maximum parking requirements could be established as a function of existing transit accessibility. The latest City of Chicago zoning reform allows for reduced parking requirements within a 600' radius of a rapid transit or commuter rail station. This is a crude approach to understanding the contribution of transit to reducing parking demand. The accessibility model is a more sophisticated measure of the level of service provided by the transit system. For commercial development, parking requirements can be adjusted in proportion to the effectiveness of the transit system delivering customers and employees to the site as measured by the accessibility metric.

The latest zoning reform uses a measure of transit accessibility which is all too common and, unfortunately is misleading. A simple band around a transit station does not suffice to describe an area as transit accessible, because these bands are not sensitive to important questions like: Where does the transit go? and How easy is it to get there? The accessibility metric described in this thesis answers those questions and could be a foundation for a more sophisticated understanding of a location's transit accessibility.

Assessment of Service Changes on Low-Income and Minority Populations

At the time of the writing of this thesis the CTA is facing a large funding shortfall for the 2005 fiscal year. Efforts are underway to change the regional transit funding formula and secure additional funding to maintain service levels. If these efforts are unsuccessful, however, the CTA will be forced to close the funding gap through a combination of fare increases and service cuts. Service cuts are very unpopular and are subject to intense political and legal scrutiny. The last round of service cuts, in 1997, remain fresh in the memory of CTA staff and community activists.

Any service cut is likely to provoke controversy. One particularly important concern is to avoid the perception that the cuts disproportionately impact protected populations. The accessibility model offers a sophisticated measure of the level of service provided by a transit system. Access to jobs is a particularly important function of a transit system for low-income and minority populations who may have few other options for transportation. The agency may have more confidence in the fairness of its service changes if their impact on transit accessibility is measured quantitatively and weighted by concentrations of low-income or minority populations.

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APPENDIX B: GENERATING ACCESSIBILITY CURVES IN TRANSCAD

The following steps are used to generate accessibility curves in TransCAD:

In the transit routes layer:

A transit network is created with the value of time = 1, fare equal to zero and the various path attribute weights equal to those described in Chapter 4. Many transit network “versions” are created by using selection sets to select the transit routes which are applicable to the current scenario under analysis.

In the nodes layer:

Using transit > multiple paths a transit skim is created from all centroids to all other centroids and all variables of interest are saved.

The resulting matrix contains all of the LOS variables of the transit network under the current scenario. To calculate transit accessibility use matrix > contents and select Add Matrix. Add four matrices and name them travel time, impedance, opportunities, and score.

In the travel-time matrix, use matrix > fill > cell-by-cell to add all the time related path attributes together into a single matrix.

In the impedance matrix, use matrix > fill > formula to calculate the transit impedance according to the following formula (estimated for 2mi radius around loop using CTTTP1990).

$$\text{Impedance} = 1.08438 / [1 + 0.08438 \exp(0.076223 * \text{TransitTravelTime})]$$

In the opportunities matrix use matrix > fill > vector multiply to fill the rows of the matrix with the data found in the 1990 CTTTP Part 2 (Workers at Destination U201_010101).

In the score matrix use matrix > fill > cell-by-cell to multiply impedance by opportunities.

Finally, to calculate a zone's total accessibility score, use file > properties > marginals (select sum) to calculate the sum of accessibility scores.

Use matrix > export, select column in score matrix to save the HBW accessibility score at the origin in a table.

Display the table using the thematic map tools

APPENDIX C: ACRONYMS

AFC	Automatic Fare Collection
APC	Automatic Passenger Counter
APTA	American Public Transit Administration
AVL	Automatic Vehicle Location
AVAS	Automatic Voice Annunciation System
CATS	Chicago Area Transportation Study
CBD	Central Business District
CDOT	Chicago Department of Transportation
CTA	Chicago Transit Authority
FTA	Federal Transit Administration
GIS	Geographic Information System
HOV	High Occupancy Vehicle
Metra	Northeastern Illinois Regional Commuter Railroad Corporation
MSA	Metropolitan Statistical Area
Pace	Pace Suburban Bus Division
RTA	Regional Transportation Authority
TAZ	Travel/Traffic Analysis Zone
TOD	Transit Oriented Development