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ASSESSING SPATIAL ACCESSIBILITY TO HEALTHCARE IN A FOUR-COUNTY REGION, IN
For Automobiles and Transit

DEPARTMENT OF URBAN + REGIONAL PLANNING
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1. ABOUT MCCOG

The Client

Madison County Council of Governments is a Metropolitan Planning Organization as well as a Council of Governments serving Alexandria, Anderson, Chesterfield, Edgewood, Pendleton, Ingalls, Daleville, Fortville, parts of Vernon Township in Hancock county and Salem Township in Delaware county. There are 3 subregions within the Anderson MPA (Governments, 2017)

- North – This subregion is primarily a rural, agrarian culture with Alexandria in the east and Elwood to the west. Across Indiana, rural areas are seeing a loss in population as residents migrate to more urban areas. (Governments, 2017)

- Central-East – This subregion includes Anderson, Edgewood, Markleville, and the Chesterfield-Daleville Area to the east. The subregion is a revitalizing community after massive automobile industry investment left

- Southwest – This subregion includes Fortville, Ingalls, Lapel, and Pendleton. It has seen rapid growth as the Indianapolis Metropolitan Area continues to sprawl outwards.

Around 139,509 people live in the Anderson Metropolitan Planning Area and the economy of the city is dependent on efficient transportation to access education, health and jobs.
The city and the population is growing and there is a need to improve and expand transportation infrastructure.

As a Metropolitan Planning Organization, MCCOG conducts long-range planning activities and examines the region’s future needs and investments through a continuous, comprehensive and cooperative process. As a Council of Governments, MCCOG fosters communication and coordination among local governmental agencies to face mutual challenges.
2. INTRODUCTION

Healthy lifestyles and populations are prime goals to be attained by every region. Providing access to primary healthcare and hospital aid is the main aim of all health care systems to maintain and improve health of populations. Over the years, researchers and practitioners have greatly focused on improving accessibility to health care. With the implementation of the Affordable Care Act that mandates US residents to obtain health insurance, the need to further enhance accessibility has increased immensely as having insurance does not equate to accessible healthcare. Hence, it is imperative for professionals to reach out to a much larger population. Primary healthcare is a vital aspect of a country’s health care system and its advancement leads to burgeoning of the economic development scenario. There are many dimensions to the term ‘accessibility’ to healthcare. It simple terms, it refers to ability of population to obtain health services (Eda Unal, 2007)

In the US, accessibility to healthcare has evolved over the years, however, due to various factors and not just the single sole reason being need for health services. It is greatly influenced by government policies and programs designated for health care and private service entities to gain profit. These factors do not work do not contribute to equitable access to health service and hence it is necessary to look at spatial accessibility. Geographic accessibility serves as an important feature of the overall healthcare system and thus, it is essential to quantify physical access to healthcare. There is drastic variation in spatial accessibility to health care especially in developing countries and rural areas that are underserved in developed countries. The two-step floating catchment area method is a gravity-based model that defines a service area with respect to a threshold travel time and accounts for the availability of healthcare providers to the population within the area. It helps to pinpoint degree of spatial accessibility in a region and hence
can help identify areas that are medically underserved. However, in this paper, the gravity-based model, Hansen model is carried out in four-county region in Indiana to determine areas that have low geographic accessibility to medical facilities. The results will help us to cater to healthcare needs of underserved areas in Madison County, Delaware County, Hamilton County and Marion County, identify the part of population that is affected by poor spatial accessibility to healthcare demographically, provide equitable access to healthcare, preventing and managing diseases, prevent delayed treatments and stop deaths from occurring due to transportation inconveniences.

3. ACCESSIBILITY TO HEALTHCARE

The literature regarding health care access has been well defined by Khan and Guagliardo (Eda Unal, 2007) and a useful outline (Table 1) has been devised to distinguish it into four groups namely, potential versus realized/actual referring to stages and spatial access versus social access referring to dimensions. ‘Potential’ care delivery refers to a needy population coexisting in space and time with a willing and able healthcare system (Eda Unal, 2007) while ‘realized’ care refers to a situation where all barriers to provision are overcome.

In order to advance from the potential access to realized access stage, a number of barriers that serve as impediments need to be overcome. These barriers were introduced by Penchansky and Thomas (1981) and refers to the five ‘dimensions’ of spatial and social access in the health care access groups, namely: availability, accessibility, affordability, acceptability and accommodation. The terms affordability, acceptability and accommodation are non-spatial and reflect healthcare financing arrangements and cultural factors (Eda Unal, 2007). The first two terms, namely, accessibility and availability are spatial and is defined as travel impedance (distance or time) between patient location and service points and number of local service points from which a client can
choose, respectively (Eda Unal, 2007). Spatial accessibility refers to the agglomeration of these two terms and hence need to be considered simultaneously. (Guagliardo 2004, Luo and Wang 2003)

<table>
<thead>
<tr>
<th>ACCESS DIMENSIONS</th>
<th>Spatial (Geographic)</th>
<th>Non - Spatial (Social)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential</td>
<td>Studies of distance and availability that do not consider utilization measures</td>
<td>Studies of affordability, culture and other non-spatial factors that do not consider utilization measures</td>
</tr>
<tr>
<td>Realized (Actual)</td>
<td>Utilization studies that consider spatial factors</td>
<td>Utilization studies that consider affordability, culture and other non-spatial factors</td>
</tr>
</tbody>
</table>

Access to healthcare is a complicated concept and since there exists a demand – supply relationship in a gravity model, both factors need to be given due consideration. If services are sufficiently provided and are made available there will be an opportunity to obtain healthcare services. The extent to which the population ‘gains access’ is equally important and is affected by various factors like social, cultural and financial barriers. Thus, when access is measured in terms of ‘utilisation’, physical accessibility, financial affordability and acceptability are relevant apart from adequacy of supply. (David B. Evans, n.d.)
According to WHO universal health coverage and universal access, access has three dimensions:

- Physical Accessibility
- Financial Affordability
- Acceptability

Physical accessibility refers to a demand-supply scenario where there is sufficient health services within reasonable reach of those who require them. It describes appointment systems and other aspects of service organizations.

Financial affordability refers to people's ability to pay without burdens or hardships. It accounts for not only health service costs but also operational costs such as transportation costs to and from work and time taken away from work. Household income has an impact on this factor.

Acceptability refers to peoples' willingness to seek services. This factor can be greatly influenced by social and cultural factors such as foreign language, difference in religion and sex and can demotivate them from seeking services.

All health services need to fulfil the criteria mentioned above in order to be acceptable to the patients for universal health coverage to be satiated. However, in this paper, we will be focusing on the physical and spatial accessibility to healthcare using a gravity – based model for assessment.

3.1 SPATIAL ACCESSIBILITY TO HEALTHCARE

Spatial accessibility to healthcare is one of the pre – requisites for equitable and quality healthcare services for all segments of population, urban and rural. It is important to assess
spatial access to healthcare because health services, organizations and providers (supply) are spread out and accounts for huge variation in locations and thus results in large spatial nuances in healthcare. Spatial barriers such as long distance from original location to healthcare provider destination wanes the quality of accessibility to healthcare and is a major contributor to exclusion from high quality access to healthcare. Residencies of people (demand) do not coincide with geographical placement of health providers and hence it is not uniformly distributed. According to Hart, (Hart, 2000) healthcare shortage has been especially dominant in rural areas and impoverished communities. Every year, almost $1 billion is provided by the US government for access problems to healthcare systems to mitigate serve underserved areas. Analyzing spatial accessibility and substantial visualization will help to display service location (supply) concentrations, provide residents with service location information and help to understand the match between supply and demand. The strength of spatial accessibility analysis methods is the provision to study relationships between variables and understand it spatially.

While non-spatial access emphasizes on non-geographical factors such as ethnicity, race, age and sex, the prime focus of this place is to determine ‘potential’ spatial accessibility to health care in Anderson, Indiana. As discussed earlier, spatial accessibility includes availability and accessibility, regionally.

### 3.1.1 Historical Context

In the 19th century, an important factor, distance to healthcare providers was recognized as a significant barrier to healthcare (Guagliardo, 2004). In the late 90’s, lack of spatial accessibility to healthcare arose to be a prominent issue and some actions were taken to measure accessibility, identify areas deprived of spatial access and understand social disparities in spatial accessibility in urban and rural areas. This issue was prominent in the national policy agenda since the 1967 report of National Advisory Commission on Health
Manpower during which non-uniform distribution of healthcare professionals was common with a concentration in affluent neighborhoods. Since the recognition of distance serving as an obstacle to healthcare in sparsely populated rural areas which led to the decline of healthcare supply, immense work has been conducted to enhance access in rural areas.

However, after the 90’s, spatial accessibility still remained a problem in communities. One of the reasons is that urban spatial indicators are more commonly used to study larger geographies and are less relevant to urban areas. Thus research in the field depreciated and cities have not been studied extensively. Although, over the years, it has gained importance and a lot of funding assistance is provided by the US government for research, analysis and assessment of physical accessibility in efforts to reduce morbidity and mortality rates as a result of poor spatial accessibility.

3.2 TRANSPORTATION BARRIERS

3.2.1 Measures

1. Vehicle Access and Mode of travel

- Various researches studied the link between transportation to health care utilization and it was determined that people who provide transportation to a member of the family and those who have a valid registered driver’s license have greater accessibility and utilization of health care. (Samina T. Syed, 2014)

- (Samina T. Syed, 2014) determined in the state of Texas that out of 593 people, 38% accounted for white people, 55% African American and 60% Hispanics identified lack of access to vehicle as a barrier that could result in missing out of treatments. Another surveyor looked at a group of cancer
patients and it was determined that people are less likely to receive first line chemotherapy in households that did not have a vehicle.

- Studies proved that people among low socioeconomic status populations found that switching to walking or using public transportation and still not using private transportation can delay healthcare services.

- (Samina T. Syed, 2014) stated that 25% of people missed an appointment as they were dependent on getting a ride and do not own a car. It was noted that 82% of people that kept their appointments had access to cars while compared to 58% of people that didn’t keep appointments.

- In addition, from further studies, it is also proved that 55% of missed appointments were due to transportation problems.

Thus we can say that studies clearly indicate lack of accessibility of transportation is associated with less healthcare utilization and missed medical appointments especially for those from lower economic backgrounds.

2. Urban and Rural Geography

There are stark differences between urban and rural areas in terms of transit options, cost of transit, availability of and distance to healthcare providers. Based on reports, studies and analysis, the results are mixed when looking at transportation barriers for healthcare for urban and regional areas.

- When Blazer dwelled into surveying a number of adults over 65 years of age, Wo understood why patients were delayed, neglected or missed their appointments both in urban and rural cases.
In another case, there is no difference in report for urban and rural areas for use of health services and identification of their transportation barriers.

However, some rural cases have more issues with transportation barriers and travel distances with regards to healthcare systems.

- In this example, only rural areas were analysed with no comparisons to urban areas and out of 64 subjects, 31% were lacking transportation and 37% missed appointments due to transportation.

3. Travel Burden by Time and Distance

Around nine cases were evaluated for transportation barriers to healthcare and the result was:

- 6 cases found that distance was a barrier to healthcare while the impact of distance on healthcare access was measured. One of the cases looks at correlation of distance between providers and the health care utilization was reported.

- One study found that there was no relationship between distance to the provider and health care utilization.

- Another surprising finding from two cases suggest that increase in distance to healthcare providers was a sign of improved healthcare access.

- Two cases looked at relationships between distance and medication or clinical use as it was reported that, longer the drive from the physician, less were insulin levels and poor glycemic levels independent of other external factors.
4. INTRODUCING GRAVITY – BASED MODELS TO ASSESS SPATIAL ACCESSIBILITY

One of the main goals of healthcare as discussed earlier is uniform distribution of healthcare resources such that serves all geographic areas equally. However, this is an ideal situation that is unattainable due to geographic nuances, location of hospitals and its mismatching with population residents where the degree of mismatch varies from place to place, for example, in urban agglomerations, the concentration and distribution of healthcare providers (supply) will be more uniform in distribution with lesser distance as a transportation barrier however in the case of rural America, the distribution and concentration of healthcare providers is non-uniform and scarce hence affecting health in the region and increasing mortality rates.

4.1 TWO-STEP FLOATING CATCHMENT AREA METHOD

The two-step floating catchment area method, introduced by Luo and Wang was developed from a background of shortcomings of other methods used to calculate spatial accessibility. With the advancement of geographic information systems and spatial methods of analyses, health care research has shifted focus to improvement of spatial accessibility rather than distribution and spread of diseases and determinants of health. The greatest strength of this method is that it eliminates the usage of pre-defined regional boundaries and considers areas based on the weighted centroid of population. It consists of two steps and the end product is an accessibility score or index that can be visually represented on the map. The first step involves calculating the provider to population ratio while the second step involves calculating the accessibility score.
Step 1 - Calculating Provider to Population Ratio

The PPR can be calculated as follows – For each physician location ‘j’, search all population locations that are within the threshold travel time $d_0$ from location ‘j’ (catchment area) and compute physician to population ratio, $R_j$ within catchment area;

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} < d_0\}} P_k}$$

Where;

$P_k$ is the population of tract ‘k’ whose centroid falls in the within the catchment (i.e., $d_{kj} < d_0$);

$S_j$ is the number of physicians at location j;

$d_{kj}$ is the travel time between k and j

Step 2 – Calculating Accessibility Index

Developing an accessibility index corresponds to summing up the PPR’s in the overlapping service areas. First a catchment area with a radius corresponding to a convenient drive time (distance) is considered from the population center. For each population location ‘i’, search all physician locations ‘j’ and sum up the physician to population ratios, $R_j$ at these locations. The accessibility index/ score for resident location ‘i’, $A_i^P$ is computed as follows -

$$A_i^P = \frac{\sum_{j \in \{d_{ij} < d_0\}} R_j}{\sum_{j \in \{d_{ij} < d_0\}} \sum_{k \in \{d_{kj} < d_0\}} \frac{S_j}{P_k}}$$

Where;
R_j is the physician-to-population ratio at physician location ‘j’ whose centroid falls within the catchment centered at ‘i’ (d_{ij} < d_0);

d_{ij} is the travel time between ‘i’ and ‘j’;

A larger value of A_f corresponds to better accessibility in the region and vice versa. Floating catchment area methods and GIS methods have the advantage of not being restricted by administrative boundaries as it takes into consideration that patients do cross boundaries and borders for medical services.

This method was initially used to conduct the analysis but due to its shortcoming such as fixed catchment area, the Hansen gravity model was more appropriate and was chosen to conduct the analysis

### 4.2 Hansen Gravity Model

Accessibility models are usually based on gravity potential and the supply and demand analogy. Models can interpret the level or degree of accessibility using the gravity mechanism of attractiveness. For studies, research and analysis, different kinds of resistance factors are used depending on the type of study and particular context. For the analysis of this study, the auto travel time and transit travel time during congestion is used to determine spatial accessibility and hence ensures maximum reliability. The different kinds of gravity models that have been introduced are - Stewart 1947, Hansen 1959, Ingram 1971, Vickerman 1974, Harris 1954, Huff 1963, Keeble et al. 1988, Dalvi–Martin 1976, Linneker–Spence 1991, Spence–Linneker 1994, Geertman–Ritsema van Eck 1995, Bruinsma–Rietveld 1998, Brunton–Richardson 1998, Kwan 1998, Levinson 1998, Smith–Gibb 1993, Gutiérrez 2001, Scheurer–Curtis 2007. One of the most commonly used gravity models are potential models
The type of model used in this context is the Hansen model which claims that accessibility is “the generalization of the connections of the population, reaching across distances”. The accessibility potentials of accessible destinations are strongly connected to the interaction of masses based on the gravity models (Kincses, 2015). The Hansen model equation greatly relies on the equation of gravity from a Physics perspective. This is evident from the usage of a constant which is a square number and is reflective of the physics deduction of the model. Following is the equation used for the analysis of spatial accessibility to healthcare in the study region

\[ A_{im} = \sum O_j \cdot C_{ijm}^{-2} \]

Where;

- \( A_{im} \) is accessibility at point ‘i’ to hospital at point ‘j’ using mode ‘m’
- \( O_j \) is the opportunities (number of beds) at point ‘j’
- \( C_{ijm} \) is the impedance (travel time) to travel between ‘i’ and ‘j’ using mode ‘m’

5. STUDY REGION

A midwestern state located in the Great Lakes region, Indiana has a total population of 6.7 million people and a growth rate of 0.33%. The major employment sectors are manufacturing and farming. Around 30% of Indiana’s population lives in and around rural areas compared to only 21% in the nation. The capital city of Indiana is Indianapolis which accounts for more than 10% of the population. Indiana’s health care provision ranks way below the national average (Eda Unal, 2007). The state ranks 41st among the 50 states while Massachusetts and Maryland ranks 1st and 2nd respectively.
According to statistics from 2004, the top-ranking states for number of physicians and nurses per 100,000 residents are –

<table>
<thead>
<tr>
<th>Rank</th>
<th>State</th>
<th>Physician per 100,000 residents</th>
<th>Rank</th>
<th>State</th>
<th>Nurses per 100,000 residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Massachusetts</td>
<td>450</td>
<td>1</td>
<td>South Dakota</td>
<td>1207</td>
</tr>
<tr>
<td>2</td>
<td>Maryland</td>
<td>411</td>
<td>2</td>
<td>North Dakota</td>
<td>1179</td>
</tr>
<tr>
<td>3</td>
<td>New York</td>
<td>389</td>
<td>3</td>
<td>Massachusetts</td>
<td>1177</td>
</tr>
</tbody>
</table>

The study region in Indiana is selected at the geographical unit of traffic analysis zones. The study region is located in central Indiana and includes four counties namely – Madison county, Delaware county, Hamilton county, Marion county located in the central region of Indiana. Marion county is the most populated county in the state which also includes the county seat, state capital and largest city, Indianapolis. From the image, it is also clear that the interstates – I-65, I-69, I-70, I-74 and I-465 passes via the county.
From the table below, it can be seen that, population in Marion county is almost 8 times that of Delaware and Madison county and 3 times that of Hamilton county. The median age is the lowest in Marion county while it is the highest in Hamilton county. The work force is largest in Marion county due to the presence of large employment opportunities in Indianapolis while it is the lowest in Delaware county.

The number of Primary care physicians for every 100,000 people is the highest in Hamilton county (140 units) while it is the lowest in Madison county. This is part of the analysis and also can impact the studies. A low number of physicians in an area means that the supply is minimal and does not meet the demand.
### 6. HOSPITALS WITHIN THE STUDY REGION

Major hospitals in Indiana that are within the study region are considered as opportunities which is represented as number of beds in the analysis.

There are around 160 hospitals in Indiana ([Hospital Data, n.d.]), including private and public, multi-hospital systems and stand-alone speciality hospitals. In 2012, 806,058 patients visited the hospitals and there has been an economic activity of $31.3 billion.

Indiana University Health in Indianapolis is ranked the best hospital in Indiana according to ([Hospital Data, n.d.]) and also has the most number of beds among the hospitals taken into consideration in the study region. Marion county comprises of the maximum number of major hospitals in the study region in comparison to the other counties.
Table 4 – Hospital Information (Source - (Hospital Data, n.d.))

<table>
<thead>
<tr>
<th>TAZID</th>
<th>Hospital Name</th>
<th>Number of Beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>13012</td>
<td>Community Hospital Anderson, IN</td>
<td>139</td>
</tr>
<tr>
<td>16014</td>
<td>St. Vincent Anderson Regional Hospital, IN</td>
<td>154</td>
</tr>
<tr>
<td>10016</td>
<td>St. Vincent Mercy Hospital, IN</td>
<td>74</td>
</tr>
<tr>
<td>99082</td>
<td>Indiana University Health Ball Memorial Hospital, Muncie, IN</td>
<td>349</td>
</tr>
<tr>
<td>30082</td>
<td>St. Vincent New Hope Inc., Fishers, IN</td>
<td>8</td>
</tr>
<tr>
<td>99070</td>
<td>St. Vincent Hospital and Health Services, Indianapolis, IN</td>
<td>721</td>
</tr>
<tr>
<td>99065</td>
<td>Community Hospital East, Indianapolis</td>
<td>306</td>
</tr>
<tr>
<td>99057</td>
<td>Franciscan St. Francis Health, Indianapolis, IN</td>
<td>192</td>
</tr>
<tr>
<td>99064</td>
<td>Kindred Hospital Indianapolis, Indianapolis, IN</td>
<td>59</td>
</tr>
<tr>
<td>99064</td>
<td>Indiana University Medical Center, Indianapolis, IN</td>
<td>620</td>
</tr>
<tr>
<td>99064</td>
<td>Indiana University Health, Indianapolis, IN</td>
<td>1399</td>
</tr>
<tr>
<td>31108</td>
<td>Indiana University Health North Hospital, Carmel, IN</td>
<td>145</td>
</tr>
<tr>
<td>31054</td>
<td>St. Vincent Carmel Hospital Inc., Carmel, IN</td>
<td>124</td>
</tr>
<tr>
<td>32030</td>
<td>St. Vincent New Hope Inc., Noblesville, IN</td>
<td>7</td>
</tr>
</tbody>
</table>
7. DATA ANALYSIS

Most of the data used for the analysis was taken from the Madison County Council of Governments data portal. The origin–destination matrix used for auto travel times was the skim matrix used to calculate other accessibility measures at the organization. This ensures the accuracy of the values. In order to obtain transit travel time, web scraping technique was used with the help of a Google API key and python scripting.

7.1 GRAVITY MODEL BASED ON AUTO TRAVEL TIMES

The gravity model is based on the origin-destination matrix constituting of travel times from one traffic analysis zone to another. This can be resembled as a gravity model by
calculating ‘attractiveness’ between zones; i.e. attractiveness between centroid of origin traffic analysis zones and destination zones containing the hospitals. In our study region, there are 14 hospitals and 897 traffic analysis zones. Hence, using the Hansen model equation, the attractiveness of the origin TAZ’s to the hospitals are calculated using the resistance factor, travel time to the power of 2. The opportunities refer to the number of beds in the hospital which is a parameter used to calculate the supply of healthcare.

First, the origins and destinations are formatted as a matrix and then the Hansen model equation corresponding to \((\text{number of opportunities}) / (\text{travel time}^2)\) is used. Data regarding the number of beds was obtained from ‘American Hospital Directory’ and also via direct contact with the hospitals.

The regional accessibility is then evaluated by adding up the values obtained earlier. This gives us the spatial accessibility to healthcare for automobiles during congestion flow.

From the figure below which represents spatial accessibility to healthcare, it can be seen that, around Community Health Anderson and Anderson Regional Hospital, accessibility to healthcare is high around the region while it radially decreases away from the hospitals. Whereas, accessibility around Ball Memorial Hospital in Muncie is low, although it is a major hospital in Delaware county. However, in the northern parts of Marion county and south western parts of Hamilton county, accessibility is high due to higher density of hospitals and a higher concentration of high-income residents and low poverty rates compared to Madison county and Delaware county. Moreover, car ownership is also higher in this region, since there is no transit services in Hamilton count. Accessibility is also higher in the Indianapolis region as it is a thriving metropolitan city, with the highest population in Indiana and close proximity of major hospitals. Accessibility is however lower in the suburbs of Marion county, outside the loop of major highways in the city.
The underserved areas are in the center of the four-county region, mostly, north eastern Hamilton county and north western parts of Madison county and majority of Delaware county. In Madison county, accessibility to healthcare by automobiles is lower outside Anderson and in the north of the county.

*Figure 4 - Spatial Accessibility to Healthcare for Cars*
7.2 TRANSIT NETWORKS IN THE STUDY REGION

IndyGo

The Indianapolis Public Transportation Corporation (IndyGo) provides transit options for commuting to people in the City of Indianapolis. There are around 31 fixed routes and 7000 bus stops and carries approximately 10.2 million passengers, traveling around 9 million miles annually. But according to (Freemark, 2017) it is not convenient to use IndyGo transit service because –

- Only 4% of Marion county’s population live within a quarter mile distance of a bus stop and service is only every 15 minutes during peak hours.

- Less than 9000 people commute by transit every day in the city

- Indianapolis spends the least per capital on transit operations among metropolitan cities with around 1 million inhabitants.

Accessibility to hospitals like Kindred Hospital Indianapolis, Indiana University medical Center and Indiana University Health are located in the heart of the city, transit connectivity to these hospitals is high for surrounding regions in Marion county.

CATS

The City of Anderson Transit System is a public transportation system that serves the people of the city of Anderson. It has seven fixed routes and does not have computer applications of timetables or information about the schedule. In order to board a CATS
bus, the schedule online needs to be referred to, which will tell you the exact time and location. Real time information is not provided

![City of Anderson Bus](image)

*Figure 6 - City of Anderson Bus (Source: (City of Anderson, n.d.))*

**MITS**

Muncie Indiana Transit System is the public commute service provided in the city of Muncie. There are 14 fixed routes and real time information about buses are available online through a computer application. The service is free for students' veterans and discounted for seniors and people with disabilities.
7.3 WEB SCRAPING

Web scraping is a data extraction technique that was used in this context to extract transit times from Google as it was not readily available. It accesses the World Wide Web using Hypertext Transfer Protocol or a web browser. It is a form of retrieving data that is gathered and copied from the web into a central local database and used later for analysis. For the analysis, Python was used to scrape the web to attain transit time data in the four-county region. First a package allowing scraping for Google Matrix Travel Time was obtained in Python. Then a code was written after understanding the Google Matrix such that the major inputs would be coordinates of the origin and destinations. In this case, the origins were the centroids of each traffic analysis zone and the destinations were the coordinates of the hospitals. This code is run and the output generated is the distance between each origin and destination and the travel time for transit from each centroids of traffic analysis zones to the hospitals. The output generated is converted to the appropriate format in a matrix form so that the Hansen Gravity model equation can be used to calculate spatial accessibility.
7.4 GRAVITY MODEL BASED ON TRANSIT TRAVEL TIMES

The data for transit times was not readily available and retrieval of the data included using a Google API and python scripting using a technique called web scraping to retrieve data from Google which is explained above. Once the code was launched in python, text values were outputted which were converted to travel times in minutes. This was then converted to an origin-destination matrix which was used to evaluate spatial accessibility. Following is the code used –

```python
import googlemaps
import requests
import json
import datetime

## API KEY for GOOGLE MATRIX TRAVEL TIME
api_key_matrix='AIzaSyC6qnElaYunAmOL8-fx02bDSvm79sxP-CQ'

# input text file name
inp = open("INPUTFILE.txt","r")

## example format of input text file

<table>
<thead>
<tr>
<th>oy</th>
<th>ox</th>
<th>dy</th>
<th>dx</th>
</tr>
</thead>
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41.84083141 -87.66074501 41.88381164 -87.76009448
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# output text file name
out = open("special_output_08.txt","w")

#sample output text file results

99989 [{'elements': [{'distance': {'text': '1.9 mi', 'value': 3138},
'duration': {'text': '8 mins', 'value': 505}, 'status': 'OK'}}]
99990 [{'elements': [{'distance': {'text': '4.0 mi', 'value': 6514},
'duration': {'text': '10 mins', 'value': 620}, 'status': 'OK'}}]
99991 [{'elements': [{'distance': {'text': '2.1 mi', 'value': 3436},
'duration': {'text': '9 mins', 'value': 557}, 'status': 'OK'}}]
99992 [{'elements': [{'distance': {'text': '43.3 mi', 'value': 69695},
'duration': {'text': '49 mins', 'value': 2924}, 'status': 'OK'}}]
99993 [{'elements': [{'distance': {'text': '42.7 mi', 'value': 68671},
'duration': {'text': '46 mins', 'value': 2777}, 'status': 'OK'}}]
99994 [{'elements': [{'distance': {'text': '44.5 mi', 'value': 71565},
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99995 [{'elements': [{'distance': {'text': '44.0 mi', 'value': 70799},
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99996 [{'elements': [{'distance': {'text': '44.2 mi', 'value': 71152},
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99997 [{'elements': [{'distance': {'text': '38.4 mi', 'value': 61733},
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'duration': {'text': '43 mins', 'value': 2562}, 'status': 'OK'}}]
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'duration': {'text': '48 mins', 'value': 2851}, 'status': 'OK'}}]

# Variable Definition
coord = [] # Coordinates Array
N=0; M=4 # Size of the array
# Google Maps Client

gmaps = googlemaps.Client(api_key_matrix)

# Input the coordinates (X, Y)

for line in inp.readlines():
    coord.append([])
    for i in line.split():
        coord[-1].append(float(i))
inp.close()

# Total length
N = len(coord)

#arrival_time = datetime.datetime(2019, 4, 19, 0, 0)

# Calculate the travel time by using Google MAPS API
for i in range(0, N, 1):
    ori = (coord[i][0], coord[i][1])
    des = (coord[i][2], coord[i][3])

    # Origin and Destination: LODES Census Block Centroid, Mode: Driving
    # or Transit, Units: Imperial, Datetime: 4/19/2017, arrival at 9AM
    dirs = gmaps.distance_matrix(ori, des, mode='transit', units='imperial')
    print(i)
    if dirs['rows'][0]['elements'][0]['status'] == 'ZERO_RESULTS':
        print(i, file=oup, end=""
    print('"", file=oup, end=" ")
    print(dirs['rows'][0]['elements'][0]['status'], file=oup, end=" ")
else:
    print(i, file=oup, end=""
    print('"", file=oup, end=" ")

    #print(dirs['rows'][0]['elements'][0]['distance']['value'], file=oup, end=""
    #print(dirs['rows'][0]['elements'][0]['distance']['value'], file=oup, end =""
    #print(dirs['rows'][0]['elements'][0]['duration']['value'], file=oup, end =""
    print("\n", file=oup, end="")
The same procedure used to calculate spatial accessibility to healthcare for automobiles was used to calculate accessibility for transit services.

*Figure 8 - Spatial Accessibility to Healthcare for Transit*

From the figure above which represents spatial accessibility to healthcare for transit services, it is evident that transit services are only available in cities like Anderson, Muncie and Indianapolis. Hamilton county which comprises of the two main towns Fishers and Carmel are gentrified residential areas that do not have transit networks. Majority of the
study region are underserved by healthcare for transit services. Public transportation is an important factor in society as it is directly linked to access to jobs, health and education. Car ownership percentages according to statistics are low and poverty rates are high in Delaware county and Madison county which proves that there is a large transit-dependent population. This method is an indicator that spatial accessibility by transit services is low in Madison county, Hamilton county and Delaware county.

8. RECOMMENDATIONS AND LIMITATIONS OF STUDY

The study was conducted in a four-county region in central Indiana. Based on the analysis, it is clear that spatial accessibility to healthcare is limited both for auto and transit modes. However, transit accessibility is very low. Due to low car ownership percentages and high poverty rates in counties like Madison county and Delaware county, one of the main means of transportation should be public transit. But due to limited frequency and headways, performance is lacking. Spatial accessibility to healthcare is an important factor that rethat requires more attention in the study region. Following are the recommendations to improve spatial accessibility based on the analysis conducted:

- With the initiation of the Healthy Places for Healthy People Project in 2018 by EPA in Anderson, Madison county, improving transit systems (CATS) and car connectivity to hospitals and hospital districts should be one of the main goals of the project in order to improve overall health of the community.

- Spatial accessibility to healthcare should be considered as an important access measure while constructing road infrastructure and in the transportation planning process along with employment access, general access etc.
• Connectivity, frequency and headway of transit networks should be improved in order to attract more riders especially low-income residents who do not own cars to enhance transit accessibility to healthcare.

• Transit networks should make sure that there is a bus stop within quarter mile of a hospital for easy access.

• Transit options should be provided in Hamilton county for equity purposes to cater to the low-income population living in the county,

• Since accessibility to hospitals by cars is extremely low in Delaware county, alternative options should be provided in the town for easy access to healthcare by cars such as improved transit services (MITS).

In the study, some of the limitations are –

• Travel time information for some traffic analysis zones were not available and hence is portrayed as low accessibility.

• Travel time is the only impedance factor chosen. In order to improve the study, cost of services could also be chosen.

• In the study, spatial accessibility to healthcare was calculated within the study region to 14 main hospitals. The study did not take into consideration the population outside the study region as for healthcare services, according to literature review, it is common to travel more than 30 minutes for better healthcare options.

9. CONCLUSION

The study region included 4 counties in Central Indiana – Madison county, Marion county, Hamilton county and Delaware county. 14 major hospitals located within the study region
are taken into consideration to analyse spatial accessibility of traffic analysis zones within the study region to the destinations which are the hospitals. The data is retrieved from US Census Bureau, Madison County Council of Governments data portal, TIGER shapefiles, direct contact with the hospitals, American Hospital Directory and by using a Google API key in python to retrieve transit data. The Hansen model which is a gravity-based model is used to calculate spatial accessibility of the 14 hospitals to all the traffic analysis zones within the study regions.

It is noticed that spatial accessibility for automobiles is higher in central Anderson, Madison county and in Indianapolis, Marion county, while the north eastern parts of Hamilton county, north western parts of Madison county and majority of Delaware county are underserved.

From the analysis, it is evident that spatial accessibility to healthcare for transit is better in metropolitan cities like Indianapolis and smaller cities like Muncie and Anderson. Whereas, in majority of the other areas, transit services are non-existent. The spatial accessibility to healthcare by transit services is poor in the four-county region according to analysis.

10. REFERENCES

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- Andrew Lovett, R. H. (2002). Car travel time and accessibility by bus to general practitioner services: a study using patient registers and GIS. Norwich, UK.


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