Understanding Transportation Accessibility of Metropolitan Chicago Through Interactive Visualization

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ABSTRACT

Accessibility is an important element in urban transportation planning. Accessibility measures combine mobility and land use measures to provide a more complete picture of the transportation-land use nexus than either of these measures alone. By providing insights into the varying degrees to which different areas of a region are connected to opportunities by the transportation system, accessibility analysis helps urban planners to understand the relationship between transportation and land use, and provides reference for them to improve the equality of the residents. Calculating accurate accessibility values and visualizing them in an efficient way is a complex and challenging process. In this paper, we present a web-based system that visualizes multimodal accessibility to multiple land uses of Chicago metropolitan area, as the first step of an effort to build an integrated platform for accessibility analysis tasks. We also discuss some use cases of this system, and show its effectiveness by providing experts feedback of this prototype.

Categories and Subject Descriptors

I.3.8 [**Computer Graphics**]: Applications; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*graphical user interfaces*

General Terms

Design

Keywords

accessibility analysis, geographic visualization, urban transportation planning

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1. INTRODUCTION

Accessibility is an important concept in urban planning. As a measure of the ease of reaching valuable destinations, accessibility can be interpreted as a combination of *mobility* and *potential*, where *mobility* measures the ability of moving in the traffic network, and *potential* reflects the number or size of destination opportunities.

Since the work by Hanson [7], accessibility has been used as an indicator of the performance of urban transportation systems in serving residents of an urban area and received substantial attention. Using accessibility has obvious advantages over using other measures such as mobility or congestion, as mobility or congestion only reflect the ease of traveling along the traffic network or how movement is constrained, while accessibility takes into consideration both the ability of traveling and the ability to reach valued destinations [6].

As a measure of reachable opportunities, accessibility is important for individual residents as well as the planning and transportation professionals that seek to address the needs of residents. However, the measurement of accessibility often requires regional measurement of travel time and opportunities, which require time and resources to compute. A traditional workflow of accessibility analysis may be to first use desktop GIS, such as ArcGIS or QGIS, to manage transport network data, then build software or modules to perform customized tasks, usually a specific implementation of one or more accessibility measures. Results are then visualized in GIS and exported of static maps [12]. While planners may be interested in seeing existing accessibility levels or in measuring impacts of their planned changes, the scope of their particular project may be prohibitive to undertaking such analysis.

In this paper we present a prototype web-based system for accessibility analysis. It provides target users (urban planning researchers, transportation planners, economic development professionals, policy analysts, etc.) with an integrated environment to look at numerous aspects of accessibility in the Chicago metropolitan area. By readily making available

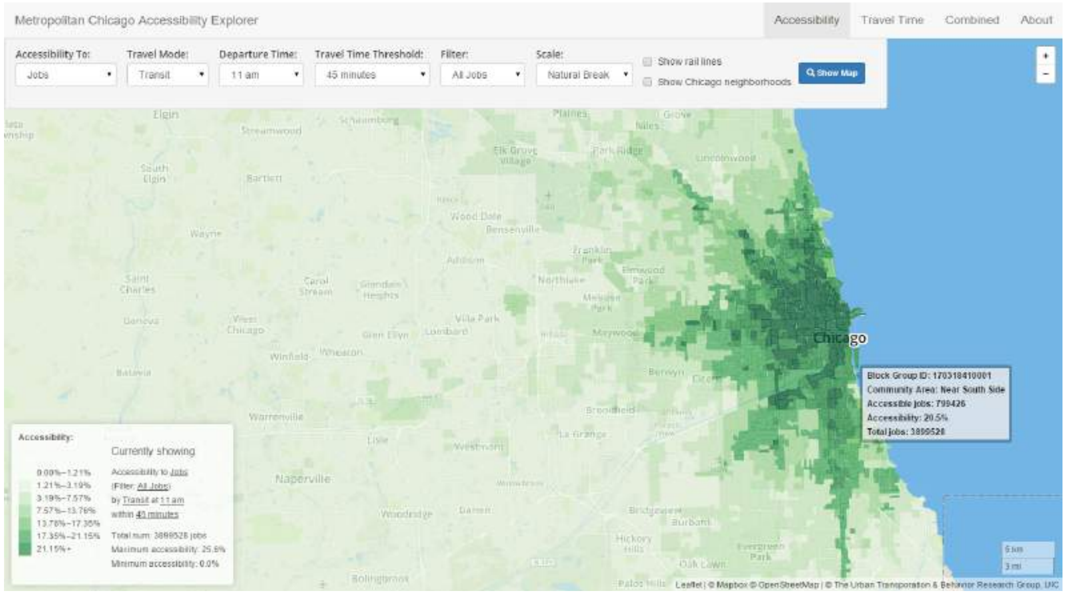

Figure 1: Accessibility View of the system. Users can investigate accessibility values and patterns as a choropleth map. This snapshot shows what percentage of jobs (all types) can be reached from each block group within 45 minutes by taking public transit at 11 am. It also shows detailed accessibility information about a block group in the Near South Side of Chicago.

accessibility measures at a regional level, what this visualization seeks to do is enable easy assessment of needs and provide a way to intuitively assess the likely impact of a change in land use or transportation service provision.

The contribution of this work is in the scope of accessibility that is visualized and the way it is presented. Geographically, this work focuses on the large region of Chicagoland. Quantitatively, this tool visualizes accessibility to multiple regional amenities, and by multiple travel modes. Each measure is developed at the census block group level, providing geographically detailed measurement. The use of a web interface makes the results of this work accessible to a very wide range of audiences and makes sharing and collaboration possible.

2. RELATED WORK

2.1 Accessibility measures

The term accessibility has been around for more than four decades, and as Handy [6] states, 'improving accessibility' has been appearing more frequently in the goal statements of almost all transportation plans in the U.S. How to measure accessibility is an active research topic with efforts focused on proposing new or improved accessibility measures, making measuring more rigorous, realistic, and tractable.

The advantage of accessibility over other measurements such as mobility or congestion, is that accessibility not only considers the movement ability within transport network, but also takes the value of destinations into account. Over the past forty years, different accessibility measures have been developed for a variety of evaluative and analytical purposes. Accessibility measures can be broadly categorized into four classes: **opportunity-based**, **gravity-based**, **utility-based**, and **space-time** [3].

Opportunity-based measures deal with the number of reachable opportunities within a given distance or travel time. One of the two major opportunity-based measures is the **cumulative opportunity measure**, which counts the number of opportunities that can be reached within a specified distance or travel time from an origin [16, 15]. The cumulative opportunity measure is easy to understand, and simple to calculate [3].

The other opportunity based measure is the *gravity-based measures* where attractiveness of a destination is weighed by the impedance cost [10]. Unlike the cumulative opportunities measure which weighs everything within its threshold equally and ignores anything outside of the threshold, this measure considers every opportunity discounting each by the costs of reaching it.

Other measures include *utility-based measures* and *space-time measures*, both of which require large amounts of data and more intensive computation [3, 8, 9]. Details about these measures is available in [3].

2.2 Accessibility analysis

Accessibility analysis is a comprehensive process consisting of three steps. The first step is to develop or choose one or more appropriate accessibility measures based on the purpose of the analysis or evaluation and the essence of the planning issue. The second step is to specify parameters and calculate the accessibility measures. In this step, parameters are specified for the chosen accessibility measures, and an accessibility calculation is performed. Generally speaking, to define an accessibility measure, five sets of parameters are needed: **spatial unit**, which defines the basic unit area for which accessibility is measured (census tract, building block, block group, etc); **types of opportunity** for which accessibility is assessed (jobs, hospitals, schools, etc); **modes of transportation** (automobile, public transit, bicycle, etc); **origins and destinations**, from/to which accessibility is measured; and **travel impedance**, which represents the spatial separation between an OD pair (travel distance, travel cost, travel time, etc) [10]. The third and last step in accessibility analysis is to analyze, present and interpret the results. In this step, calculated results are visualized and investigated in the context of the research or planning questions raised.

In this process, the accessibility calculation (second half of the second step) and analysis (the last step) are traditionally conducted inside a geographic information system (GIS). For accessibility analysis, useful GIS functionality includes its capability in collecting, storing, and manipulating spatial data, in calculating shortest paths, in modeling transportation networks, and in visualizing the calculated accessibility values [11, 14]. However, general-purpose GIS has several limitations in performing accessibility related tasks. Liu & Zhu [10] identified a deficiency in using the buffer-generation function of GIS for excluding activities that are close to an origin in measuring accessibility. Also, standard accessibility measures built into GIS software are actually distance measures and are not suitable for advanced analysis where human factors should be also considered. Moreover, the output of desktop GIS software is on-screen visualization and exported static map images, which are not convenient to view or to share between collaborators.

2.3 Tools and techniques

OpenStreetMap. Since it's start in 2004, the OpenStreetMap (OSM) project [5] has been creating an open source map of the world collaboratively from contributors all around the world. One of the primary outputs of this project is geographic data generated during the creation and editing of the map. This data is comparable to proprietary data sources [17] and has been widely used in a variety of applications.

GTFS. GTFS is short for General Transit Feed Specification. This specification describes a common format for public transportation schedules and associated geographic information. Public transit agencies are able to publish their transit data as GTFS feeds, which can be consumed by computer applications that interpret the feeds according to the specification. A typical GTFS feed include information about multiple aspects of a transit system, such as stops, routes, trips, and schedules [4].

OpenTripPlanner. OpenTripPlanner (OTP) [13] is an open source platform for multimodal and multi-agency trip planning written in Java. Two primary modules of OTP are the Graph Builder module and the Routing module. The Graph Builder module takes OSM data as input to generate street networks, and uses GTFS feeds released by transit agencies to generate transit networks. It then combines the two types of traffic networks into one multimodal transport network, stored in the so-called *Graph*. For more details about the structure of the transport network built by OTP, see its wiki page [1]. The Routing module, on the other hand, takes the built *Graph* as input, together with user specified parameters, to perform tasks such as shortest path search from a given origin to a given destination, or batch origin/destination (OD) pair analysis.

3. OVERVIEW

In this section, we first clarify relevant terminologies, then we define our tasks, reason our design decisions, and describe the input data set. After that, we provide an overview of the system workflow.

3.1 Terminologies

In order to facilitate the discussion, we clarify definitions of relevant terminologies in the context of urban and transportation planning:

- A *multimodal transport network* is a transportation network that includes multiple modes of transport. It usually consists of different types of roads and subways (sometimes even railways, ferry channels or air routes).
- An *accessibility measure* refers to a method or methodology of measuring or calculating accessibility, while *accessibility measurement* is the process of measuring accessibility or an implementation of an *accessibility measure*.

3.2 Tasks and Design Decisions

Based on the discussion in Section 2, we identify the following tasks that the system should support:

- Show what activities can be reached by residents of a specific neighborhood in a reasonable time by a given mode;
- Show changes to accessibility over the course of a day as transit systems adjust their schedules to demand;
- Show the spatial equities (or inequities) of transportation availability.

In order to support these tasks, following design choices are made:

- We adopt cumulative opportunity measure as our main way for measuring of accessibility. Although gravity-based measures are the most widely used type of accessibility measure, cumulative opportunity measure is considered easier to understand and interpret by transportation planners, high level administrators, and the general public [3].
- We use OTP to calculate travel times. Using this specialized tool allows us to measure accessibility for multiple transport modes, and at different times in a day.
- We develop the system as web-based, with the focus on providing an easy-to-use interface for users to view, analyze, and compare accessibility visualizations. There are two advantages in a web-based tool. Firstly, it is light-weight; users will not need to purchase or install any software. Secondly, web-based makes it accessible to a wider range of audiences.

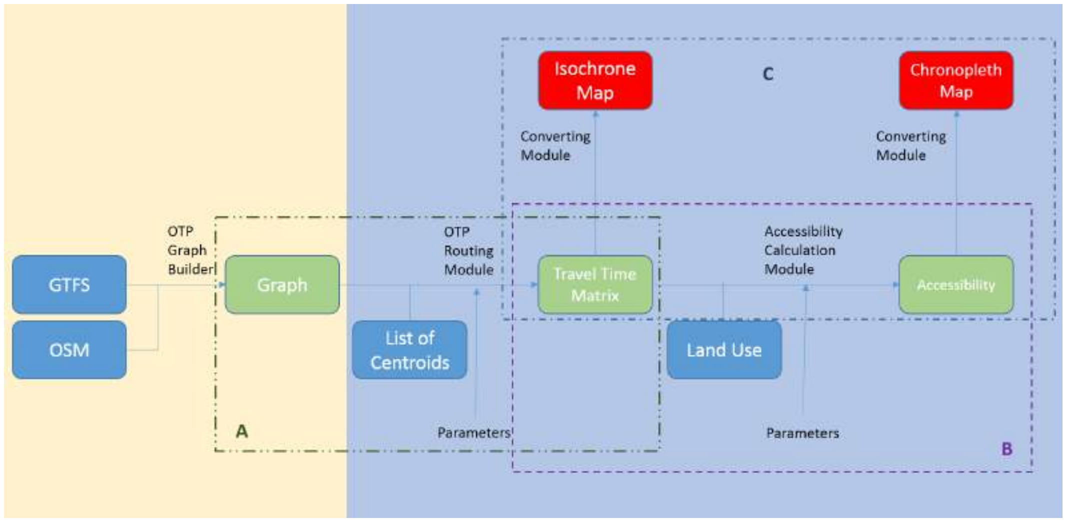

Figure 2: Workflow of the visualization building system. In the Graph Build stage, traffic network data are fed into OTP to generate a Graph. In the Calculation stage, this Graph is used to calculate travel times for each OD pair, which is then used, with land use data, to evaluate accessibility. Calculated accessibility and travel times are converted to JSON files. In the diagram, external data is shown with blue background; intermediate output is shown in green; final output is red. The Graph Build stage is shown with yellow background; the Calculation stage is shown with blue background: (A) travel time calculation phase; (B) accessibility calculation phase; (C) file converting phase.

3.3 Input Data Sets

Geographic data. We use shapefiles for block groups of the Chicago metropolitan area from Topologically Integrated Geographic Encoding and Referencing (TIGER) 2010, the latest available version from the U.S. Census Bureau. The centroid of each block group is extracted and used as the origins and destinations for calculating travel times.

Traffic network data. OpenStreetMap data of the Chicago metropolitan area is used to obtain street network information. GTFS data from all three public transit agencies in the Chicago region are used, namely the CTA (Chicago Transit Authority) - the bus and subway service provider of the city of Chicago, PACE - the suburban bus service provider of the Chicago area, and Metra - the commuter rail agency in the Chicago metropolitan area.

Opportunities and land uses data. We use job count data for the metropolitan area, and eight other land use count data, including schools (public or private), hospitals, parks (counts and area), fire stations, grocery stores, and libraries, are available at the block group level for the City of Chicago. Job count by sector data is from the U.S. Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) program. It contains the number of jobs in different categories for each block group. Land use count data as of 2014 is maintained by Cook county's GIS department. It contains the number of nine different kinds of land uses in each block group.

3.4 System Workflow

The workflow of our accessibility visualization system is illustrated in Figure 2. It has three stages: the Graph Build stage, the Calculation stage, and the Visualization stage (not shown in the figure). The Calculation stage consists of three phases: the travel time calculation phase, the accessibility calculation phase, and the file converting phase. The Graph Build stage uses OSM street network data and GTFS transit feeds as input, feeds them to the Graph Builder module of OTP, and generates the output of this stage, a multimodal integrated transport network called the Graph. In the travel time calculation phase, the system takes the Graph, together with the OD pair list, to calculate travel times for each OD pair by different travel modes at various departure times, by issuing customized batch analysis commands to the Routing module of OTP [2]. In the accessibility calculation phase, the system reads opportunity/land use data, and calculates accessibility (Section 4) for each block group. The calculated accessibility and travel times are then converted to JSON files in file converting phase. These JSON files are stored in the server and ready to be fetched by the web interface in Visualization stage (Section 5).

4. MEASURING ACCESSIBILITY

As discussed above, there are multiple ways to measure accessibility. Since our goal in building this system is to provide an online platform that allows users (planners, transportation professionals, policy analysts, etc.) to view accessibility for the metropolitan area of Chicago, and to present the information in the most easily interpretable fashion, we adopted a cumulative opportunity measure as our main way of measuring accessibility. This cumulative opportunity measure counts the number of opportunities (e.g. jobs) that can be reached within some travel time threshold (e.g. 45 minutes) by a particular mode (e.g. automobile, public transit). Accessibility for a given threshold by a particular mode is calculated as a simple sum of all opportunities in block groups that can be reached within the predesignated

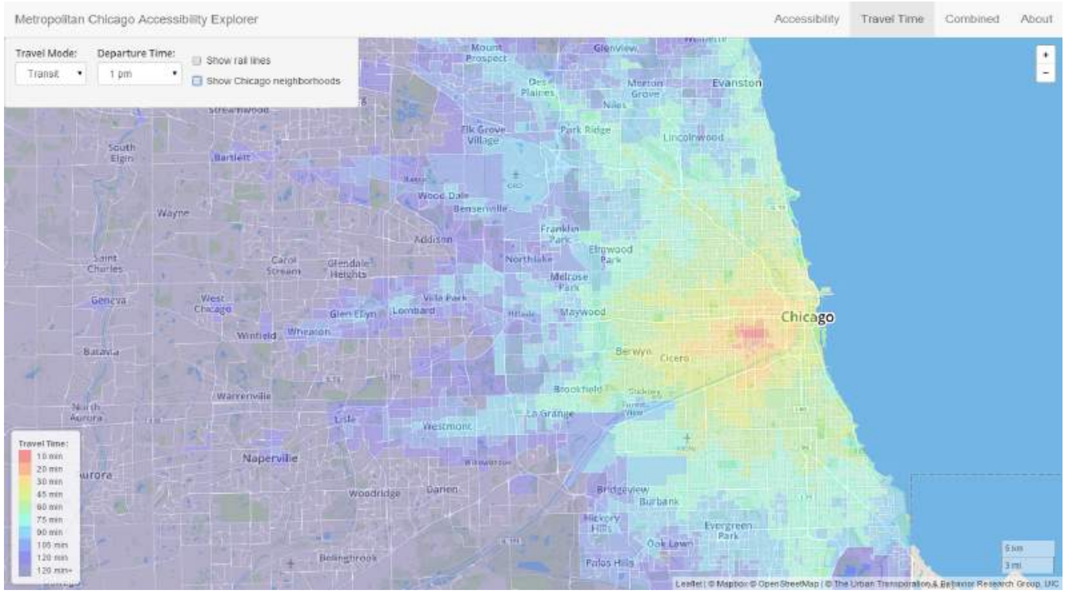

Figure 3: Travel Time View. Users can investigate the travel time from any block group to other block groups showed as an isochrone map. This snapshot shows travel times from a block group in the Near West Side of Chicago to each other block group by taking public transit at 1 p.m.

time threshold:

$$A_{i,O} = \sum_{T_{i,j} \leq thld} O_j,$$

where $A_{i,O}$ is the accessibility to opportunity O (such as jobs, schools, hospitals, etc.) from block group i, $T_{i,j}$ is travel time from block group i to j, $thld$ is travel time threshold, and O_j is the number or size of opportunity O in block group j.

Our system currently calculates accessibility to 41 different categories of jobs and 9 land uses, at the block group level, by 4 different modes of transport, within 12 thresholds (from 5 minutes to 60 minutes). See Table 1.

Table 1: Accessibility measure parameters used

Parameter	Value
spatial unit	census block group
type of opportunity	jobs (41 categories) park area park count school public school private school fire station hospital grocery store library
travel modes	car, transit, bicycle, walk
origins and destinations	from each block group to every block group
travel impedance	travel time (12 thresholds)

5. VISUALIZATION DESIGN

In order to support tasks identified in Section 3.2, we build our visualization with three views: 1) Accessibility view, in which users select from available parameters to view the corresponding accessibility as choropleth maps, 2) Travel Time view, which shows travel time from a certain block group to all block groups as isochrone maps, and 3) Combined view that shows accessibility choropleth maps and corresponding travel time isochrone maps side by side.

5.1 Accessibility View

As showed in Figure 1, users are presented with an interactive map in Accessibility view. They can easily specify parameters such as land use/opportunity, transport mode, departure time and travel time threshold, and see accessibility values visualized as a choropleth map.

We also allow the user to specify how the choropleth map should categorize accessibility values into different levels. One way of clustering is to use Jenks natural breaks optimization, a data clustering method designed to determine the best arrangement of values into different classes. An advantage of using Jenks optimization is that it minimizes each class's average deviation from the class mean, while maximizing each class's deviation from the means of the other groups. In this way, we avoid block groups with similar accessibility being assigned different colors. Users can also use a fixed scale, which clusters accessibility by their actual values (e.g. 10% - 15%, 15% - 20%).

When viewing the visualized accessibility, users can hover their mouse over any block group to see detailed information about that block group, including the actual accessibility value, total number of currently selected type of opportunity, accessibility percentage, and the community area it belongs to (See Figure 1).

To help quickly identifying problematic regions, we also allow users to bring up CTA subway and Metra railway lines, and Chicago community area boundaries for reference.

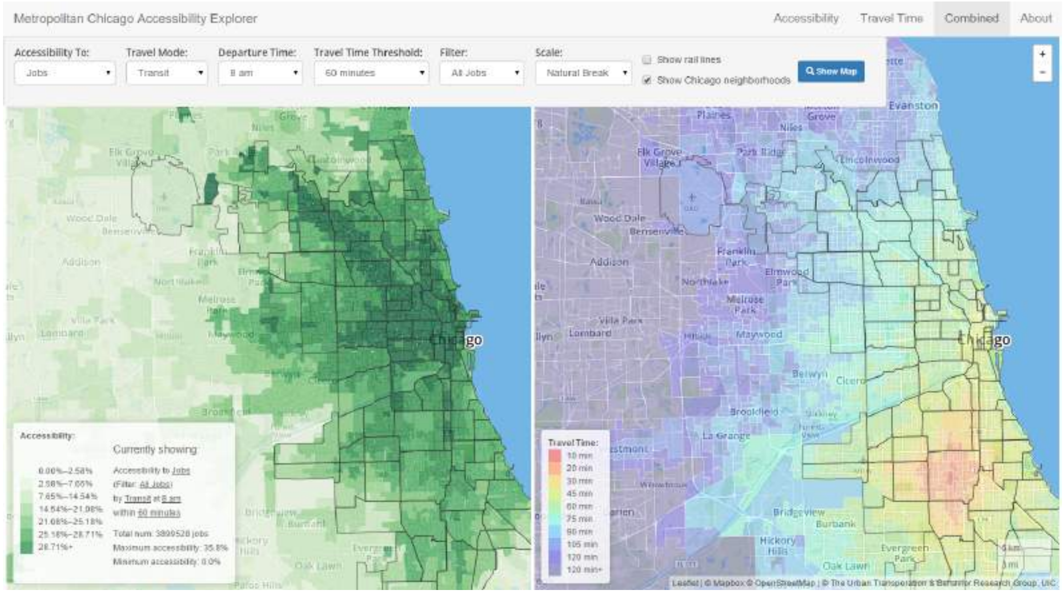

Figure 4: Combined View. This view allows users to investigate accessibility while viewing travel time as a reference. This snapshot shows accessibility to jobs (of all types) within 60 minutes by public transit as well as travel time from a block group in the West Englewood community area.

5.2 Travel Time View

Travel Time view has a similar look as Accessibility view, but with fewer menu options. Only Travel mode and Departure time are available. See Figure 3. Users choose a block group as the origin by clicking their mouse in the block group to see travel time visualized as an isochrone map.

Hovering their mouse over any block group shows users detailed travel time from the origin block group to this one, as well as the name of the community area it belongs to.

Different from Accessibility view, the legend in travel time view is not varying as visualized layers change. Currently we have 10 isochrone levels: less than 10 minutes, 10 to 20 minutes, 20 to 30 minutes, 30 to 45 minutes, 45 to 60 minutes, 60 to 75 minutes, 75 to 90 minutes, 90 to 105 minutes, 105 to 120 minutes, and more than 120 minutes.

Similar to Accessibility view, users can choose to show rail lines and community area boundaries on the map, in case they feel these layers are helpful.

5.3 Combined View

Combined view shows accessibility and travel time visualizations side by side, allowing users to investigate accessibility patterns with the isochrone map available as a reference. See Figure 4.

Rather than having two menus, one for each view, Combined view uses a unified control menu, whose options are the same as in Accessibility view. The travel time map updates automatically based on the accessibility map. In this view, when users change the accessibility layer (e.g. from showing accessibility by driving to showing accessibility by walking), the isochrone map updates accordingly, thus consistency is maintained between these two views.

6. USE CASES AND USER FEEDBACK

This section presents two use cases and user feedback from users of the system.

6.1 Use cases

Our system allows both transportation planning professionals and economic development practitioners to easily identify places with transportation access problems to jobs, parks, or other amenities. They can then think about how to solve these problems they are facing - by improving transportation, by encouraging businesses to move into certain areas, or by encouraging increased investment in parks in these areas, etc. In this section, we show two real world use cases of this system in ongoing projects.

Spatial and temporal variation of accessibility. A consulting firm is interested in unemployment and transit access, and would like to investigate some communities with the highest unemployment and some with relatively low unemployment. Figure 5 shows accessibility to jobs within 60 minutes by public transit at 8 a.m. (left) and at 6 p.m. (right), together with travel time from Chatham (top), one of the areas with highest unemployment, and from Lincoln Park (bottom), one of the areas with the highest employment.

Comparing accessibilities to different jobs. An economic development consultant would like to study patterns of accessibility to different types of jobs from some of the southern suburbs of Chicagoland in order to inform localities about attracting jobs or improving transit services. Figure 6 shows side by side accessibilities to different type of jobs within 60 minutes by public transit at 8 a.m. From the left to right, it shows accessibility to the following job categories: All, Construction, Manufacturing, Management of Companies and Enterprises, Education Services, and Health

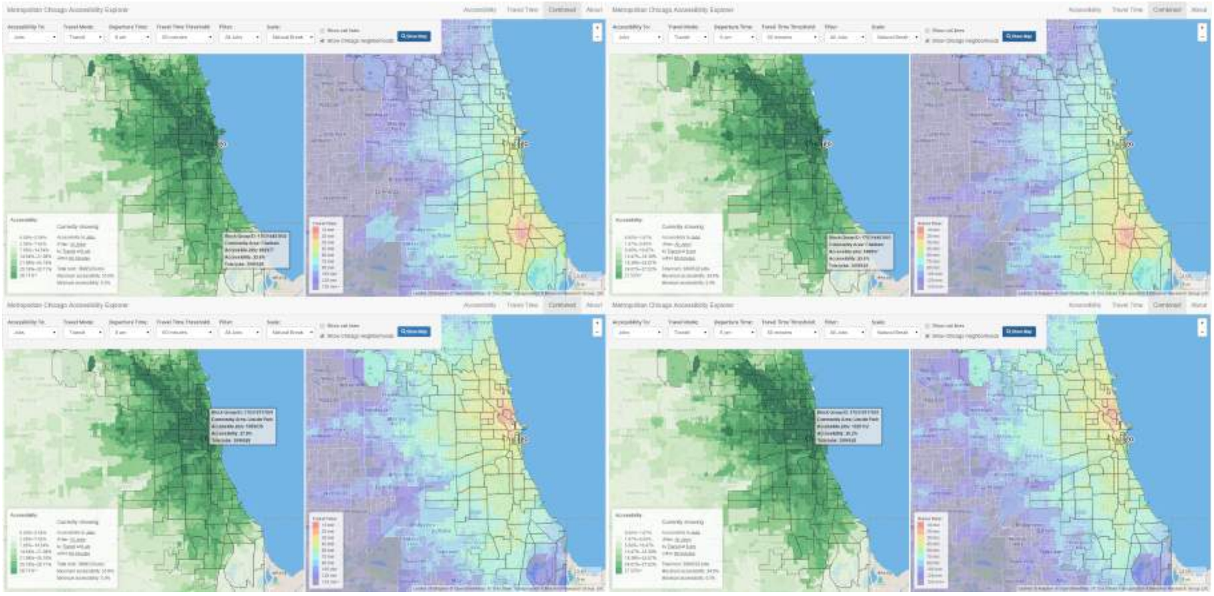

Figure 5: Use Case 1: Accessibility Variation. Accessibility varies in different places and at different times. Mode: public transit; Time: 8 a.m. (left) and 6 p.m. (right); Threshold: 60 minutes; Scale: Jenks natural break. Travel time isochrone maps are showed for the Chatham community area (top) and the Lincoln Park community area (bottom).

Care and Social Assistance. A fixed scale is used in this case.

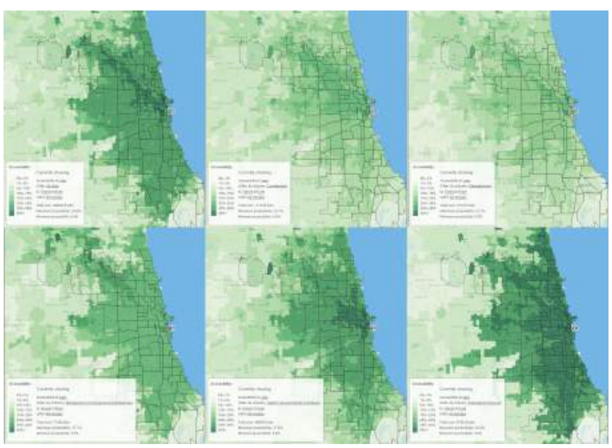

Figure 6: Use Case 2: Job accessibility Comparison. Accessibilities to different types of jobs. Mode: public transit; Time: 8 a.m.; Threshold: 60 minutes; Scale: fixed scale. Job Categories (from top left to bottom right): All, Construction, Manufacturing, Management of Companies and Enterprises, Education Services, and Health Care and Social Assistance.

6.2 User Feedback

In order to evaluate the effectiveness of the system and to find potential improvements for the future, we interviewed six users of our system. Participants included an instructor of transportation planning (User A) and a student working on data analysis (User E) from a university, three transportation planners (User B, C, F) from government sectors, and a policy analyst working on economic development (User D) from a private company.

In order to see how useful the system is, we asked participants about 1) their interests in the results we present, 2) how they would have done their analysis without this system, and 3) whether this tool provides important functionalities to their jobs:

Users showed plenty of interest in the versatile results presented by this system. All 6 users are interested in accessibility to jobs; 3 users are interested in travel times; 2 of them have interest in accessibility to schools, and 2 have interest in accessibility to grocery stores. As for transport modes, all participants say they are *very interested* in travel by public transit. All participants show different levels of interest in travel by walking or bicycling (3 are *very interested* in walking; 1 is *pretty interested*; 2 are *a little interested*. 2 are *very interested* in bicycling; 3 is *pretty interested*; 1 is *a little interested*). 5 out of 6 users have interests in travel by automobile.

Users agreed this system brings convenience to them and helps make their jobs faster and easier to do. 5 participants say they would have had to calculate the accessibility by themselves if our tool did not exist and have used other software, such as WalkScore or ArcGIS, for the job.

All participants think this system provides useful functionalities to their work. User A says the functionalities are very important, while others feel the functionalities are somewhat useful.

Some users also shared their thoughts about the system with us, which are summarized as follows:

Applicability. User C appreciates that our system is able to serve a wide range of audience, pointing out "public outreach" as the most attractive aspect of this tool. User D and User F both think the inclusion of all major transport modes in the system is of great usefulness, allowing them to investigate accessibility of Chicago in many different perspectives.

Improvements. Two users gave us suggestions on improving the system. User C thinks it would be good if the system allowed using a quartile scale to cluster accessibility values. User C also hopes the system could have covered an even larger geographic region. User D suggests that we add an aggregate accessibility measure that includes accessibility to all opportunities in a weighted manner to provide more comprehensive results. User D also suggests that we add a map of population-weighted accessibility, so that neighborhoods can be prioritized based on how populated they are. Accessibility may be low in rural areas but not many people live there, so in some cases this low accessibility can be disregarded. The system could serve economic development personnel better with this functionality.

7. CONCLUSION AND FUTURE WORK

This paper presents our recent work in building web-based interactive visualization of multimodal urban accessibility. In this work we discussed tasks we would like to accomplish with this system and made our design decisions based on them. We introduced the techniques and the input data used in this project, then showed an overview of system workflow, defined our accessibility measure model, and presented the visualization and user interface. We showed two use cases of this system and presented user feedback to evaluate the system.

The primary differences between this attempt and previous ones are that this system visualizes accessibility in a much larger scope, both geographically and quantitatively, and that the visualizations are presented in a light-weight fashion using a web-based interface, accessible by large audience.

This work provides a good example of how a platform helps researchers better understand accessibility patterns in a geographical area. We showed that an automated build system that converts land use data and geographic data to a ready-to-render format without user intervention is very convenient for urban planning personnel. Also, an easy-to-use user interface with well-designed customization options to investigate data from multiple perspectives is also important in allowing pattern finding and decision making.

We are currently working on adjusting this system to make it more general-purpose, so that it can be applied to any geographical region rather than only for the Chicago metropolitan area. Other future work includes adding more customizability (calculating accessibility based on other accessibility measures, allowing customized isochrone levels, etc.) and allowing extracting accessibility data of any area of interest.

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