Analyzing Multi-Modal Accessibility of Metropolitan Chicago Through Automated Visualization System

Category: Design Study

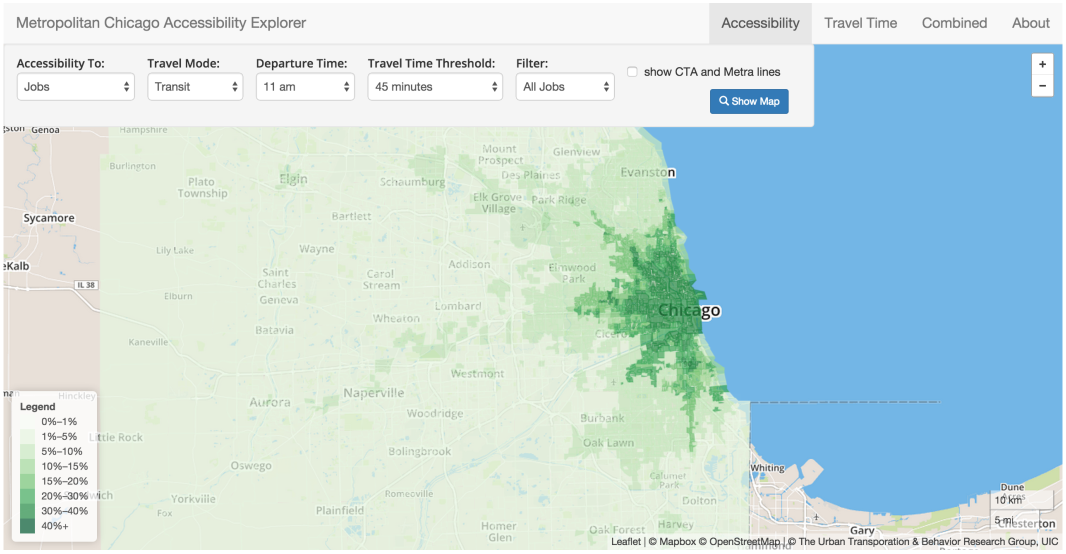

Fig. 1. **Snapshot of Accessibility view of our prototype web interface.**

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. Accessibility measures also provide 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 we designed and developed to visualize multi-modal 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 potential use cases of this tool, and show its effectiveness in real world tasks by providing experts feedback of this prototype.

Index Terms—accessibility analysis, geographic visualization, urban transportation planning

1 Introduction

The concept of accessibility has been introduced to urban transportation planning community for more than 40 years. In urban planning, accessibility is a measure of the ease of reaching valuable destinations. It 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 value of a destination, or the likelihood that an individual goes to a destination.

Since the groundbreaking work of [13], 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 insufficiently reflects how easy of traveling along the traffic network itself or how movement is constrained, while accessibility takes into consideration both the ability of traveling and the ability to reach valued destinations.

Accessibility are important for both public sectors and individual residents, but it is always hard for public sectors to improve accessibility for residents because different people have different individual priorities in life and thus perceive accessibility differently. For example, someone who has a stable career may want to live at a place that has high level of accessibility to open spaces, but does not care about accessibility to jobs in that region, while for someone else who works as a contractor infovis programmer, the increase in accessibility to high-tech jobs within might be very important.

The challenge to a public transportation agency is that when designing a transportation system, all types of accessibilities should be taken into consideration.

In urban planning community, a traditional way of calculating and visualizing accessibility measures is using GIS-based software. Usually, geographic information systems such as ArcGIS are used to manage the spatial database where transportation networks data is stored. Then standalone software or GIS extensions are developed to perform customized tasks, usually an implementation of an accessibility measurement. After the accessibility is calculated, GIS is used to support on-screen visualization and export of high quality static maps [24].

The disadvantages of this methodology is it depends heavily on GIS software. GIS software is powerful tool, and usually costs a lot of money. In most cases, only a small fraction of GIS software's functionality is used to conduct accessibility analysis. What's more, on-screen visualization and static maps are not easy to be accessed by a wide range of audiences, and are difficult to share between collaborators.

In this paper, we present our recent work of building a prototype web-based visualization system for accessibility analysis. Our goal in designing and developing this system is to provide urban planning researchers and transportation system professionals with an easy-to-use, integrated environment to look at accessibility measures and look for hidden patterns in accessibility measures of Chicago Metropolitan area.

The contributions of this work include:

1. Our accessibility visualization system allows automated building of visualizations for numerous accessibility measures with user-specified data sources and parameters;
2. It allows people who work in transportation and who work in economic development or related fields to easily identify places with transportation access problems;
3. It looks at access by multiple modes, to multiple regional amenities, and provided a secondary travel time visualization to allow more in-depth look at traffic conditions in the Chicago region.
4. It uses open-source software and libraries and has web-based interface, making it accessible to a wide range of audiences.

This paper is organized in the following way: after this introduction section, we provide some background knowledge about accessibility measures and discuss related work in visualizing accessibility in Section 2. In Section 3, we illustrate in detail our back end system that takes multiple data source and calculates accessibility automatically, followed by Section 4, where we present and reasoning about our front end visualization design. We briefly discuss use cases of our system and provide some feedback from domain experts in Section 5, and conclude our current work and list our future plans in Section 6.

2 Background and Related Work

2.1 Accessibility measures

The term accessibility has been around for more than 4 decades, and 'improving accessibility' has been appearing more than frequently in the goal statements of almost all transportation plans in the US [12]. How to measure accessibility is always an active research topic in urban transportation planning community. Lots of research effort has been put into proposing new accessibility measures or improving existing ones in order to make measuring accessibility more rigorous, realistic and tractable.

Besides accessibility, other measurements were also used for some period of time, such as mobility and congestion. Mobility measures the ability of moving from one place to another [11][13]. For example, a person driving a car is with higher mobility than a person who walks. Congestion, on the other hand, is a measure of how movement is constrained by too many users for the capacity of the system. Congestion can be treated as the inverse of mobility in many cases, though mobility can be low even when congestion is also low if the traffic network is very insufficient.

However, there is an inherent deficiency in mobility measure: it does not take human factors into account. A high level of mobility only means moving in the traffic network is fast, but only when there are valued destinations, it can be treated as having high level of accessibility. For example, traveling on high ways in rural regions are fast, hence with high level of mobility, but accessibility there is not high, because there are no potential opportunities for interaction. This is the major advantage of using accessibility over simply using mobility to measure performance of a transportation system. Because for a transportation system, moving people around is not the purpose; it is a means. The purpose of a transportation system is to make opportunities or activities *accessible* for residents.

Similarly, even if congestion level in a traffic network is quite high, people can still have high accessibility to activities if there are a lot of them in a relative small region. A good example of this case is Chicago Loop. Travel in Chicago Loop is slow in terms of distance that can be covered in a given unit of time, but one can reach many things in the same short period of time.

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 measures**, **gravity-based measures**, **utility-based measures**, and **space-time measures**.

Opportunity-based measures Opportunity-based measures deal with the number of reachable opportunities within a given distance[1] from an origin [2]. There are two major opportunity-based measures. The first method is to find the closest destinations with opportunities to an origin and calculate their distances, and the other method, called **cumulative opportunity measure**, is to count the number of destinations or opportunities that can be reached within a specified distance from an origin [31][30]. Cumulative opportunity measure is easy to understand, simple to calculate, but with the potential to artificially regard opportunities 14 minutes away as valuable while treating those 16 minutes away as having no value [7].

Gravity-based measures The central idea of gravity-based measures is that the potential of opportunity between two places is positively related to the sizes of the attractiveness of the places and negatively related to the travel impedance between them [18]. First introduced in [13], it is still the most widely used general method for measuring accessibility, although it is more complex to calculate than opportunity-based measures [15][33][27].

Utility-based measures Utility-based measures are the most complex and data intensive measures. This type of measure borrows the notion of consumer surplus from microeconomic theory and takes individual traveler preferences into consideration in measuring accessibility [7]. Research studies that utilized this methods include [1] and [25].

Space-time measures This type of accessibility measures puts emphasis on the range and frequency of a series of activities in which a person participated and the possibility of sequencing them to have a path in which all of the activities can be undertaken [15]. This type of measure requires a good accessibility to include not only good spatial accessibility but also good temporal accessibility. Space-time measures are also complex and require large amount of data and intensive computation [15] [17]. Improvements in this type of measure have been constantly made through various research efforts, such as [22][16][23][6][32] and [5].

Other measures of accessibility include **constraints-based measures** [34], **place rank measure** [7] and **composite accessibility measure** (which combines space-time and utility-based measures in one measure) [24].

Each type of accessibility measure has its own advantages and limits. The answer to 'which type of method to use' depends on what to measure. For a city level accessibility measurement, cumulative opportunity or gravity-based measures are suitable. When the interest is in measuring accessibility from an individual perspective, one of the more complex methods may be a better option.

2.2 Accessibility analysis and GIS

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. We have introduced multiple commonly used accessibility measures in Section 2.1.

The second step is to specify and calculate the accessibility measures. In this step, parameters are specified for the developed or selected accessibility measures, and accessibility calculation is performed.

Generally speaking, to define an accessibility measure, a series of parameters need to be specified. First of all, the *spatial unit* for accessibility analysis. It defines the basic unit area for which accessibility is measured. The spatial unit can be a census tract, a building block, or

[1] In accessibility analysis, distance is a generic term for travel impedance. Commonly used unit of distance include physical distance, travel time and generalized cost.

a census block group. Secondly, the *type* of opportunity for which accessibility is assessed. It can be job opportunities, hospitals, schools, park areas, etc. The third parameter is *travel mode*, which can be by car, by transit, by bicycle, by walking, or in some rare cases by other specialized transportation. The fourth parameter is *the origins and destinations*, from which and to which accessibility is measured. Last but not least, *travel impedance*. Travel impedance, which represents the spatial separation between an origin and a destination, is in most cases measured using travel distance, travel cost or travel time. For traveling by transit, travel time is time-dependent, varying at different time in a day, while for other travel modes, travel time can be considered as a constant throughout a day [18].

The third and last step is to present, analyze and interpret the results. In this step, researchers and urban planners investigate visualized accessibility in the context of their respective research questions to answer.

In this process, accessibility calculation (later half of the second step) and analysis (the third step) are usually conducted inside a geographic information system (GIS). A GIS system provides an integrated platform for capturing, storing, editing, analyzing, managing and visualizing a wide variety of spatial or geographical data. It can perform tasks like shortest path search, geocoding, buffering, feature editing and extracting.

GIS is have become a more and more familiar aspect of urban planning in the past few decades. One of the early contributions in the progress of contemporary GIS was the development of the Canada Geographic Information System (CGIS) in 1963 [28]. It had some basic functionalities that are included in almost every GIS software, including area calculation and spatial statistical information summarizing. Another significant milestone in the history of GIS occurred in 1970. At that time, Harvard Laboratory for Computer Graphics and Spatial Analysis, a pioneering in GIS development, created the first general-use GIS and used it for analyzing the US population census [20]. More recently, another milestone that took place in 1995 is that United Kingdom, for the first time, covered its whole territory with standard-scale digital maps [19].

These early milestones pushed GIS technology into its current state, called 'the era of ubiquitous GIS' by Maliene et al. [20]. However, as GIS evolves and becomes much more sophisticated, one side effect has become obvious that GIS has become less and less accessible to non-specialist users. In fact, GIS have been with limited accessibility to general public since its debut, partially because of large amount of investment needed in hardware, software and training in order to use GIS. Now, hardware has become significantly cheaper, but GIS software is still expensive, and has become more complex to learn.

For accessibility analysis, useful GIS functionality include its capability for collecting, storing, and manipulating spatial data, for calculating shortest paths, for modeling transportation networks and for visualizing the calculated accessibility values [22][29]. However, GIS have several limitations in performing accessibility related tasks. Liu & Zhu [18] identified a deficiency in using buffer-generation function of GIS for excluding activities that are close to an origin in measuring accessibility. Also, standard accessibility built into GIS software are actually distance measures and are not suitable for advanced analysis where human factors should be also considered.

GIS is able to find shortest path between two points, to find list of paths that connects a set of places, and even to find all locations within a given distance or time from a specified point in the network. However, it is not sufficient to be used in accessibility analysis where modes of travel and other parameters such as socioeconomic characteristics, level of demands, and attraction of the activities should be taken into account [8]. Therefore, if one wants to use GIS for accessibility analysis, customized plug-ins or extension modules still need to be written.

Moreover, GIS-based software is not good at allowing comparison between layers in a very convenient fashion. Its output is on-screen visualization and exported static map images, which are not convenient to view or to share between collaborators. Also, if accessibility of multiple sets of parameter is to be analyzed, GIS has no fully automated process to do that. Users need to specify parameters for each set manually.

2.3 OpenTripPlanner, OpenStreetMap and GTFS

OpenStreetMap Since it's start in 2004, OpenStreetMap (OSM) project [10] has been creating open source map of the world collaboratively by contributors all around the world. One of the primary outputs of this project is geographic data generated during the creating and editing of the map. This data is comparable to proprietary data sources [35] and has been widely used in a variety of application.

GTFS GTFS is short for General Transit Feed Specification. This specification descirbes 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 [9].

OpenTripPlanner OpenTripPlanner (OTP) [26] is an open source platform for multi-modal and multi-agency trip planning written in Java. Two primary modules of OTP are Graph Builder module and Routing module. Graph Builder module takes OSM data as input source to generate road networks, and uses GTFS feeds released by transit agencies to generate transport networks. It then combines the two types of traffic network into one multi-modal traffic network, stored in the so-called *Graph*. For more detail about the structure of traffic network built by OTP, see its wiki page [3]. 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 pair analysis.

These powerful tools make it possible to build a sophisticated multi-modal time-dependent traffic network that reflect reality to a very high extent.

2.4 Our design choices

Based on above discussion, we can identify following observations in current methodologies of accessibility analysis:

1. different accessibility measures have different advantages and disadvantages.
2. GIS is expensive to use, in terms of finance and time.
3. Accessibility analysis only uses a small fraction of GIS functionality. And this fraction of functionality is not suffient for accessibility analysis. Writing customized extensions are needed.
4. GIS is lacking of support for result comparison and is not good at sharing between collaborators.

Taken these observations into account, we made following design choices for our accessibility visualization system:

First We used cumulative opportunity measure as our accessibility measure. Although gravity-based measures is 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 general public [7].

Second We used OTP to calculate *Travel Time Matrix* (more on this in Section 3). We argue that using this specialized tool that is dedicated to routing services and handles multi-modal time-dependent travel queries is a better choice than GIS in our case. OTP is open source. It has web supports, which is convenient for our web-based system.

Third We did not design our visualization tool as a GIS-based software. Instead, we developed it as web-based, with the focus on providing an easy-to-use interface for users to view, analyze and comparing accessibility visualizations. There are three advantages in a web-based tool. Firstly, it is light-weighted; users will not need to purchase or install any software. And because of this, secondly, our tool is accessible to a wider range of audience. Thirdly, since it is not bound to GIS, there are large possibilities in designing user interface to facilitate comparison between accessibility visualizations and make collaboration easier.

3 Accessibility Building System

Our web-based accessibility visualization system consists of three stages, Graph Build stage, Calculation stage, and Visualization stage. Calculation stage consists of three phases: travel time calculation phase, accessibility calculation phase, and file converting phase. The whole process is listed as below:

1. Graph Build stage
2. Calculation stage
    (a) travel time calculation phase
    (b) accessibility calculation phase
    (c) file converting phase
3. Visualization stage

In this section, we present back end of the system (Graph Build stage and Calculation stage). The whole pipeline of the back end is illustrated in Figure 3. The front end of the system (Visualization stage) will be discussed in next section.

Graph Build stage is performed completely within OpenTripPlanner. The input of this stage is OSM street network data of Chicago metropolitan area and GTFS transit feeds of three public transit agencies in Chicago area, CTA, PACE and Metra. These two sets of data is fed to OpenTripPlanner's Graph Builder module to generate the output of this stage, a multi-modal integrated traffic network called the Graph.

Travel time calculation phase is performed by issuing customized batch analysis commands to OTP. The input of this phase is the output of last stage, the Graph, as well as the list of centroid of every block group in the region of interest. Also fed to the OpenTripPlanner are two parameters for calculation: list of travel modes and corresponding departure time. This stage generates a Travel Time Matrix (TTM) for each given travel mode at each specified departure time, which contains travel time values from each block group to every other block groups.

In accessibility calculation phase, the system reads opportunity and land use data of each block group, and thresholds of travel time as calculation parameter. Together with travel time matrices from last phase, the system, for each block group, calculate percentage of opportunity and land use that can be reached within the given threshold amount of time by each travel mode at specified departure time.

Calcualted accessibility and travel time matrices are then converted to JSON files in file converting phase. These output JSON files are stored in the server and ready to be fetched by the web interface in visualization stage. In JSON objects converted from accessibility data, keys are block groups IDs, and values are accessibility value. Each JSON file corresponds to one set of accessibility (one travel time threshold, one departure time, one travel mode) for all block groups. For example, file 'transit-8/1800/hospital.json' stores percentage of hospitals can be reached within 30 minutes from each block group at 8 am by transit. In JSON objects converted from travel time matrices, keys are block group IDs, and values are travel time to this block group from the block group corresponding to this file. Each JSON file corresponds to one block group, at one start time, by one travel mode. For example, file 'transit-8/42.json' stores travel time from the block group with ID 42 to all block groups at 8 am by transit.

Visualization stage will be discussed in detail in next section.

3.1 External Data Source

As discussed in the previous section, to calculate accessibility measure of a position-in-interest (POI), we need to specify five parameters. Travel impedance is fixed to travel time in our system but can be specified to different values during calculation stage and be selected by user in visualization stage. Similarly, travel modes are specified as a parameter to the system during calculation stage and are selected by users in visualization stage. Information of the other three parameters, spatial unit, origins and destinations, and types of opportunities, are from external data sets instead.

3.1.1 geographic data

Spatial unit in our implementation of accessibility measure is block group. Their geographic information is thus needed. We used two sets of geographic areas. One is Chicago Metropolitan area, the other is the city of Chicago. We converted shapefiles of block groups of these two areas to TopoJSON.

As for origins and destinations, we used centroid of each block group to represent that block group. Thus POI in our implementation is lists of centroid coordinates of block groups.

3.1.2 traffic network data

OpenStreetMap data of Chicago metropolitan area is used to obtain street network information. We extracted the data from http://extract.bbbike.org/.

In order to enable calculating travel time and accessibility for traveling by transit, GTFS feeds are needed. We have 3 GTFS data sets, each is for one of the three public transit agencies in Chicago region, namely CTA (Chicago Transit Authority), the bus and subway service provider of the city of Chicago, PACE, the suburban bus service provider of Chicago area, and Metra, the commuter rail agency in the Chicago metropolitan area.

3.1.3 opportunities and land uses data

One data set we used for the prototype system is the list of coordinates of centroids of all block groups within the area of interest. We have two lists, one includes four counties in Chicago Metropolitan area and the other includes block groups in the city of Chicago;

Another data source needed is land use data of corresponding areas. In our prototype system, we used job data for metropolitan area, while other land uses, including school (public or private), hospitals, park (counts and area), fire stations, grocery stores and library, are available for each block group in the range of the city of Chicago. Job counts data used in this work was from the U.S. Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) program. It contains the number of jobs in different industrial categories for each block group. There are 5914 block groups in metropolitan Chicago area. (There are 5916 block groups in total but 2 of them are entirely in the Lake Michigan so we removed them.) Land uses data is as of 2014 as maintained by corresponding counties' GIS departments. It contains the number of aforementioned land uses in each block group. There are 2195 block groups in the City of Chicago.

3.2 Graph build stage

Graph build stage is performed completely in OTP, using OTP's Graph Build module. In the stage, the system loads traffic network data from OpenStreetMap street network data and the three GTFS transit feeds into OTP's Graph Build module, which then combines them into an integrated directional graph that represents our multi-modal traffic network.

This stage is showed in the left side of 3.

3.3 Calculation stage

3.3.1 travel time calculation phase

In this phase, the system calculates travel time from specified origins to destinations, in our case centroids of block groups. It takes travel modes and corresponding travel departure times as parameters. In our current implementation, we calculated following travel modes: automobile, public transit, bicycle and walking. For traveling by taking public transit, we calculated travel time at each hour in a day separately, because transit travel time (and thus accessibility) is time-dependent and varies significantly at different time in a day. For other three modes, we used 8 AM as travel departure time.

Feeding data for Chicago metropolitan area to the system gives us a TTM of 5914 rows by 5914 columns, where $TTM_{i,j}$ = travel time

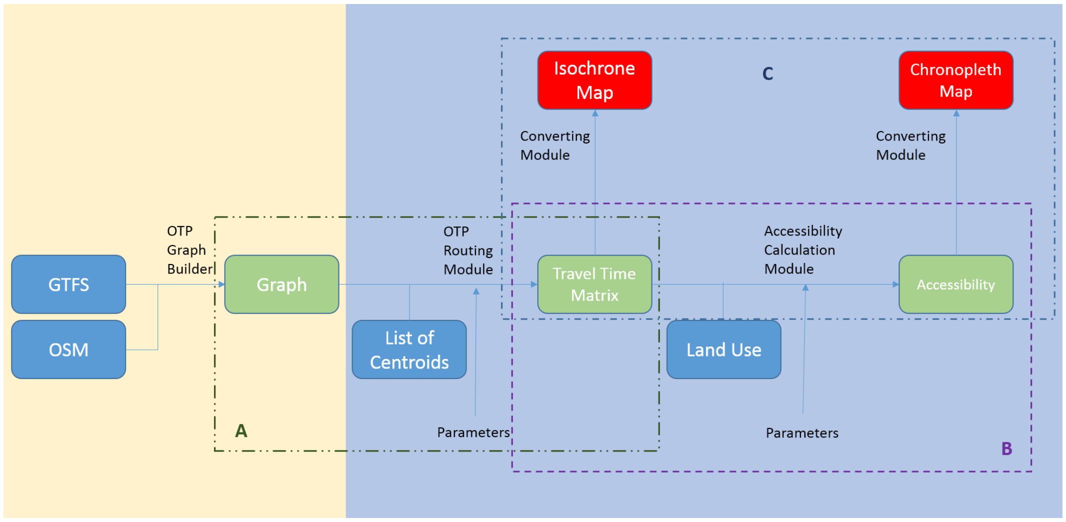

Fig. 2. **Pipeline of the visualization building system.** External data is in blue color; Intermediate output is in green color; Final output is in red color. Graph Build stage is with yellow background color; Calculation stage is with blue background color; (A) travel time calculation phase; (B) accessibility calculation phase; (C) file converting phase.

from block group i to block group j. Similarly, data for city of Chicago returns a TTM of 2915 by 2915.

For this phase, we modified opentripplanner-jython library by Matthew Conway [4] to write Python scripts to perform batch processing via Java-written OTP.

3.3.2 accessibility calculation phase

Based on TTM, accessibility is then calculated in this phase for different thresholds that are fed to the system as a parameter. We calculated accessibility for 12 thresholds, from 5 minutes to 60 minutes, with a 5-minute increase between each. This is done by, for each origin, traversing each destination and if $TTM_{i,j} <= Thres_0, Thres_1, ..., Thres_x$ and $TTM_{i,j} > Thres_{x+1}$, we add the number of jobs to $Acc[Thres_0], ..., Acc[Thres_x]$. This gives us how many opportunities or land uses one can reach from a specific origin using a certain type of transportation within a certain amount of time.

Then the system divides the number of reachable opportunities by the total number of opportunities in the region (either Chicago metropolitan area or the city of Chicago) to get final accessibility value as percentage. Formulae used are as follows:

$$Acc_{i,cat} = \sum_{TTM_{i,j} \leq threshold} Job_{j,cat} / \sum_{j} Job_{j,cat}$$

where $Acc_{i,cat}$ is the accessibility to jobs in category cat from block group i, $TTM_{i,j}$ is travel time from block group i to j, and $Job_{j,cat}$ is the number of jobs in category cat in block group j.

And for land uses:

$$Acc_{i,opp} = \sum_{TTM_{i,j} \leq threshold} Opp_j / \sum_{j} Opp_j$$

where $Acc_{i,opp}$ is the accessibility to land use opp from block group i, $TTM_{i,j}$ is travel time from block group i to j, and Opp_j is the number of opportunities in block group j.

As mentioned above, our system currently calculates accessibility to 41 different categories of jobs (see Table 2) and nine land uses, at block group level, for all block groups, by four different modes of transport (see Table 1). Including more accessibility measures into our auto-built system is part of future work of this project.

3.3.3 file converting phase

In this phase, the system converts calculated TTM and accessibility data to JSON files, which will be fetched by web interface when users want to see a certain set of accessibility data or travel time data. Each JSON file stores one set of data. In this way, it is very fast to download data each time when user wants to show a specific set of accessibility or travel time (see side note in Section 3.3.4).

Currently, for accessibility choropleth maps, we have 9000 JSON files, as we calculated accessibility for 12 travel time thresholds, 15 departure times (12 for transit and 1 for each of driving, walking and bicycle), 41 categories of job opportunities data and 9 land uses data. For travel time isochrone maps, we have 132,435 files, as we have 15 departure times, 5914 block groups in metropolitan area plus 2915 block groups in the city of Chicago.

Table 1. Accessibility measure parameters used

Parameter	Value
spatial unit	census block group
type of opportunity	job 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

3.3.4 side note about data storing

An intuitive way to visualize accessibility measure is to save data as attributes of features in a shapefile and use certain web-based mapping library to render the shapefile and color it based on values of a specified feature. This approach works for many other projects where only a small amount of features are in the shapefile, and/or the features all have regular shapes (such as rectangular or hexagon), thus need only very small amount of space to store their geometric information. However, neither of these conditions is met when visualizing accessibility at block group level for a relatively large region, like in our case. Firstly, the numbers of block groups are quite large. Recall that there are 5914 block groups in Chicago metropolitan area and 2915 block groups in the city of Chicago. Secondly, the shapes of block groups are irregular polygons rather than regular ones, and thus need a large amount of coordinates to define the geometries. Even after converting to TopoJSON, the geographic information is around 2.8MB, not to mention if simply using the shapefile directly, or using GeoJSON file converted from the shapefile.

To deal with this issue, we stored geographic information separated from calculated travel time result and accessibility result. There are two advantages in storing the data this way. The first one is saving disk space on the server. As discussed above, using TopoJSON files to store geographic layers and JSON files to store calculated accessibility and travel time data extremely decreased disk space needed to store the data. The other advantage, which is more important, is that by decoupling geographic data and calculated results, users will only need to download geographic data, which has relatively large file sizes, for one time. This provides users a very fast loading time, as one set of accessibility result is less than 200KB.

To convert shapefiles to TopoJSON files, we used TopoJSON command line tool available in NPM. Shapefiles are converted to TopoJSON removing all properties but GEOID10, which is a 14-digit code that is can unique to each block group and is used to distinguish block groups.

4 Visualization Design

The purpose of our visualization interface is to provide a way to allow users (typically urban planners, domain scientists and transportation administrators) to investigate accessibility data that has been prepared in previous stages together with travel time information also visualized as a reference.

We want to allow users to investigate the data set from as many perspectives as possible. Our visualization consists of three views. The first view is Accessibility view, in which users select from available parameters to view corresponding accessibility choropleth maps. The second view is Travel Time view, where users selects to show travel time isochrone maps from a certain block group to all block groups. The last view is a combination of accessibility view and travel time view. In Combined view, users can view accessibility choropleth maps and corresponding travel time isochrone maps side by side, thus be able to make sense and gain insights from the viewing the two related visualizations at the same time.

4.1 Accessibility View

As showed in , our web interface is designed as an interactive online map. We use Mapbox for map tile service and Leaflet as mapping framework.

At the top of Accessibility view is control menu, where uses specify parameters to bring up different sets of accessibility measure.

To customize which set of accessibility to look into, the first set of options that users can select is which opportunity or land use they would like to investigate. They can select to show accessibility to jobs or to any one of the nine land uses.

Similarly, users then select a transportation mode from the list of available options they would like to show accessibility for. They can select between four modes of transport: by driving, by transit, by bicycle, or by walking.

If transit is selected in the second step, a new drop down menu will appear, allowing users to select a departure time. Users can choose from any of the 24 hours in a day to investigate.

Then users should specify a travel time threshold that they are interested in. We have 12 different thresholds available, from 5 minutes to 60 minutes, with a 5-minute difference between each one.

If in the first step *Jobs* is selected, also available to customize is a job category filter. In U.S. Census Bureau's LODES data, jobs are categorized using different classification methods, including age, earning, industry, race, ethnicity, education and gender. The fields correspond to variables in the U.S. Census Bureaus LODES data format and are listed in Table 2.

Table 2. Categories of Jobs

Category	Classes
Age	$\leq$ 20; 30 - 54; $\geq$ 55
Earning	$\leq$ \$1250$/mo.$; \$1251/mo. - \$3333/mo.; >\$3333/mo.
Industry	Agriculture, Forestry, Fishing and Hunting; Mining, Quarrying and Oil and Gas Extraction; Utilities; Construction; Manufacturing; Wholesale Trade; Retail Trade; Transportation and Warehousing; Information; Finance and Insurance; Real Estate and Rental and Leasing; Professional, Scientific, and Technical Service; Management of Companies and Enterprises; Administrative and Support and Waste Management and Remediation Services; Educational Services; Health Care and Social Assistance; Arts, Entertainment, and Recreation; Accommodation and Food Services; Other Services [except Public Administration]; Public Administration
Race	White, Alone; Black or African American; American Indian or Alaska Native Alone; Asian Alone; Native Hawaiian or Other Pacific Islander Alone; Two or More Race Groups
Ethnicity	Not Hispanic or Latino; Hispanic or Latino
Education	Less than high school; High school or equivalent, no college; Some college or Associate degree; Bachelor's degree or advanced degree
Gender	Male; Female

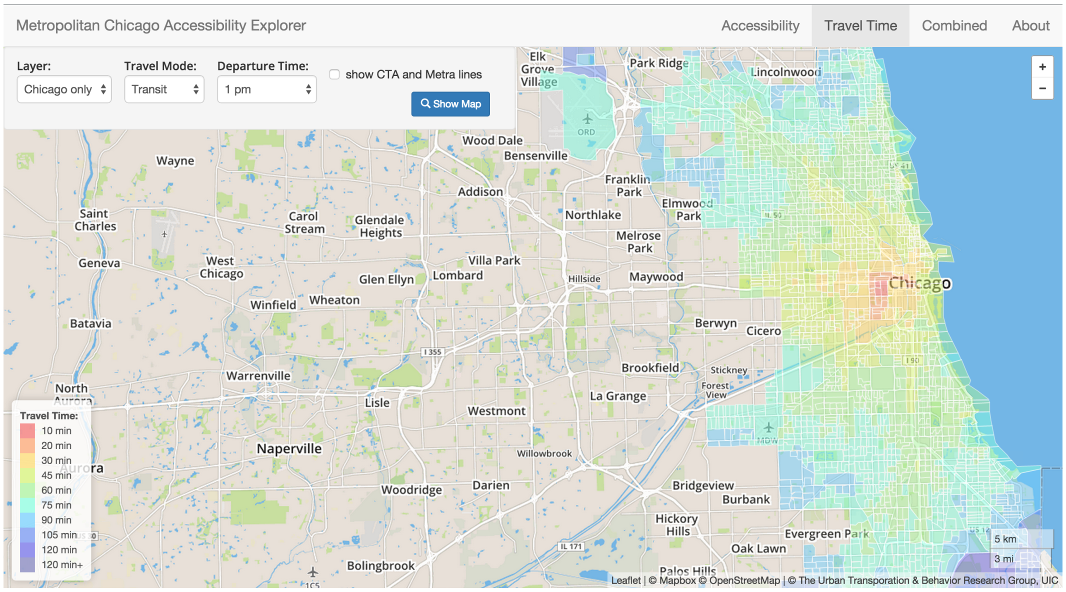

Fig. 3. **Snapshot of Travel Time View.**

After users specify all parameters, they can click on 'Show Map' button to bring up the choropleth map of the corresponding set of accessibility data. It will send an request to the server with the parameters just specified. The server will then return the specific set of accessibility data (stored in a JSON file) based on the parameters. If this is the first time the user request a set of accessibility for a geographic area, the geographic data (stored in a TopoJSON file) of this area will be downloaded before the accessibility data. Leaflet framework will then convert the TopoJSON file to GeoJSON layer and render it.

When visualizing the layer, we used Jenks natural breaks optimization method to cluster block groups into 7 classes, and rendered them using a monochromatic green color scheme, with deepest color means highest accessibility and shallowest means lowest. An advantage of using Jenks optimization to dynamically divide block groups, is that when determining the best way to assign values into different classes, it minimizes each classs average deviation from the class mean, and maximizing each classs deviation from the means of the other groups. In this way, we avoids that block groups with similar accessibility to be assigned different colors.

We used the implementation of Jenks method available at https://gist.github.com/tmcw/4977508. Jenks natural breaks classification method is a data clustering method designed to determine the best arrangement of values into different classes. This is done by seeking to minimize each class's average deviation from the class mean, while maximizing each class's deviation from the means of the other groups. In other words, the method seeks to reduce the variance within classes and maximize the variance between classes [14][21]. In JavaScript code, an array of all accessibility values in currently loaded JSON file is stored and then passed to Jenks function. Based on the returned value of Jenks function and the accessibility value property, each feature in the GeoJSON layer is assigned one of the 7 colors.

When viewing the visualized accessibility data, users can hover the mouse over any block group to see detailed accessibility value of that block group, the GEOID10 of it, as well as the total number of jobs in currently selected category or total number of currently selected land uses, depending on whether jobs or other land uses are being displayed.

When the layer is loaded, a legend for currently layer appears at the bottom-left corner of the map, providing users information about how accessibility values have been arranged by Jenks optimization method.

There are also options that allow users to bring up CTA subway lines and Metra lines. When selected, these railway lines will appear on the map, serving as a reference to users for their investigation.

Users can zoom in and zoom out the map, based on their purpose of using this tool. When viewing the visualization in a high zoom level, borders of each block group are added to the layer. When zoom level is low, however, borders are hidden to not overwhelm the screen space and to allow users see borders of two areas in different color.

4.2 Travel Time View

Another view is travel time view. This view has a similar interface as accessibility view, but with different menu options. Since we have two geographic areas, in the first menu option, users are able to select which one to show, either the Metropolitan layer or the Chicago only layer. See Figure 3.3.4.

Then users select a travel mode from available ones that are they are interested in. If transit is selected, the same drop down menu as in Accessibility view will appear, and users can select a departure time of which they would like to see travel time.

After specifying these parameters, users can click on 'Show Map' to load the data. The system will download corresponding geographic data and renders it. Then users can choose a block group as travel origin by clicking the mouse in the block group to see the isochrone map of travel time from this block group to all block groups. User can easily switch travel origin to another block group by clicking at that block group.

When users click at one of the block groups, a request is sent to the server with the specified parameters and the id of that block group. The server then returns the corresponding JSON file. Based on the values in the JSON file, JavaScript code assigns a color to each feature in the layer according to it's travel time value.

Hovering the mouse over any block group show users detailed travel time from the origin block group to current block group, as well as the GEOID of this block group.

Different from Accessibility view, legend in travel time view is not varying as visualized layer changes and is always at the upper-right corner of the map. 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. In the future, we plan to add functionality to allow users to customize isochrone levels.

Same to Accessibility view, users are able to select to show CTA lines and Metra lines on the map, in case they feel these layers are helpful to their work.

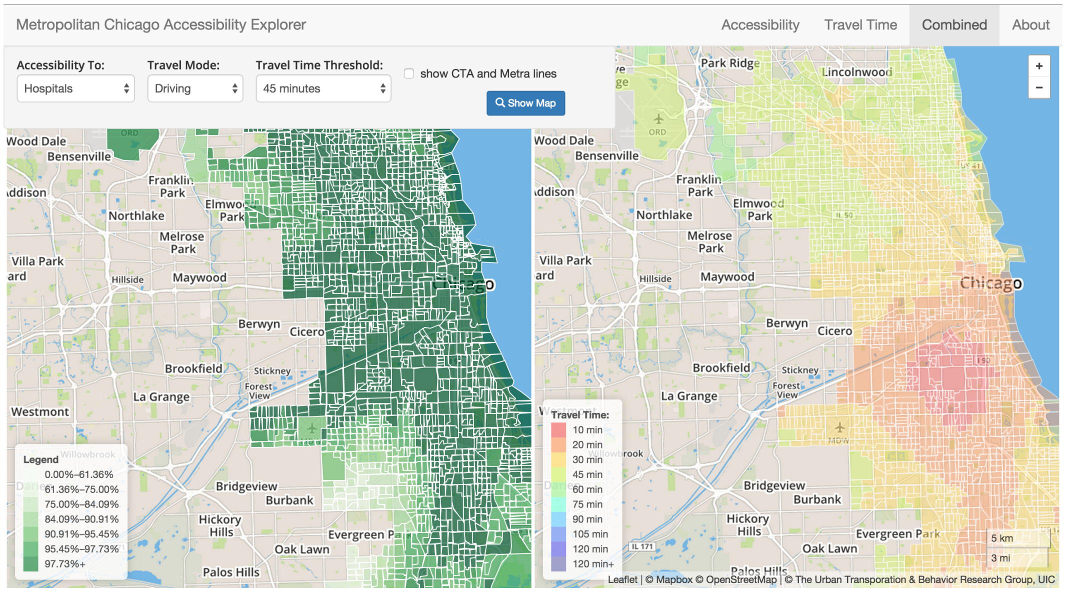

Fig. 4. **Snapshot of Combined View.**

4.3 Combined View

The third view of the web interface is Combine view. This view shows accessibility map and travel time map side by side, allowing users to investigate in accessibility patterns with the isochrone map available as a reference. See Figure 3.3.4.

Rather than having two menus, one for each view, Combined view uses a unified control menu. Menu options are the same as in Accessibility view. Travel time maps updates automatically based on Accessibility maps.

In this view, when users change accessibility layer (say, from showing accessibility to a land use by driving to showing accessibility by walking), isochrone map will update accordingly (origin is not changed by changing accessibility. It is only changed when users click at another block group in travel time side of Combined view.)

Besides layer changing, the two maps also pan and zoom at the same time, allowing easier comparison between the two maps.

5 Use cases and Expert Feedbacks

Our tool allows both people who work in transportation and those in economic development or related fields can easily identify places with transportation access problems to jobs, parks, or other amenities. They can then think about how to solve these - by improving transportation, or by encouraging the location decision of businesses or investment in parks etc. to these areas.

Since the release of the system in Feb. 2015, two entities have asked us for data we calculated and visualized. Both entities were interested in comparing the accessibility of corridors and locations that they are working in and trying to see how the neighborhoods they are looking at fare as compared to other parts of Chicago. Both entities focused on economically disadvantaged areas.

6 Conclusion and Future Work

In this paper, we present our recent work of building web-based interactive visualization of multi-modal urban accessibility data.

With it's sophisticated back end and easy-to-use front end, it provides a good example of how a platform that helps researchers from around the world to better understand accessibility pattern in a geographical area can be designed and built.

The contribution of this work is neither proposing novel methods to measure accessibility nor introducing new techniques to visualize accessibility. On the contrary, it used an existing accessibility measure and .

The main difference of this work from previous ones is in the scope of what we are presenting and how. Geographically, this tool focused on the large region of Chicago metropolitan area. Quantitatively, this tool visualized accessibility to multiple regional amenities, and by multiple travel modes.

By pointing out potential use cases and from feedback from domain scientists, we showed that our an automated build system that converts land use data and geographic data to ready-to-render format without user interference is very convenient for urban planning personnel. Also, an easy-to-use with well-designed customization options to investigate data from multiple perspectives is also important in allowing

Future work that have been put into agenda of this project include:

- the ability to calculate accessibility based on other accessibility measures;
- the ability to show opportunities and land uses distribution throughout the geographic area;
- allow customized isochrone levels;
- back end: download OpenStreetMap data of corresponding area to shapefile or bounding box coordinates provided by user;
- allowing users to feed land use data and geographic data to the system with a set of parameters specified, and render the accessibility choropleth maps and travel time isochrone map accordingly.

Currently our systems only visualized accessibility at block group level, but the calculating and mapping process is general and can be used for any level, as long as a shapefile with features at the level in interest as well as land use data corresponding to the level of spatial unit are provided, the system can do the calculation and generate ready-to-render JSON files for this level of spatial unit. Future work for allowing our system to calculate accessibility for other spatial units will focus on providing user interface to enable uploading input data.

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