The effect of urban development characteristics on the success of TODs

by

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A REPORT

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Abstract

Transit-Oriented Development (TOD) is a set of policies that cities implement around transit stations to incentivize development and create a pedestrian-friendly environment that aims to increase the transit ridership and reduce the use of personal vehicles. Before applying the TOD policies, and in order to ensure their success, the TOD levels will be measured around each station by using some TOD measurements and evaluation techniques. The goal is to get an overview of the TOD levels at each station area and know which areas should be prioritized for the implementation of the TOD policies. The goal of this paper is to enhance this method by identifying which station areas encounter more development (areas with high, mid, or low levels of TOD), and thus, help decision-makers know which areas should be prioritized for the implementation of TOD policies. To do that, we calculated the residential and commercial density, land use diversity, land use mixedness, and economic development in 94 Chicago Transit Authority (CTA) stations for two separate years, 2010 and 2017. After comparing the results, we found out that, although some station areas with low levels of TOD have encountered a noticeable increase in their TOD level, station areas with mid levels of TOD have encountered more change. Thus, we came to a conclusion that station areas with mid levels of TOD should be prioritized in the implementation of TOD policies because they yield in more successful TOD areas in a short time period.

Table of Contents

List of Figures

List of Tables

Chapter 1 - Introduction

Transit-Oriented Development (TOD) is a set of policies used by cities with the goal of creating a more sustainable environment by reducing the use of private automobile in transit station areas. Primarily, this can be done by having high density, mixed-use, pedestrian, and bike-friendly areas within 500-800 meters of transit stations (CTOD, 2009; The City of Calgary, 2004). In some studies that are concerned with the implementation of the TOD policies, and in order to help decision-makers know which areas will be more successful in hosting the TOD policies, a TOD measurement study for all station areas within the city will be done. Those given studies would entail measuring the existing levels of TOD around each transit station by using Land Suitability Analysis techniques like Analytic Hierarchy Process (AHP), or Spatial Multiple Criteria Analysis (SMCA).

There are different criteria upon which the TOD evaluation and measurement is done, but all studies, in one way or another, depend on five major criteria: Density, Diversity, Design, Destination accessibility, and Distance to transit. Those criteria, usually referred to as the 5Ds, were initialized by Ewing and Cervero as the urban development characteristics that are most associated with the development of TODs (Ewing & Cervero, 2010). After choosing the criteria and quantifying each one of them, the TOD will be measured in all the station areas that need to be studied to produce a final TOD index that shows the TOD level in all those areas. Finally, sometimes certain station areas will be given the priority in the application of the TOD policies based on the outcome of the TOD index and the decision-maker's approach.

This paper will discuss a very important idea, which areas will yield in more successful TOD areas, areas with high, mid, or low TOD levels? It is important to answer this question because the outcome of the TOD measurement studies could affect the judgment of decision-makers. To answer our question, we need to choose certain station areas and compare them with each other, before and after the TOD policies were implemented in order to know which areas encountered more development, the ones with high, mid, or low TOD levels.

We chose Chicago as our area of study because the city implemented its TOD policies in 2013, which means we have enough information to make a comparison between the period before implementing the TOD policies, 2010, and the period after implementing the TOD policies, 2017.

After measuring the TOD levels in 94 CTA stations in the year 2010 and 2017, we compared the results and found out that station areas with existing mid TOD levels tend to encounter the most positive change compared to other station areas with low or high TOD levels. This tells us that if decision makers were to prioritize the development in certain station areas based on their TOD levels, then, based on our findings, the implementation of TOD policies should be prioritized for station areas with mid TOD levels because they will have a better chance of being successful TOD areas in a short period of time.

Chapter 2 - Literature Review

TOD definition

Although The concept of TOD was recently introduced to planning, it is an old phenomenon that developed over time. It started before the 1900s where at the streetcar stops there was a commercial cluster that served both commuters and local residents (Dittmar & Ohland, 2004).

The term Transit Oriented Development (TOD) was first introduced to modern planning when Peter Calthorpe published his book "*The Next American Metropolis*" in 1993. Calthorpe defined TOD as an area where housing, jobs, and civic facilities are placed within a walking distance from transit stops in a dense and pedestrian friendly environment (Calthorpe, 1993). Before that TOD was generally defined as a mixed-use, transit served area that has a goal of reducing the use of personal vehicles and encouraging the use of transit (Carlton, 2009). Modern planners define TOD as the concentration of housing, jobs, activities, and public services in a pedestrian friendly environment within a walking distance from a well-served high quality transit station with the goal of reducing the use of personal vehicles (Cervero, 1998; Curtis, Renne, & Bertolini, 2009; Loo, Chen, & Chan, 2010).

Dittmar and Ohland in their book "*The New Transit Town: Best Practices In Transit-Oriented Development*" had an issue with those definitions. They argued that in addition to the physical qualities that should be included in the TOD, we should also focus on the element of livability. This element can be achieved if the following goals were accomplished: location efficiency, rich mix of choices, value capture, place making, and resolution of tension between node and place (Dittmar & Ohland, 2004).

Newmark and Kaplowitz in their paper "*Defining TOD: learning from California law*" argue that in addition to the scientific definitions of TODs, there are legal definitions of TODs that are most importan. Those definitions are the ones written in the TOD law itself. They suggested that in order to ensure that the definition of TOD is will translated into an ordinance, a better engagement between the planner and the legislatures is necessary, which will ensure a more successful TOD implementation (Newmark & Kaplowitz, 2020).

TOD evaluation

There are many definitions of TOD, but they all agree on one thing, there are certain physical characteristics that should be incentivized by the use of policies around transit stations to ensure that we have a vibrant area that can help achieve the goals of TOD (Cervero & Arrington, 2008; CTOD, 2009; Sung & Oh, 2011). In identifying those characteristics, there were many researches that studied the development around transit stops to see which characteristics were mostly associated with TODs (Cervero & Kockelman, 1997; Chatman, 2013; Sung & Oh, 2011). A study that stands out is the work of Ewing and Cervero when they identified the characteristics that are most associated with TODs, or what is referred to as the 5Ds: Density, Diversity, Design, Destination Accessibility, and Distance to transit (Ewing & Cervero, 2010). Ewing and Cerveros work, among others, had a big influence on TOD measurement and evaluation studies (Banai, 1998; Dirgahayani & Choerunnisa, 2018; Frank, Cho, Andrew, Ashley, & Reed, 2018; Y. Singh, Fard, Zuidgeest, Brussel, & Maarseveen, 2014;

Yamini Jain Singh, Lukman, Flacke, Zuidgeest, & Van Maarseveen, 2017; Srivanit & Selanon, 2017; H. Taki & Maatouk, 2018).

What those studies do is, analyze all the spatial urban development characteristics that are associated with TODs, e.g., density (both residential and commercial), land use diversity, design (sometimes measured by land use mixed-ness, intersection density, or the quality of biking facilities), destination accessibility, and distance to transit. After identifying the urban development characteristics that will be used in the study, they will quantify and weight each characteristic based on its importance. Finally, they will use a certain spatial analysis technique to aggregate those characteristics and come up with a comprehensive map that shows the TOD levels in each area, or what is sometimes referred to as TOD index.

There are two major spatial analysis techniques that are used in similar studies. The first technique is, Analytical Hierarchy Process (AHP), which was used by (Banai, 1998; H. Taki & Maatouk, 2018). The second technique is, Spatial Multiple Criteria Analysis (SMCA), which was used by (Y. Singh et al., 2014; Yamini Jain Singh et al., 2017; Srivanit & Selanon, 2017). Sometimes other techniques are used like, Mixed-Method Approach that was used by (Dirgahayani & Choerunnisa, 2018).

TOD evaluation purposes

The purpose of doing the TOD evaluation and measurement studies vary. (Y. J. Singh, Zuidgeest, Flacke, & van Maarseveen, 2012) did a three-part study where they discussed, developed, and applied what they referred to as the TOD index. In this TOD index, they measured the TOD level by measuring multiple criteria, derived from the 5Ds mentioned above, and the use of quantifiable indicators that represent each criterion. In their second paper, the

TOD index was used as a tool that helps know which areas of the region should get better transit connectivity by identifying the areas that have both high TOD levels and low transit connectivity at the same time (Y. Singh et al., 2014). In the third paper, they measured the TOD around transit stops and used the TOD index as a way to help prioritize the development of the TOD policies and identify the TOD characteristics at each station (Yamini Jain Singh et al., 2017). Other studies had different priorities. Sometimes it was by suggesting policies to encourage development in low TOD level areas (H. M. Taki, Maatouk, & Qurnfulah, 2017). Other times it was by prioritizing the implementation of TOD policies in high TOD level areas (Banai, 1998; Center for Neighborhood Technology, 2012; Frank et al., 2018).

The use of TOD measurement and evaluation techniques is not limited to research purposes only. Some MPOs and cities have used the TOD evaluation methodology as a way to help with the TOD planning process. For example, The Center for Neighborhood Technology did a study where they evaluated the TOD in the Chicago region for the purpose of comparing the TOD performance in the Chicago region with other peer regions, and recommend policies for the implementation of the TOD in the Chicago region (Center for Neighborhood Technology, 2013). Another example is when the City of Seattle classified their station areas into three categories; Long, mid, and short term development, and then proceeded to facilitate the TOD policies based on those categories (City of Seattle, 2013). The Delaware Valley Regional Planning Commission, and North Central Texas Council of Governments had a similar approach where they evaluated the TOD readiness for each station area by evaluating the transit development characteristics, and the market development characteristics around each station (Delaware Valley Regional Planning Commission, 2017; North Central Texas Council of Governments, 2015). There are many other examples of cities and MPOs that did the TOD evaluation for different purposes and by using different approaches, but what we should know is TOD evaluation has different applications because of the different goals and approaches of each study.

Our research takes a different approach in using the TOD measurement and evaluation tools than the above studies. Our goal is not to evaluate the station areas and find solutions, our goal is to develop these tools by applying them on the city of Chicago, before and after the TOD policies were implemented, to see which station areas encountered the most positive change the ones with high, mid, or low TOD levels. Knowing this information will not only help enhance the way we interpret the TOD evaluation results, it will also help decision-makers decide which areas should be prioritized, if any, for the TOD policies implementation.

Outside factors

In order to do our comparison, we need to consider the effect of the outside factors that could impact our comparison. Cervero and Landis made a comparison between three different station areas with other similar areas in the same city to see the impact of only one variable, which is the effect of the availability of transit services on the development of nearby areas. The researchers said there are two factors that have a major effect on the development of station areas which could have an effect on the result of the comparison. Those factors are: 1- The economic growth of the region. 2- Policies that support higher development (Cervero & Landis, 1993). This is why in our study we decided to make our comparison on stations in the same city. This will ensure that the comparison will not be affected by outside factors like the economic growth of the region, or the use of different policies that supports higher development.

Chapter 3 - Methodology

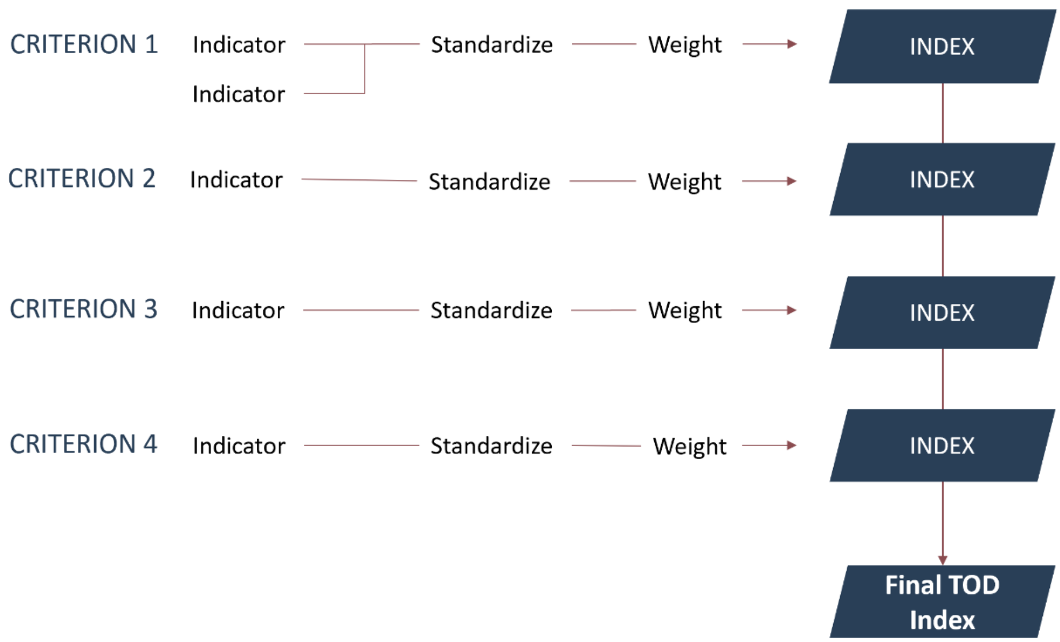

Figure 1 Index calculation process.

The idea of this paper is to know if TOD measurement techniques can help decision-makers know which station areas should have the priority in the implementation of the TOD policies. To answer this question, we decided to do a comparison between station areas before and after the TOD policies were implemented by measuring the TOD index around 94 CTA stations in order to know which areas encountered the most positive change, the ones with high, mid, or low TOD index.

Our TOD index calculation process, as shown in Figure 1, consist of five major steps. First, we identified our four criteria; density, diversity, land use mixedness, and economic development. Second, we chose the indicators that will be used to quantify and measure the four criteria within 1,320 feet from 94 CTA stations in Chicago. Third, to reduce the impact of outliers in our study, we logged the indicators that had outliers that could impact our comparison. Fourth, we standardized the indicator results by their highest value in 2010, so we can bring them all to a comparable unit. The reason for standardizing the indicators for both the year 2010 and 2017 for their highest value in 2010 is to be consistent and measure correctly how the station areas preformed in comparison to their value in 2010. For the final step, we multiplied the standardized indicators by their weights, and then added them up so we can come up with our TOD indexes for the year 2010 and 2017.

In a bid to ensure that we have correct comparison results, the selected station areas should be in similar environments. This means that there must not be any diverse outside factors, other than the ones that we are going to study, that could affect our results. For example, in this paper, one of the indicators that we studied was the residential and commercial density. If we chose a station area in a city that is experiencing an increase in growth, with another station area in a city that is experiencing a decline in growth, usually the station area in the first city will have higher levels of commercial and residential density compared to the other one. This is why choosing the study area, which will be discussed in the next section, is considered as the most important step in answering our research question.

Study area

Our study area, the city of Chicago, is located in the state of Illinois in the Midwest region of the United States. Chicago is the host of an estimated population of 2.7 million inhabitants, making it the most populated city in the Midwest.

We chose the city of Chicago as our area of study for two reasons. First, to avoid the impact of the outside factors, we decided to choose station areas that are located in the same city. Second, before choosing the city, we should make sure they implemented their TOD policies recently, so we can find enough information to do a comparison for before and after the implementation of the TOD policies. The city of Chicago implemented their TOD policies in the year 2013 for all station areas within the boundaries of the city, which means that enough data will be available through various websites like The Census Bureau, Chicago Data Portal, Cook County Open Data, LEHD and other websites that helped us do our comparison.

Chicago TOD policy

In 2010 the Chicago Metropolitan Agency for Planning (CMAP) published the current comprehensive plan for Chicago metropolitan area, Go to 2040 (CMAP, 2014). This plan addressed the importance of the use of public transit, hence, one of the key proposals of the Go to 2040 plan is the integration between land use planning and public transit by developing the areas around transit stops into prospers TOD communities. Based on this proposal, the Center for Neighborhood Technology (CNT) published a report in 2012 "*Prospering in Place*" that categorized transit stops in Chicago into high priority short-term TOD opportunities, and long-term TOD priorities (Center for Neighborhood Technology, 2012). Building on that report, CNT published another report in 2013 “*Transit-Oriented Development in the Chicago Region, Efficient and Resilient Communities for the 21st Century*”, where they compared Chicago’s region to other peer regions and saw that it was the only one experiencing decline in development around transit stops (Center for Neighborhood Technology, 2013).

Based on the findings of the CNT report, Chicago City Council passed their first TOD policy in July 2013, and refined it in 2015 by increasing the TOD area, allow for more parking reduction, and improved the affordability incentives based on the recommendations of the Metropolitan Planning Council and the Institute for Transportation and Development Policy (Chicago City Council, 2013, 2015; Metropolitan Planning Council & Institute for Transportation and Development Policy, 2015; Nationwide, 2016). The Chicago City Council set out the TOD area as the area that covers all buildings within 1,320 feet of a CTA or METRA rail station entrance, or within 2,640 feet of a CTA or METRA rail station entrance when the subject building is located along a pedestrian street or a pedestrian retail street. All buildings within the TOD area are eligible for the following:

- Building height Increase.
- Floor Area Ratio (FAR) Increase.
- Minimum Lot Area (MLA) reduction.
- Parking requirements reduction that can reach to a 100% if the parking spaces were replaced with bicycle spaces.
- Additional FAR and building height increase if affordable housing requirements were met.

Comparison conditions

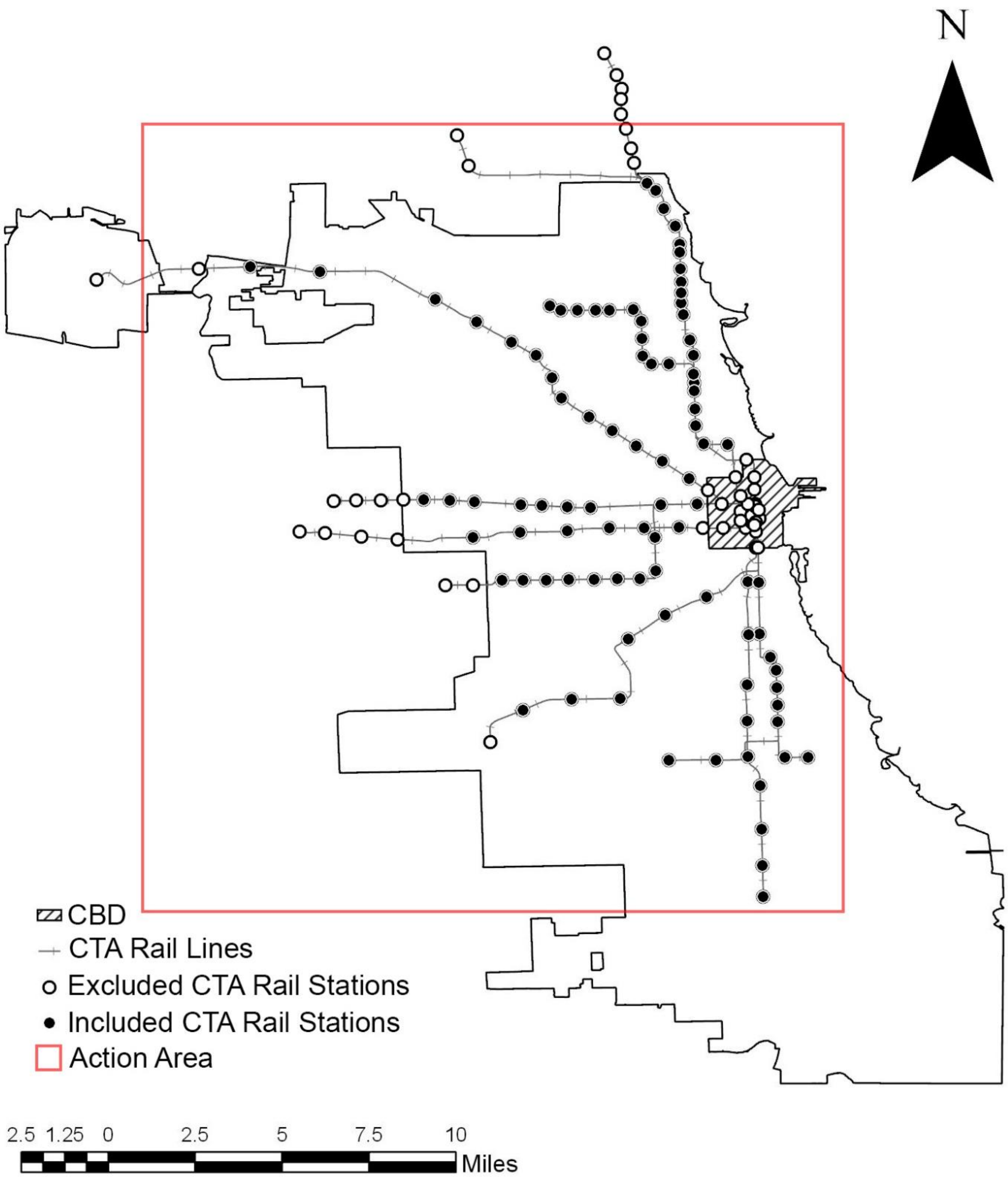

Figure 2 Chicago City map shown on it the CTA stations that will be included in the study and the study action area.

Based on the Chicago TOD policies, and to provide an accurate comparison results, our study was restricted to only Chicago Transit Authority (CTA) rail stations that were fully operational by the year 2010. As shown in Figure 2, we removed all the stations that are within the boundaries of the Central Business District (CBD), because our results might be affected from all the different policies that are applied to all the properties within this area. Furthermore, we removed any station that is located within the campus of O'Hare International Airport, or Midway International Airport. For the remining stations, we calculated a 1,320 feet buffer, and removed any station with the majority of its buffer outside the city boundaries. Finally, after filtering out all the stations that are located in areas that might impact our results, we were left with 94 CTA stations in which we proceeded to do our study.

Chapter 4 - Data Collection

Since the TOD policies were implemented in Chicago in the year 2013, then, in order to do our study, we have to take a year in the period before the implementation of the TOD policies (the start year), and a year in the period after the implementation of the TOD policies (the end year). We took the year 2010 as the start year because it gives us a time to study the existing conditions before any of the TOD polices were implemented. The year 2017 was chosen as the end year because it is the last year the Longitudinal Employer-Household Dynamics (LEHD), our main source of data, released their information for. It goes without saying that the more time we get between the year when the TOD policies were implemented, and the end year, the more accurate our results will be.

The data in this research were extracted from different sources. The base map was taken from Topologically Integrated Geographic Encoding and Referencing (TIGER) Census. All the CTA stations location, the city boundary, and the CBD boundary were extracted from the Chicago Data Portal. The population data (workers homes) for the years 2010 and 2017 was taken from LEHD data. The American Community Survey (ACS) data would have been a better source on calculating the population density than the LEHD, but the ACS provides a different estimate for the year 2010 (1-year estimates), and the year 2017 (5-year estimates), which, if used, will jeopardize our comparison results. As for the number of workers and their distribution in the different industrial sectors, it was also extracted from the LEHD data.

In this paper, and based on the data that was available, we were able to include only four indicators in our study: the residential and commercial density, land use diversity, land use mixedness, and economic development. Unfortunately, we couldn’t add more indicators in our study due to the lack of data.

Data mapping

After applying all the data that was gathered on the map of Chicago City and calculating the 1,320 feet buffer, we faced a problem with the data points that were located in the overlap of two different buffers. To solve this problem, any data point that is located between more than one station will be duplicated for each station. For example, if a certain retail shop was located at the overlap between buffer of station A and buffer of station B, in the final datasheet, the shop will be registered in both of these stations.

Chapter 5 - Indicators Calculation

Table 1 TOD Index Criteria and Indicators

Criteria	Indicator	Calculation	Weight
Density	Residential density (number of workers homes)	0.5 of the total weight	
	Commercial density (number of jobs)	0.5 of the total weight	0.35
Land use diversity	Shannon-Wiener Diversity Index	H'=-∑[(n1/N) * ln(n1/N)]	0.25
Design	Land use mixedness	MI= (∑Sc) / (∑(Sc +Sr))	0.17
Economic development	Total monthly income	number of workers * range of income	0.22

In this paper, and based on the available data, we calculated only four indicators, residential and commercial density, land use diversity, land use mixedness, and economic development. In this section, we will explain, in details, how we came up with our weighting system. We will also explain the way we calculated each indicator and discuss their results.

Table 2 Criteria Weights

Literature	Density	Land use diversity	Design	Economic development
(Y. J. Singh, Lukman, Flacke, Zuidgeest, & Van Maarseveen, 2017)	0.15	0.03	0.14	0.22
(Y. Singh, Fard, Zuidgeest, Brussel, & Maarseveen, 2014)	0.35	0.35	0.20	0.1
(Srivanit & Selanon, 2017)	0.21	-	-	0.18
(Frank, Cho, Andrew, Ashley, & Reed, n.d.)	0.12	-	0.09	0.14
(Banai, 1998)	0.38	0.21	0.14	-
(Taki, Maatouk, & Qurnfulah, 2017)	0.51	0.22	-	0.27
Average	**0.29**	**0.20**	**0.14**	**0.18**
Adjusted average	**0.35**	**0.25**	**0.17**	**0.22**

Note. The adjusted average does not sum to 1 due to rounding.

In order to come up with a just weighting system for the criteria, the average criteria weights were calculated from past studies that used TOD measurement techniques to find out the best places for applying the TOD policies. As shown in Table 2, density (both residential and commercial) has the highest weighting average, with 0.35, after that comes land use diversity, followed by economic development, and design.

Residential and commercial density

The density criterion was calculated by two indicators: residential density (represented by the number of workers homes), and commercial density (represented by the number of jobs). The number of workers homes is not an ideal indicator for residential density, but as discussed in the data collection chapter, the LEHD data was the only source that had an available data for both the year 2010 and 2017 that could be used in our comparison.

$$Density = \frac{\log(\text{residential density} + \text{commercial density})}{\max(\log(\text{residential density} + \text{commercial density})}$$

Calculating the density criterion contains of three steps. First, the number of workers homes at each station area (residential density) is added to the number of people who work there (commercial density). Second, the results then were logged to reduce the impact of the outliers on the density indicator. Finally, the logged results were standardized using the Maximum Standardization Method where all the values were divided by the highest value, so the highest value will be 1, and all the other values will get a value between 0 and 1. The maximum standardization method has been used by many studies (Frank et al., 2018; Yamini Jain Singh et al., 2017). The goal of standardizing the density indicator and all the other indicators is to bring them to a comparable unit in order to calculate the TOD index.

Land Use Diversity

Table 3 Jobs Distribution

	Number of workers			Number of workers	
Sector	2010	2017	Group	2010	2017
Wholesale Trade	4530	4654	Commercial	19677	18527
Retail Trade	15147	13873			
Educational Services	12207	8849	Educational	12207	8849
Health Care and Social Assistance	39647	44889	Health	39647	44889
Utilities	70	76	Service	49413	30431
Construction	2315	1994			
Transportation and Warehousing	1651	1181			
Information	3894	2858			
Finance and Insurance	5232	5832			
Real Estate and Rental and Leasing	2080	3570			
Professional, Scientific, and Technical Services	6005	8312			
Management of Companies and Enterprises	378	1178			
Other Services [except Public Administration]	5242	5373			
Public Administration	22546	57			
Administrative and Support and Waste Management and Remediation Services	7722	7887	industrial	12855	12318
Mining, Quarrying, and Oil and Gas Extraction	5	1			
Manufacturing	5123	4428			
Agriculture, Forestry, Fishing and Hunting	5	2			
Arts, Entertainment, and Recreation	2284	4873	Entertainment	19265	28781
Accommodation and Food Services	16981	23908			
Total Number of Workers	**153064**	**143795**		**153064**	**143795**

The LEHD data shows the number of workers in each block in Chicago City. Moreover, the number workers is broken down into twenty sectors based on the North American Industry Classification System (NAICS). To calculate diversity, we divided the twenty sectors into six classifications; commercial, educational, health, services, industrial, and entertainment as shown in Table 3. After identifying our classes that will be included in the diversity index calculation, we used the Shannon-Weiner Diversity Index to calculate it.

$$H' = -\sum[(n1/N)\ ln(n1/N)]$$

Using this equation, we calculated *N*, which is the total summation of all the six uses at each station. After that, *H* was calculated for each use by dividing the individual use, *n1* by *N*, all together multiplied by the logarithm of the same use divided by *N*. This was done for all the uses for each station. After that, we calculated the *H'* by adding all the *H*s from all the six uses for each station and change the negative to positive. Finally, we standardized all the values for the highest value using the maximum standardization method.

Land Use Mixedness

There are many studies that suggested the use of land use mixedness indicator as a way to calculate the walking and cycling friendliness of an area (Evans IV, Pratt, Stryker, & Kuzmyak, 2007; Y. Singh et al., 2014; Yamini Jain Singh et al., 2017; Zhang & Guindon, 2006). The goal of this indicator is to know the ratio of all nonresidential uses compared to residential uses. The idea is, the more equally mixed the residential land use with other land uses; the more people will be encouraged to walk or bike toward their destination. To calculate land use mixedness, we chose the number of workers who live at each station area as our residential land use, and the number of workers who work at each station area as our non-residential land use. After that, we divided the number of nonresidential uses for each station area by the sum of nonresidential uses and residential uses for each station area using the following equation.

$$MI = \frac{S_c}{S_c + S_r}$$

In this equation, MI is the land use mixedness, Sc represents the number of jobs in each station, and Sr is the total number of workers homes in each station. This equation will result in a value where 0.5 indicates an equal balance between residential and non-residential uses.

Seeing that 0.5 is the best result for this indicator, we used the 'benefit' and 'cost' standardization method. This method was used by (Yamini Jain Singh et al., 2017), where the closer the *MI* value gets to 0.5 the higher the indicator value will be, any increase after 0.5 will be accounted as a 'cost' and will be subtracted from the index value. After that, we standardized all the values for the highest value by using the maximum standardization method.

We should note that land use mixedness is different than land-use diversity because it focuses on residential uses and their relation to other uses. As Singh et al. put it: "This notion of mixed-ness is different from that of diversity and centers around how the residential land use is supported by other land uses such as commercial, industrial, institutional put together" (Y. Singh et al., 2014). In addition, the land use mixedness indicator is more suitable for our study than other indicators like block size, intersection density, or sidewalk coverage, which does not show measurable change in a short period of time.

Economic Development

The LEHD data provides three ranges of income: 1- Workers who earn $1250 /month or less. 2- Workers who earn between $1251 to $3333 /month. 3- Workers who earn greater than $3333 /month. Based on those ranges we calculated the total number of income that jobs generate in each transit station in each month. To do that, we assumed that in the first range all the workers earn $1,000, which is 20% less than the highest amount that could be earned in each month. For the second range we assumed that all workers earn $2,291, which is the midpoint between $1251 to $3333. For the third range we assumed that all workers earn $4,000, which is 20% higher than the lowest amount that could be earned in each month. Then, we multiplied the number of workers at each station by their assumed monthly salary. After that, we logged the final assumed total monthly income at each station to reduce the impact of the outliers on the economic development indicator. Finally, we used the Maximum Standardization Method to get the final result for the economic development indicator.

Final TOD Index

The final TOD index is the final step before making our comparison. The TOD index is the TOD level for each station based on our indicator's calculation and the weight that was decided for each indicator. In the final TOD index, the four indicators; density, diversity, land use mixedness, and economic development, were each multiplied by their weight and added together to make our TOD index. This was done for both the year 2010, and 2017. As was mentioned, the weighting for each indicator was calculated from past literature and averaged, as shown in Table 1.

Chapter 6 - FINDINGS

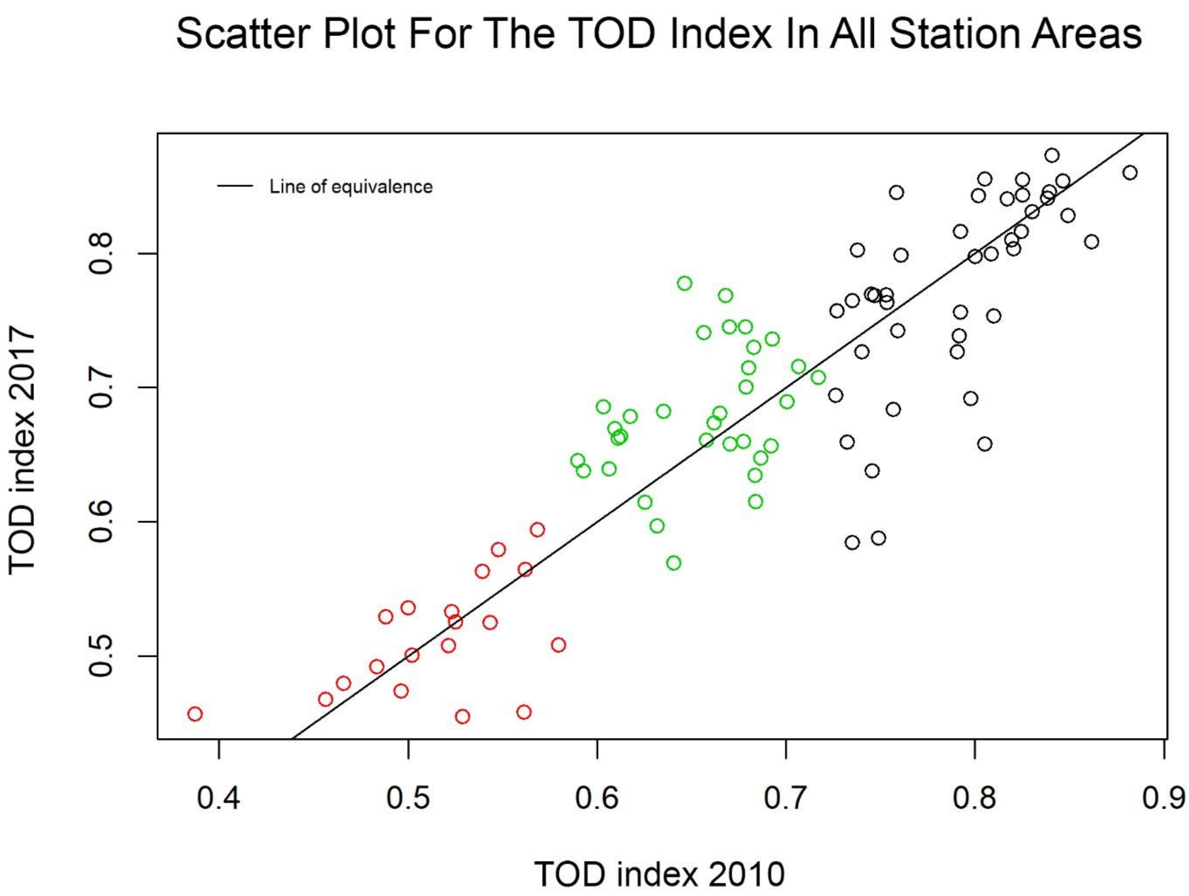

Figure 3 A scatter plot for the TOD index for the years 2010 and 2017 where the station areas are divided into three groups based on their 2010 TOD index.

As a first step, and in order to know which station areas performed better, low, mid, or high TOD index station areas, we needed to first identify the TOD index range for each one of them. To do that, we divided the TOD index data in the year 2010 into three groups by using the K-Mean Clustering method. As shown in Figure 3, the cluster for the low TOD index station areas goes from 0 to 0.58, mid TOD index cluster goes from 0.59 to 0.72, and high TOD index goes from 0.73 to 1.

Looking at Figure 3, We can see that the green cluster, which represent the station areas with mid TOD index, has the most points above the line of equivalence. This means that station areas with mid TOD index preformed better than other station areas with low, or high TOD index.

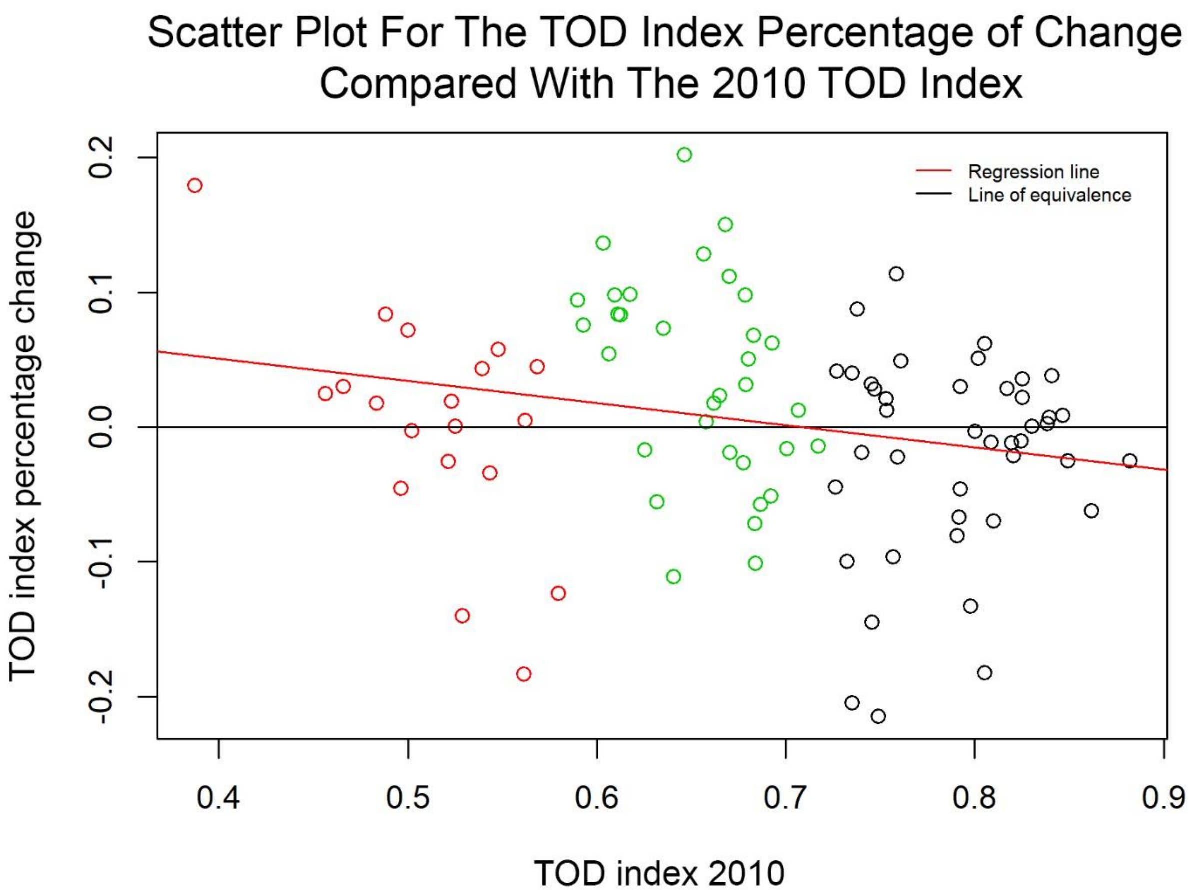

Figure 4 A scatter plot that shows the relation between the TOD index in the year 2010 and the percentage of change in the TOD index between the years 2010 and 2017.

To further analyze our data, we decided to do a scatter plot that shows the relationship between the TOD index in the year 2010 and the percentage of change in the TOD index between the years 2010 and 2017. We can see in Figure 4 that station areas with mid TOD index in the year 2010 encountered the most positive change in the year 2017, which confirms with our previous finding. Also, from analyzing the regression line we can see that it is declining, which could be caused by the many high TOD index station areas that experienced decline in their TOD index in the year 2017.

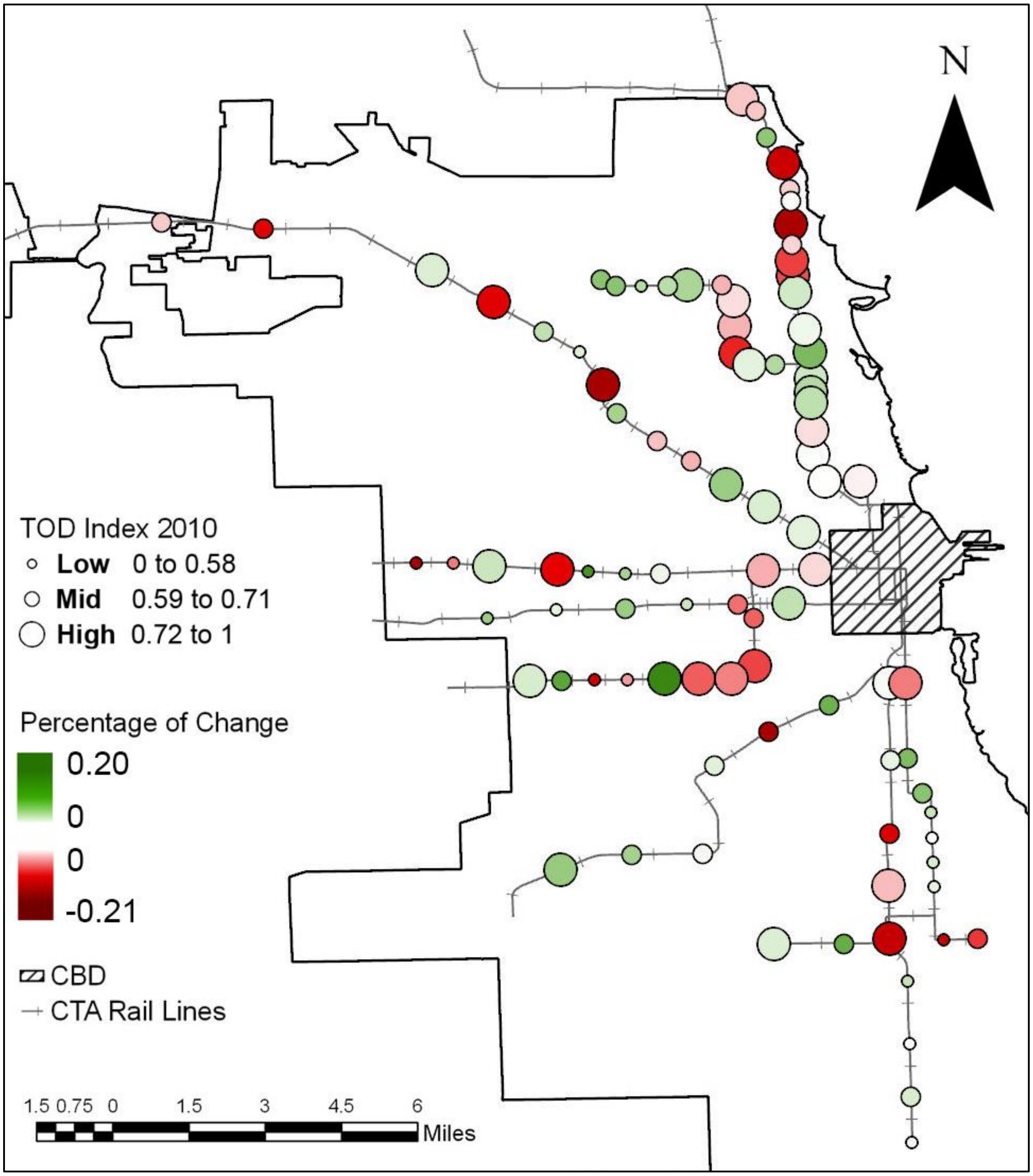

Figure 5 A map that shows the relation between the TOD index in the year 2010 and the percentage of change in the TOD index between the years 2010 and 2017.

To further investigate our research question, we did a map that shows the relation between the TOD index in the year 2010 (shown in circle size), and the percentage of change in the TOD index between the years 2010 and 2017 (shown in circle color). The circle size is divided into three different categories and each one is represented by different size where the range of each group is based on the K-Means Clustering shown in Figure 3.

We can see in Figure 5 that station areas with mid TOD index in the year 2010 (represented by mid size circle), tend to have darker green, which means higher percentage of change compared to other low or high TOD index station areas.

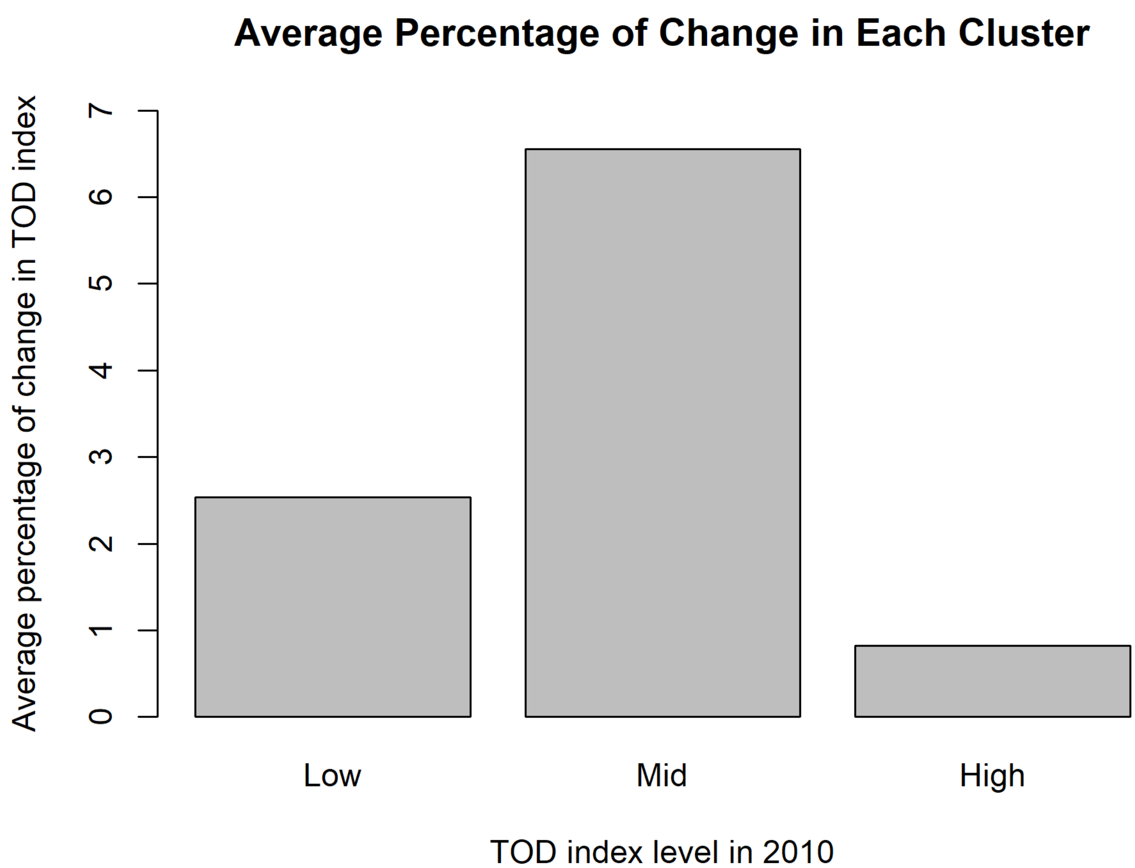

Figure 6 average percentage of change at each cluster.

After identifying our clusters by using the K-Means Clustering method shown in Figure 5, we took the average TOD index for each group (low, mid, and high) for both the year 2010 and 2017, and then calculated the percentage of change between them. Looking at Figure 7, we found out that station areas with mid TOD index in the year 2010 had the highest average percentage of change in their TOD index by the year 2017, after it comes station areas with existing low TOD index, and finally station areas with existing high TOD index experienced the lowest average percentage of change.

The only take on using the average percentage of change is that it does not take into consideration the station areas that had massive increase in their TOD index. Those station areas could have an impact on the total average percentage of change which could lead us into making inaccurate conclusions. In order to resolve this issue and reduce the effect of station areas that had massive increase in their TOD index, we calculated the number of station areas that moved from their cluster to a higher or lower cluster, to see if the results are consistent with our previous findings.

Table 4 TOD Index Performance Matrix

Tod Cluster	TOD cluster in 2017			
in 2010	Low	Mid	High	**Totals**
Low	18	1	0	**19**
Mid	1	25	7	**33**
High	2	6	34	**42**
Totals	**21**	**32**	**41**	**94**

Table 4 shows how each cluster in the year 2010 preformed in the year 2017. This was done by calculating, for each cluster, how many station areas have jumped to a higher cluster, and how many station areas have come down to a lower cluster. It must be noted that the range for each cluster for both the year 2010 and 2017 is based on the K-Means Clustering for the TOD index data for the year 2010.

We can see that station areas with mid TOD index in the year 2010 preformed the best by the year 2017 with 7 station areas jumping from mid to high TOD index cluster. Station areas with low TOD index didn’t perform as well, but still there is a slight increase with one station area jumping into mid TOD index. Station areas with high TOD index preformed the worst with 6 station areas turning into mid TOD index, and 2 turning into low TOD index.

Chapter 7 - Conclusion

The goal of this study is to help decision-makers know which station areas have higher rates of success in short periods of time based on their TOD index. To do that we need to compare station areas before and after the TOD policies were implemented to see which areas encountered the most positive change, areas with high, mid, or low TOD index. We chose to make our comparison in one city to avoid any outside factors that could impact the results of our comparison. We made our comparison in the city Chicago because they implemented their TOD policies in the year 2013, which means that enough data will be available for the comparison.

We did a scatter plot for the TOD index for the years 2010 and 2017. Looking at the scatter plot we noticed that station areas with mid TOD index in the year 2010 mostly tend to increase their TOD index in the year 2017. In order to be more conclusive and put numbers into our interpretations, we used the K-Means Clustering method to divide the TOD index data in the year 2010 into three groups: low, mid, and high. After that, we calculated the average percentage of change for each group and found out that station areas with mid TOD index in the year 2010 had the highest percent. We also calculated how many station areas have changed cluster to a higher or lower cluster from the year 2010 to the year 2017. We found out that station areas with mid TOD index performed the best.

Looking at the findings, we have concluded that station areas with mid TOD index should be prioritized for the implementation of the TOD policies because they tend to have a higher rate of success in short periods of time compared to other low or high TOD index areas.

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