EFFECTS OF BUS STOP SPACING IN PUBLIC TRANSPORTATION PERFORMANCE:

An Analysis of Parallel Corridors in Chicago

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1. Introduction

Public transportation systems are essential assets in urban areas. They provide more efficient mobility than private cars in dense areas, while also reducing traffic congestion and its environmental impacts (CMAP; 2018). More importantly, public transportation offers mobility solutions to everyone regardless of their physical and financial abilities, which means that it is also accessible to people who do not have access to a car or lack the ability to drive. This advantage over other modes of transportation plays a very important role in increasing equity, which means providing equal access to opportunities, giving the chance of equal growth and development among people of different backgrounds, abilities and goals. The biggest and most successful cities in the world also have robust public transit networks, which means not only that the benefits of transit are widely known, but also that transit has created opportunities for urban areas to develop and thrive.

One of the crucial parts of a public transit network in a city is the bus network. While rail public transit is more recognizable in a public transportation system, the vast majority of urban areas relies on buses for public transit. Buses provide flexible routing options, station and stop placements, and relatively low capital costs. In large urban areas with rail service, buses enhance the connectivity in the network, allowing better access to the rail system from neighboring areas, and filling the gaps where rail service is not provided. In many cases, rail service succeeded bus service in high demand corridors. However, given the high capital costs and demand needed to justify investments in rail, buses are the main form of public transportation.

1.1. Problem Statement

As mentioned above, buses in public transportation provide flexible routing and stop placing options. The location of the stops is a crucial element in providing accessible, safe, quick, and efficient service. One of the important parts of stop location is stop spacing. Stop spacing refers to the distance between two consecutive bus stops along a route. It is a useful metric to estimate the coverage area of a specific route or the network, based on the coverage area of each stop. Stop spacing is also an indicator of the route's type of service, as most limited-stop routes tend to have relatively wider-spaced stops, while most local routes tend to have more dense-spaced stops. Wider stop spacing decreases travel time, improving service performance and quality for riders, but at the same time it reduces the coverage area, requiring from some of the current riders to walk more, in order to access the service. At the same time, narrower stop spacing increases coverage and improves access to bus stops; however, it increases travel time and dwell time, hindering service quality for riders.

Stop spacing, for the most part, is established as a system-wide policy, and this policy has not changed in time, even though the technology to optimize stop spacing is now available. Travel patterns change over time, and stop spacing is one of the elements in public transportation planning that has the ability to enhance or hinder service, and increase or decrease operating costs and efficiency. However, because of the social aspect of public transportation, any changes to stop spacing require concrete arguments, good communications and outreach, and political will, in order to successfully inform the public about the benefits of such change.

In the city of Chicago, the average stop spacing policy for regular bus routes is 8 stops per mile, or 1/8th of a mile between two consecutive stops. This spacing has been selected to provide great transit coverage throughout the service area, but at the same time it is a main cause for delays, especially during the peak periods. These delays may also be connected to a continuous bus ridership loss in the area. In order to reduce delays and ridership loss in some high-demand corridors, the Chicago Transit Authority (CTA) has been experimenting in two ways. First, they consolidated the bus stops along Ashland Avenue, one of the corridors with the highest demand for bus service, increasing the stop spacing from 1/8th of a mile to ¼ of a mile. Second, they introduced two limited-stop "express" routes along Ashland and Western Avenues, two of the highest demand corridors. These routes have a stop spacing of ½ mile and they operate only during weekday peak periods.

1.2. Goal and Objectives of the Project

The goal of this project is to study the relationship of bus stop spacing to travel times and ridership. Identifying patterns and possible relationships between these measures can help transit agencies to understand the impact of stop spacing in operation costs and revenue, giving incentives to make changes, if needed, based on their goals.

The main objective of this project is to analyze scheduling and ridership patterns among bus routes run along parallel corridors in the city of Chicago. These corridors are (moving west from downtown Chicago) Halsted Street, Ashland Avenue, Damen Avenue, and Western Avenue. These corridors serve a high demand segment of the city, provide connections to several bus and rail lines, and have similar characteristics, except for stop spacing, which is the element to be analyzed. The secondary objective of this project is to analyze the coverage area of each route, based on the stop spacing patterns. This can be an indicator of the route coverage, using access to bus stops as a measure.

1.3. Structure of the Paper

This paper is structured as follows. In Section 2, a background review focuses on the history of bus stop spacing, current approaches, and coverage and performance issues. Section 3 includes the methodology and the way the analysis will be done. In section 4, an application in the chosen CTA bus corridors will be done, followed by a summary of the results in section 5. Finally, Section 6 includes a discussion highlighting the findings of this study and identifying areas for further research.

2. Background

The bus stop spacing issue has been largely discussed. While changes to stop spacing remain a largely political and social issue, many studies have been conducted in the past that either propose an optimal stop spacing based on their analysis, or provide models for transit agencies to define stop spacing based on their own unique characteristics and policies. Other studies focused on changes to stop spacing that happened in specific cases, analyzing the ridership and travel time impacts.

The determination of the appropriate stop spacing requires trade-offs between the convenience of passengers accessing and using a stop, and the convenience of passengers already aboard that are delayed by a bus stop (Transit Capacity and Quality of Service Manual; 2013). According to (Furth, Rahbee; 2000), bus stop location decisions have three main social impacts: (i) riding time, the time spent in the vehicle increases as stop spacing decreases; (ii) operating cost, the cycle time and the operating cost of a route increases as stop spacing decreases; and (iii) walking time, the walking time needed to access a bus stop decreases as stop spacing decreases. They also mention that a fourth impact may be the loss of ridership with wider stop spacing, as walking distance is longer. In general, transit service favors bus stop accessibility, which tends to decrease stop spacing, mainly because of historical trends and not actual stop-level analyses, however, a stop consolidation implies a risk for transit operators, as service may become or be perceived as inaccessible for some passengers (Li, Bertini; 2009).

Furth and Rahbee (2000), studied bus stop spacing and proposed a model that defines the optimal stop spacing using dynamic programming. A case study in Boston, MA was used to evaluate the model and showed that the optimal spacing was 1,350 ft (4 stops/mile), compared to the 650 ft (8 stops/mile) policy of MBTA. Li and Bertini (2009) discussed the importance of the performance and financial impact of stop spacing, proposing a similar model to define the optimal stop spacing using a large set of archived stop-level data. Their application in TriMet's network in Portland, OR showed that the optimal spacing between bus stops was 1,200 ft, instead of TriMet's policy of 950 ft. These studies show that the proposed optimal bus stop spacings converge at 4 stops/mile, while the majority of US cities with urban bus public transportation use a stop spacing of approximately 8 stops/mile.

Having usually denser placement of bus stops than the average proposed by literature highlights the perception that exists on public transit accessibility and the need of local communities for frequent bus stops. El-Geneidy et al. (2005) studied the impacts of bus stop consolidation in TriMet in Portland, OR. They mentioned that the major consequenses of bus stop consolidation are the following: (i) operation costs decline due to the running time decline, which can be translated into additional service for the same budget; (ii) the running time variation will decline, reducing the needs for excessive layover, recovery, and passenger waiting time; and (iii) passenger access time increases while in-vehicle time decreases. However, they mentioned that only the third consequence is discussed and, because of the strong political and social impacts of bus stop consolidation, there is no extensive testing and evaluation in reality, but only in simulation environments. Their findings showed that, after the stop consolidation, passenger activity was not affected, while operational costs were reduced by approximately 6 percent. Finally, the authors underlined that savings could be at a larger scale if the schedule adjustments were more thorough and sufficient.

3. Methodology

In order to analyze the relationship between stop spacing, travel time, and ridership, as well as identify the impacts of the first to the others, a series of computations was made. The methodology includes two parts: the first part analyzes the impact of stop spacing in the service area of each route, while the second part analyzes the impact of stop spacing in travel times and, eventually, in ridership.

3.1. Service Area Analysis

The service area of a stop is defined in numerous ways, based on the policy and level of detail available, and can be a function of many parameters, including the road network and slopes. Most transit agencies define the service area of a stop simply as a circular buffer around the stop. The service area of a route is defined as the area that is served by any of the route's stops. Because in many cases there are overlaps among stop service areas, it is assumed that the service area of a stop in this paper is the clipped area that is formed by the circular buffer and the Thiessen polygon of it. Figure 1 demonstrates this method.

In order to identify the relationship between stop spacing and service area, the extremes have to be defined. The stop spacing value for a route can range from 0 to the length of the route. When the stop spacing is 0, then there is an infinite number of stops along the route, which means that the service area of the route is equal to the buffer formed by the line itself and the distinct service area of each stop is 0, since there is infinite overlap between stops. When the stop spacing is equal to the length of the route, then the service area is equal to the sum of the buffers of the two terminal points, which is common with shuttle bus routes.

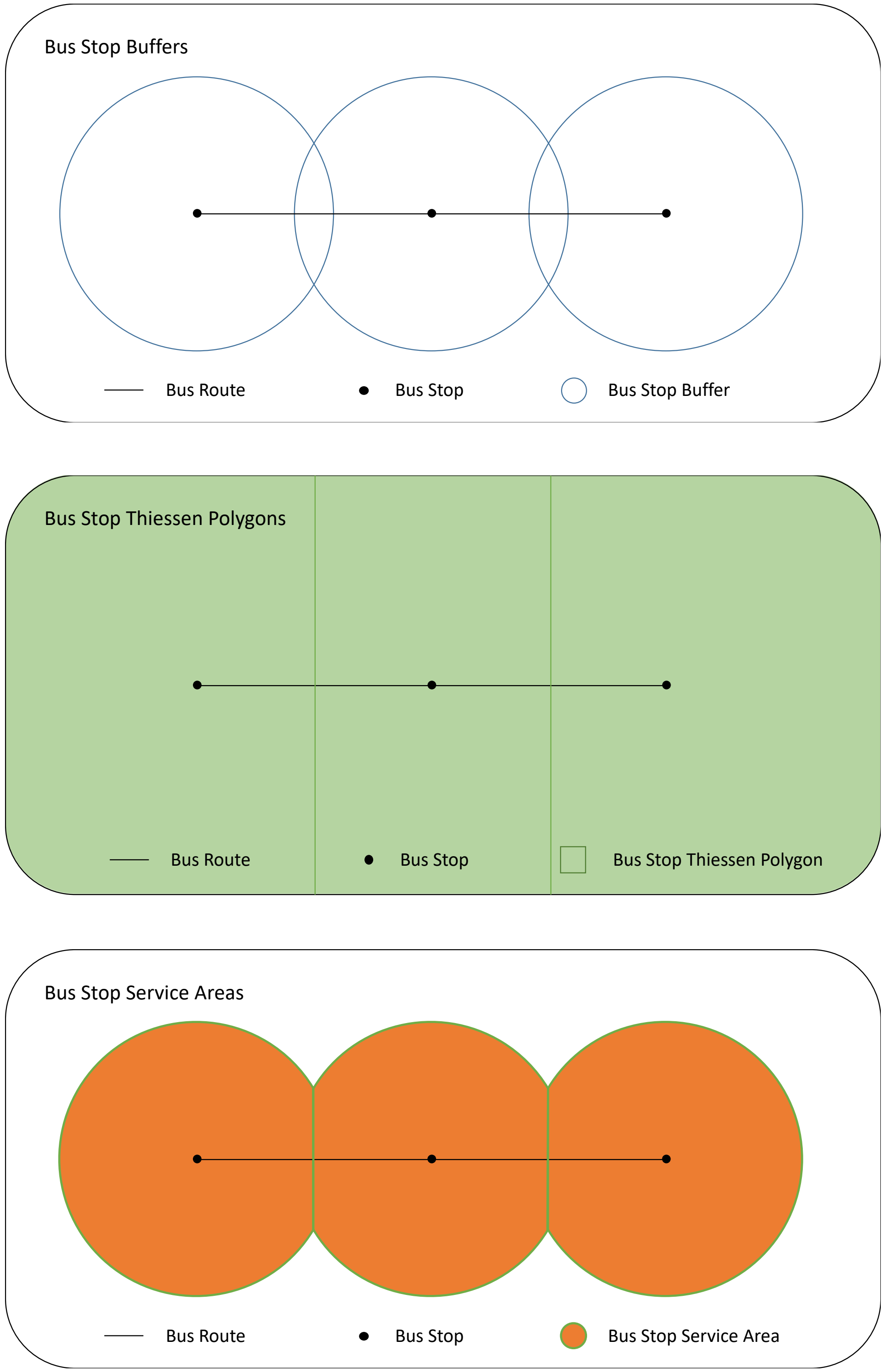

Figure 1 Steps to Define Bus Stop Service Area

For this study, the stop spacing is related to both stop service area and route service area. Stop service area is related to stop spacing by the ratio of the service area of a stop to the area that is formed by a walking distance buffer from the same stop. Route service area is related to stop spacing by the ratio of the area that is served by any bus stop to the walking distance buffer from the line (zero stop spacing extreme). Maximizing these two ratios is one of the challenges that stop spacing has to face.

3.2. Travel Time and Ridership Analysis

Analyzing travel time and ridership includes gathering the corresponding data and forming the right visualizations, in order to identify patterns and relate stop spacing to the data. For travel time, schedule data from GTFS is extracted and summarized in two ways: (i) by route, where the travel times of specific routes can be compared during the study period, which is useful when changes in stop spacing happen or modified service is introduced; and (ii) by period, where the travel times of many routes with different stop spacings are compared at a certain time during the study period, which is useful to identify the possible impact of stop spacing in travel time. For ridership, the average number of weekday boardings is used for each route, summarized by quarter, in order to provide a good source of information on ridership trends and the relationship between each route.

4. Application and Results

4.1. Study Area

The analysis is performed in 4 parallel corridors in the city of Chicago: Halsted Street, Ashland Avenue, Damen Avenue, and Western Avenue. These corridors provide a good source to study bus stop spacing, due to the fact that they carry similar characteristics. The average stop spacing policy the CTA requires for regular routes is 0.125 miles, or 8 stops per mile. In case of express routes, the average stop spacing policy is 0.5 miles, or 2 stops/mile. The study period for this project is 5 years, from October 2013 to October 2018. The analysis was done using publicly available ridership data from the data portal of the city of Chicago, and scheduling data from past GTFS feeds. The details and the routes serving each parallel corridor are discussed below:

- Halsted Street: Served by route #8 from Waveland to 79th. Offers daily early morning to late night service with a peak headway of 3 minutes and an average of 20,000 weekday riders, making it the highest ridership route in this project. There are 113 stops per direction in the main route with an average stop spacing of 0.138 miles.
- Ashland Avenue: Served by route #9 from Irving Park to 103rd. Offers daily 24-hour service with a peak headway of 8 minutes and an average of 17,000 weekday riders. There are 135 stops per direction in the main route with an average stop spacing of 0.203 miles. Also served by route #X9 from Irving Park to 95th, which offers weekday morning and afternoon peak service with a peak headway of 4 minutes and an average of 9,000 weekday riders. There are 37 stops per direction with an average stop spacing of 0.483 miles.
- Damen Avenue: Served by route #50 from Foster to 35th. Offers daily early morning to late night service with a peak headway of 5 minutes and an average of 8,750 weekday riders,

making it the lowest ridership route in this project. There are 90 stops per direction with an average stop spacing of 0.133 miles.

- Western Avenue: Served by route #49 from Berwyn to 79th. Offers daily 24-hour service with a peak headway of 5 minutes and an average of 16,000 weekday riders. There are 122 stops per direction in the main route with an average stop spacing of 0.193 miles. Also served by route #X49 from Berwyn to 79th, which offers weekday morning and afternoon peak service with a peak headway of 4 minutes and an average of 7,500 weekday riders. There are 35 stops per direction with an average stop spacing of 0.445 miles.

While route #8 Halsted has the highest ridership of all routes, the total weekday ridership of the routes along Ashland and Western Avenues is much higher when the local and express routes are combined. One interesting fact about the case with Ashland and Western Avenues is that the introduction of the express bus routes happened in December of 2015, which is within the study period. At the same time, stop consolidations happened at the local routes along Ashland and Western Avenue, increasing stop spacing to approximately 0.25 miles, or 4 stops/mile.

Figure 2 shows the number of trips per direction for each route throughout the study period. It can be seen that when the stop consolidation happened the local route trips were decreased by a smaller number than the trips added to the express routes. At the same time, it is shown that trips in 2018 were fewer than in 2016, but at the same time the express trips stayed the same. This can mean that the express routes are successful and maintained their service during a period with cost cuts in many routes, or that service was reduced during non-peak periods but was maintained during peak.

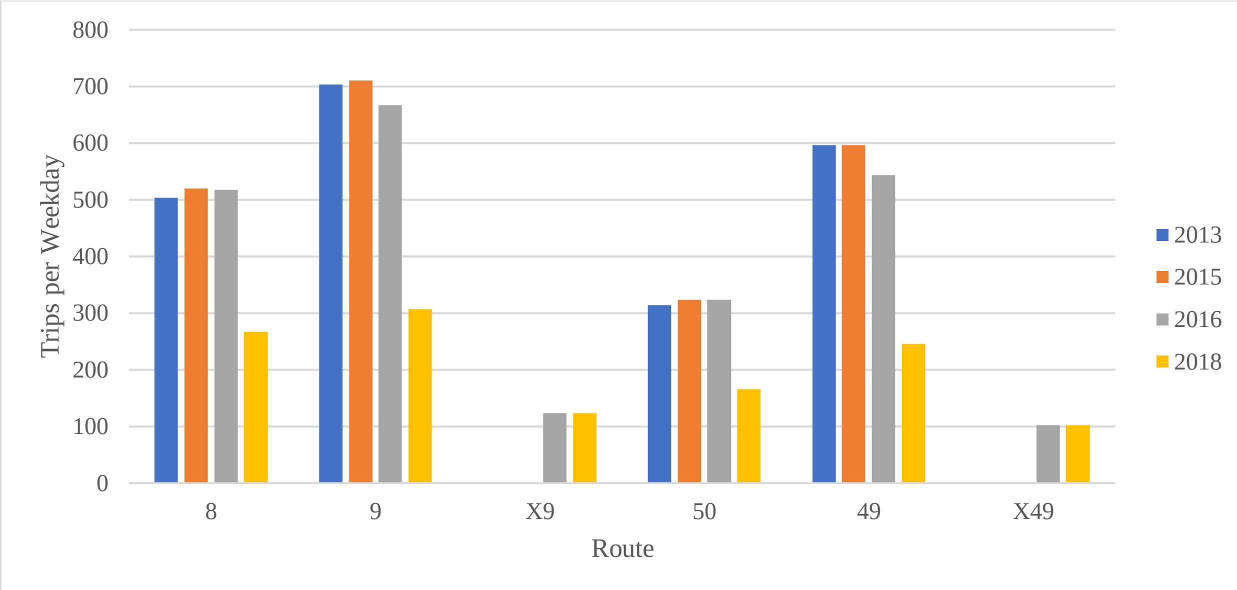

Figure 2 Average Weekday Trips per Route

4.2. Service Area Analysis

Table 1 shows the stop and route service areas, as well as the corresponding ratios. It can be seen that when stop are densely placed, the service area of each stop becomes compromised, because of overlaps. In the case of X9, spacing is wide enough to not have any overlap between stops. However, wide stop spacing also means lower route coverage, which translates to more riders having to walk more than the typical walking distance of 0.25 miles. For the express routes #X9 and #X49 this is acceptable, given that there is also local service along the same corridor.

Route	**Stop Spacing [mi]**	**Stop Service Area [acres]**	**Stop Buffer Size [acres]**	**% Stop Service Area to Buffer**	**Route Service Area [acres]**	**Route Buffer Size [acres]**	**% Route Service Area to Buffer**
8	0.138	4.075	11.626	35.05%	423.84	426.58	99.36%
9	0.203	5.907	11.626	50.81%	531.66	543.67	97.80%
X9	0.483	11.626	11.626	100.00%	410.37	525.88	78.03%
50	0.133	3.936	11.626	33.86%	340.43	354.89	95.93%
49	0.193	5.777	11.626	49.69%	473.72	482.83	98.11%
X49	0.445	10.836	11.626	93.20%	379.27	482.83	78.55%

Table 1 Comparison of Service Areas Among Examined Routes

4.3. Travel Time Analysis

In order to improve the accuracy of the travel time results, only the segments from Addison to Cermak were examined for each corridor. This way, the length of each route is the same and stop spacing as consistent as possible. The ridership analysis is done for the whole length of the routes, due to data availability per route and not per stop.

Figure 3 shows the stop spacing of each of the examined routes over time. It can be seen that stops for the local Ashland and Western routes was consolidated with the introduction of express service. Also, the average stop spacing was increased for the other routes as well, although only by a little and still within the 8 stops/mile policy.

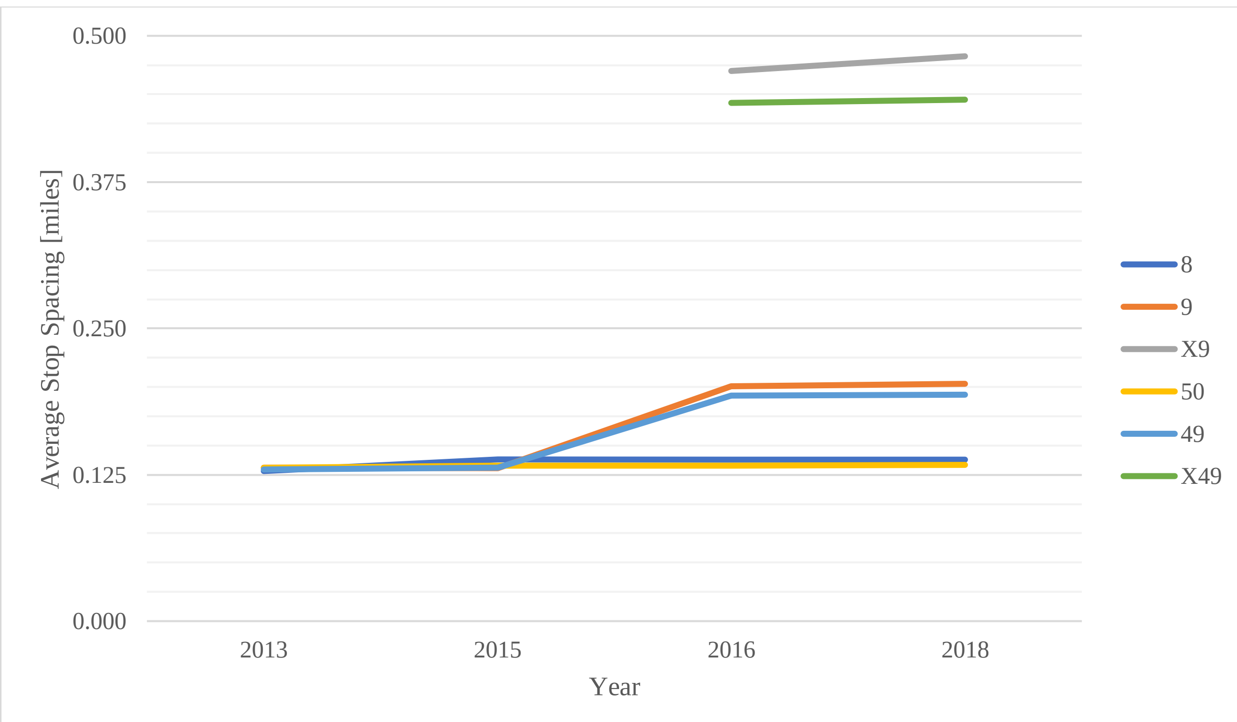

Figure 3 Average Stop Spacing by Route

Table 2 shows the change in travel time over the study period for each route. It can be seen that the stop consolidation and the introduction of the express routes led to time savings of 5-7% for both local routes, while travel time for Halsted also decreased by 4.5%. Figures 4 to 7 show the scheduled travel time for each corridor from Addison to Cermak throughout the day. It can be seen that travel time has significantly decreased for Ashland and Western, mostly during peak. For the express routes, it can be seen that the time savings are not as significant as from the stop consolidation, possibly because limited stops sometimes require longer dwell times to accommodate for the excessive demand per stop. For #X9, though, it seems that travel time in 2018 was higher than the local route, highlighting issues with the current implementation of express buses, or a possible data error.

	2013		**2015**		**2016**		**2018**		**%**	**%**
Route	Mean Travel Time	Std Travel Time	Mean Travel Time	Std Travel Time	Mean Travel Time	Std Travel Time	Mean Travel Time	Std Travel Time	**Mean 2013-2018**	**Mean 2016-2018**
8	40:04	4:26	45:14	5:39	45:14	5:39	43:11	5:19	7.78%	-4.53%
9	38:28	4:24	38:34	4:27	37:29	4:17	36:36	4:13	-4.85%	-2.36%
X9					34:48	2:40	40:17	5:03		15.76%
50	37:02	3:18	36:56	3:14	36:58	3:15	37:02	3:16	0.00%	0.18%
49	38:33	5:01	38:24	4:56	37:09	4:42	35:46	4:24	-7.22%	-3.72%
X49					35:56	3:39	36:07	3:39		0.51%

Table 2 Comparison of Travel Times from Addison to Cermak over the Study Period

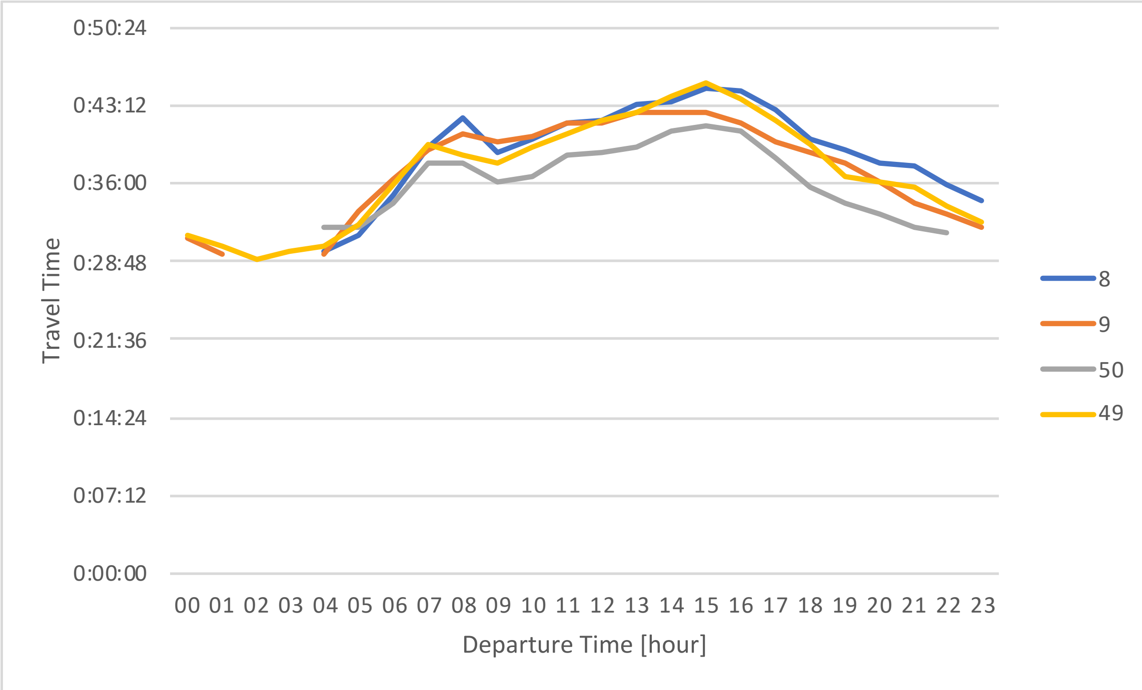

Figure 4 Travel Time by Departure Time Southbound from Addison to Cermak in 2013

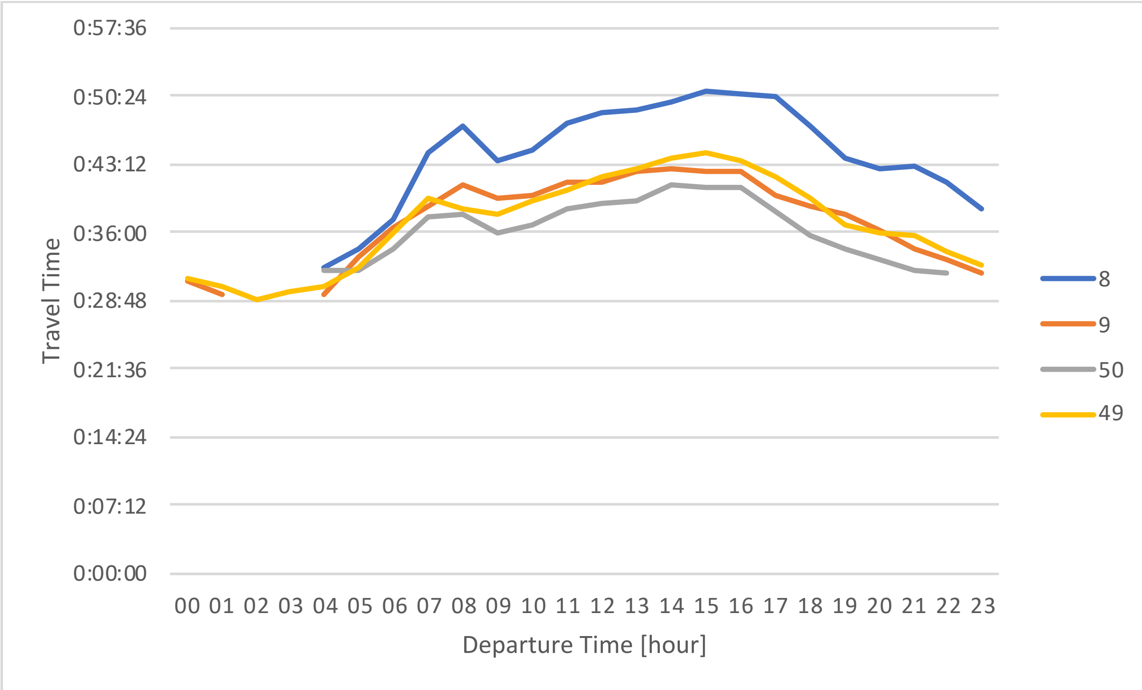

Figure 5 Travel Time by Departure Time Southbound from Addison to Cermak in 2015

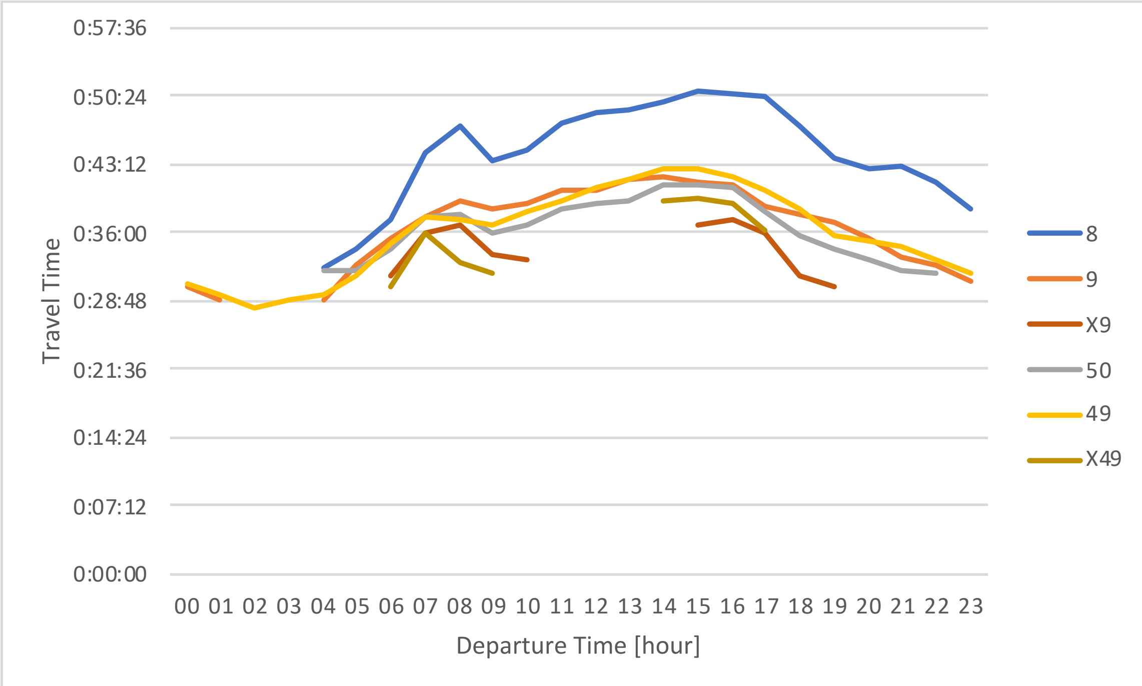

Figure 6 Travel Time by Departure Time Southbound from Addison to Cermak in 2016

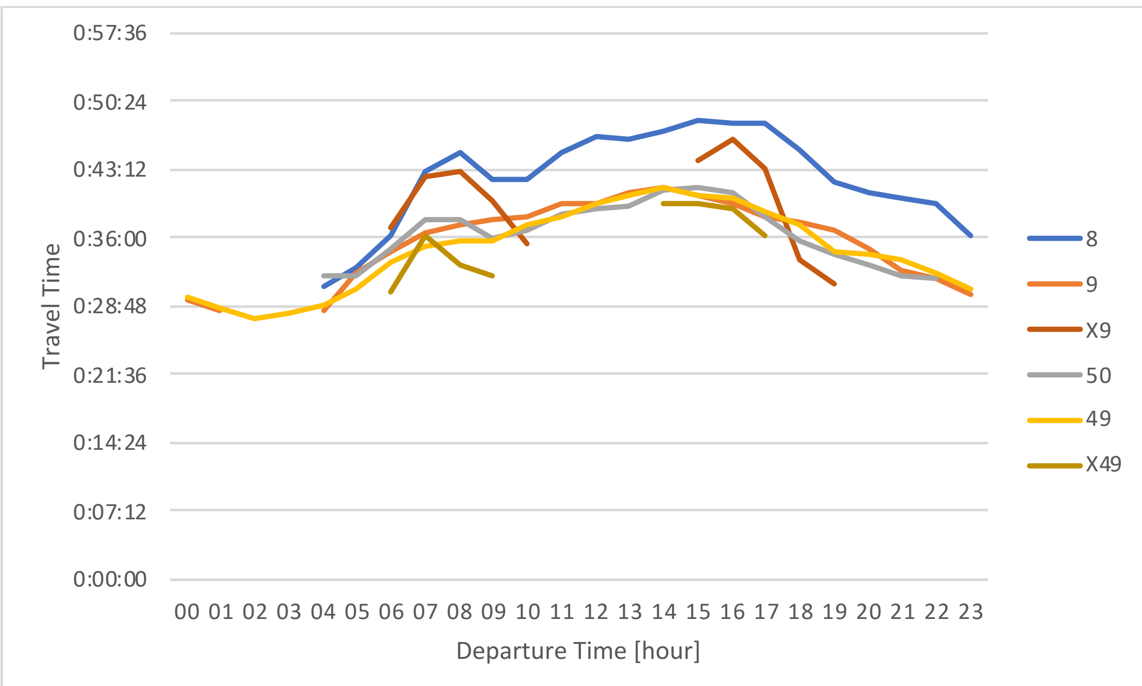

Figure 7 Travel Time by Departure Time Southbound from Addison to Cermak in 2018

Figures 8-13 show the scheduled travel time for each route during each period examined. It can be seen that, since the consolidation and the introduction of the express bus routes happened, the travel time for Ashland and Western local routes decreased significantly. On the other hand, travel times for #8 Halsted were increased in 2015 but decreased again in 2018, although higher than 2013. #50 Damen and #X49 Western Express remained relatively stable.

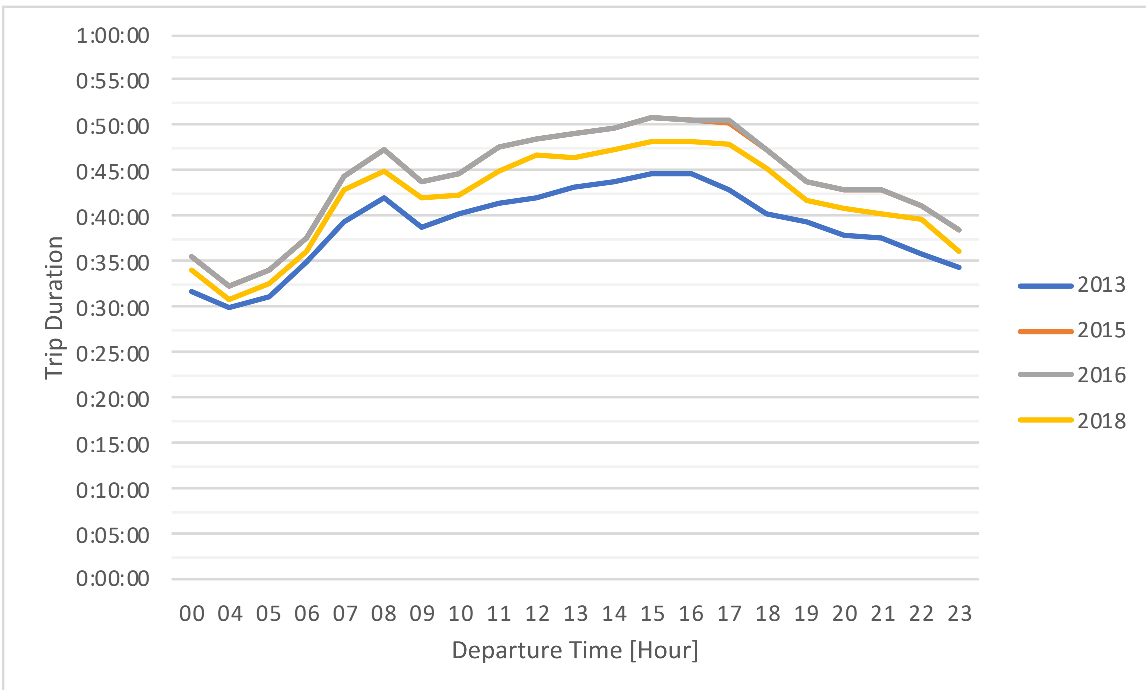

Figure 8 Travel Time by Departure Time - #8 Halsted Southbound from Addison to Cermak

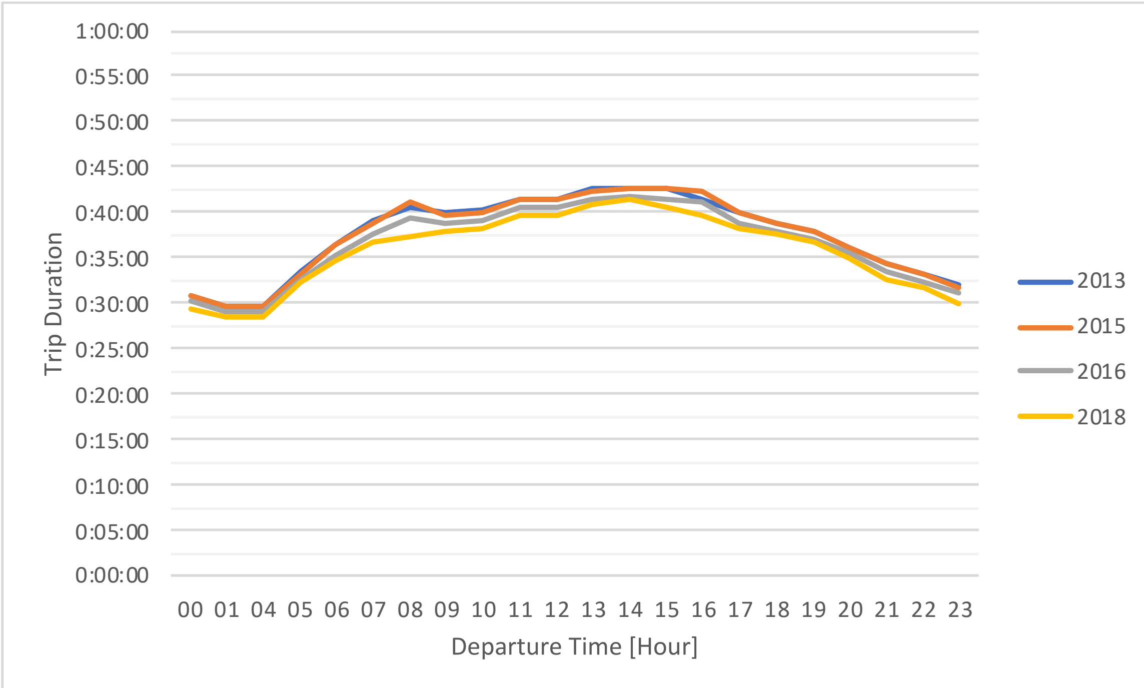

Figure 9 Travel Time by Departure Time - #9 Ashland Southbound from Addison to Cermak

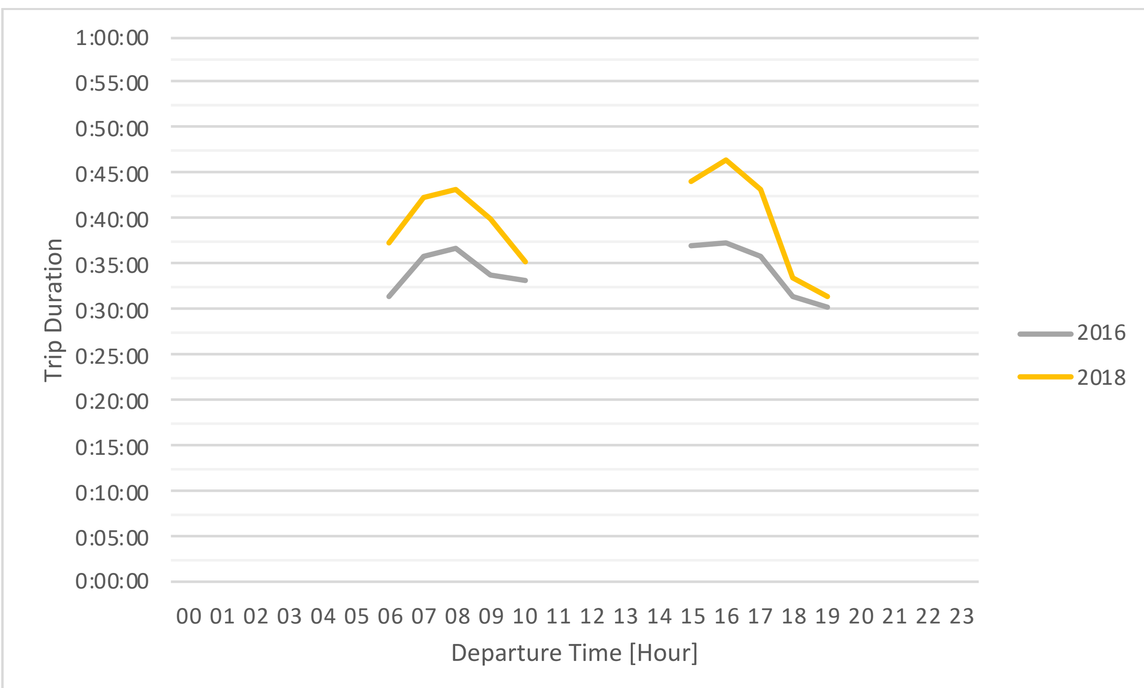

Figure 10 Travel Time by Departure Time - #X9 Ashland Express Southbound from Addison to Cermak

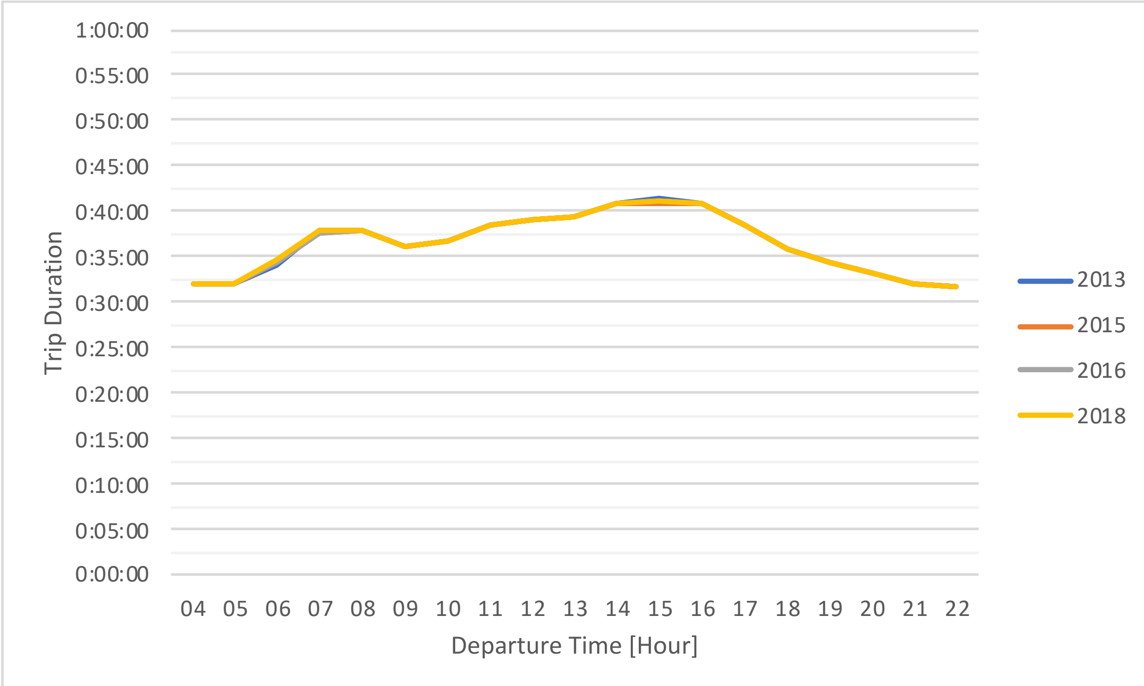

Figure 11 Travel Time by Departure Time - #50 Damen Southbound from Addison to Cermak

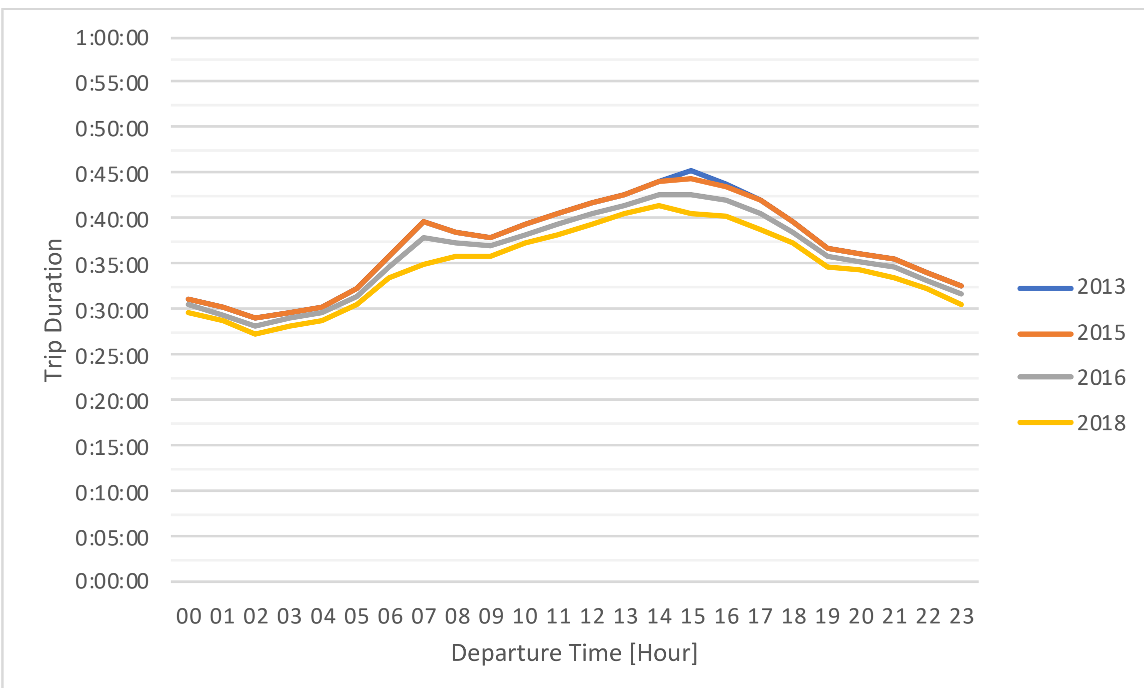

Figure 12 Travel Time by Departure Time - #49 Western Southbound from Addison to Cermak

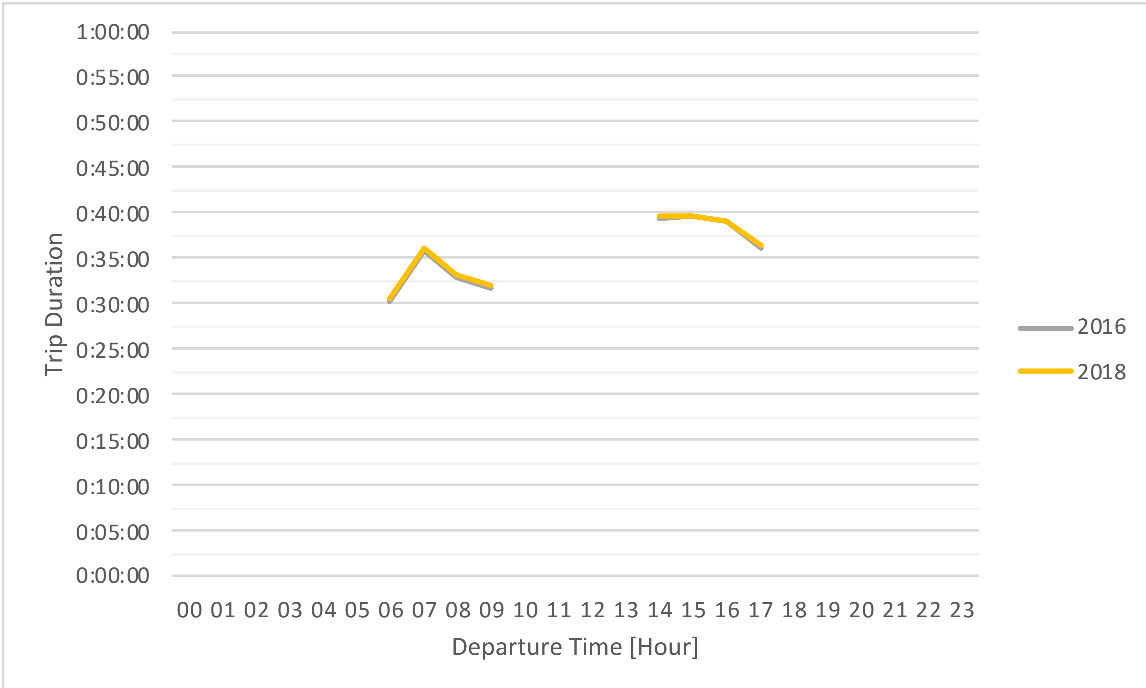

Figure 13 Travel Time by Departure Time - #X49 Western Express Southbound from Addison to Cermak

4.4. Ridership Analysis

Figure 14 shows the average weekday ridership for each route throughout the study period. It can be seen that the consolidation of stops and the added express service did not affect ridership, as the sum of the local and the express routes match the previously local route. Otherwise, there is a small decline in ridership following the general trend in CTA buses.

Figures 15-16 focus on the Ashland and Western corridors, showing that the stop consolidation and the introduction of express service did not affect ridership.

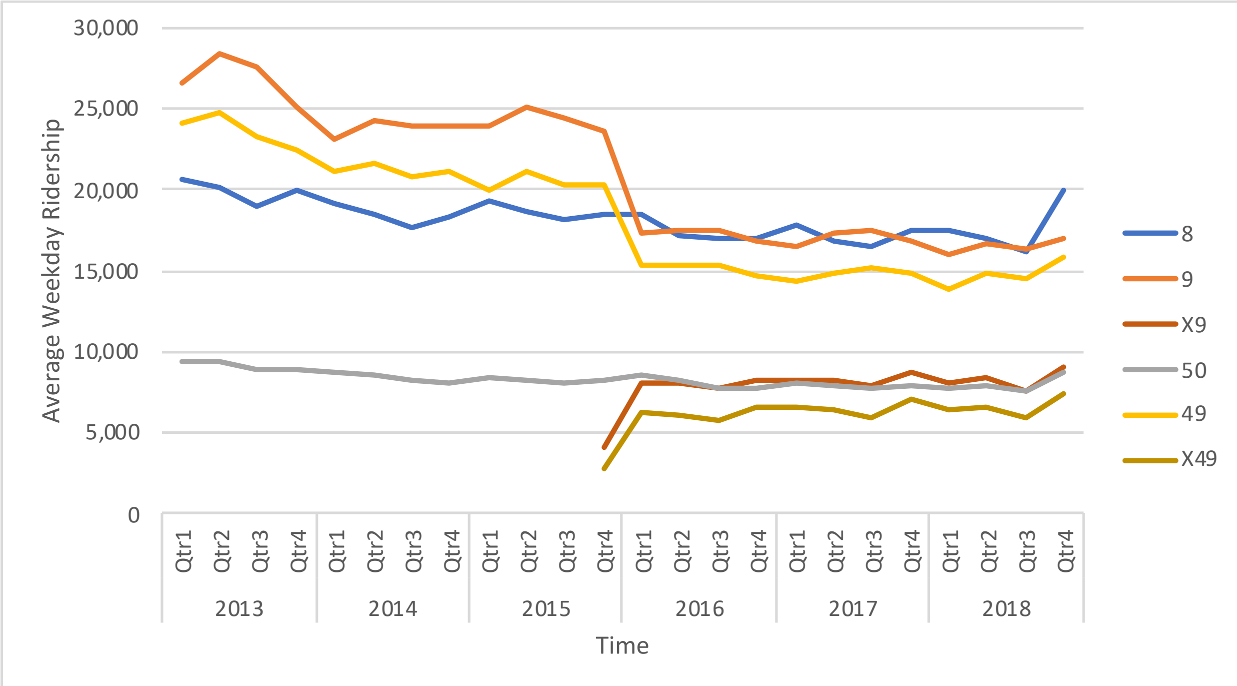

Figure 14 Average Weekday Ridership by Route

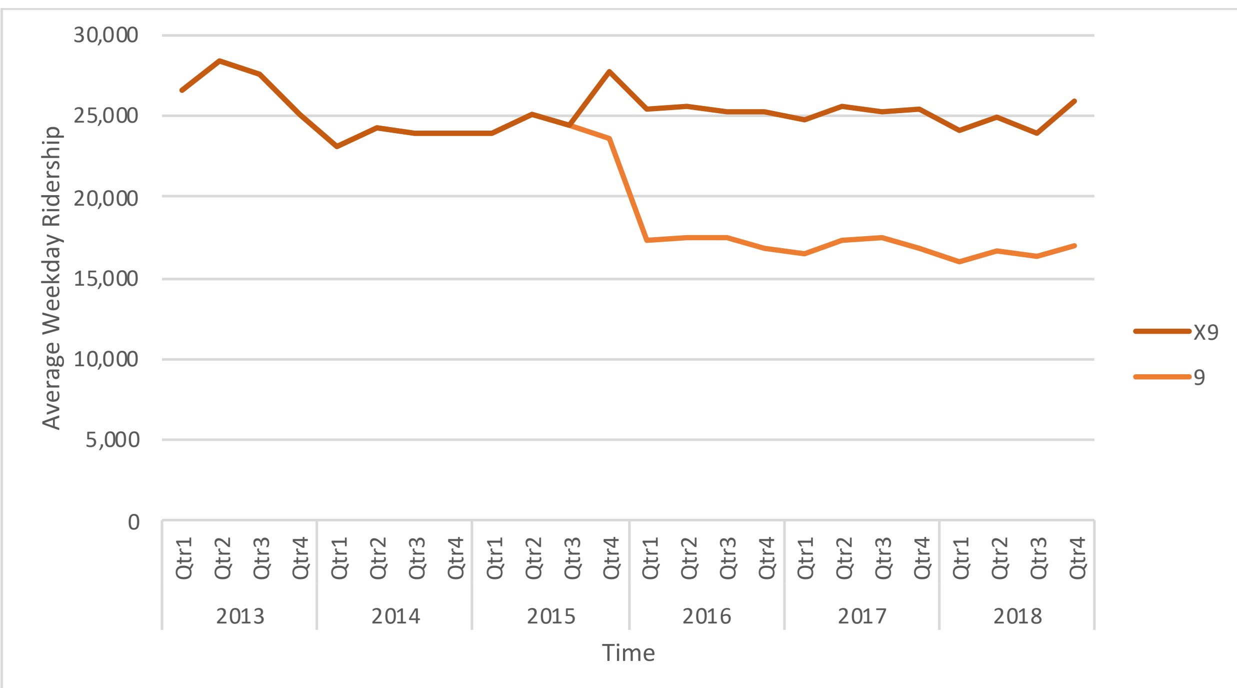

Figure 15 Cumulative Average Weekday Ridership on Ashland Avenue

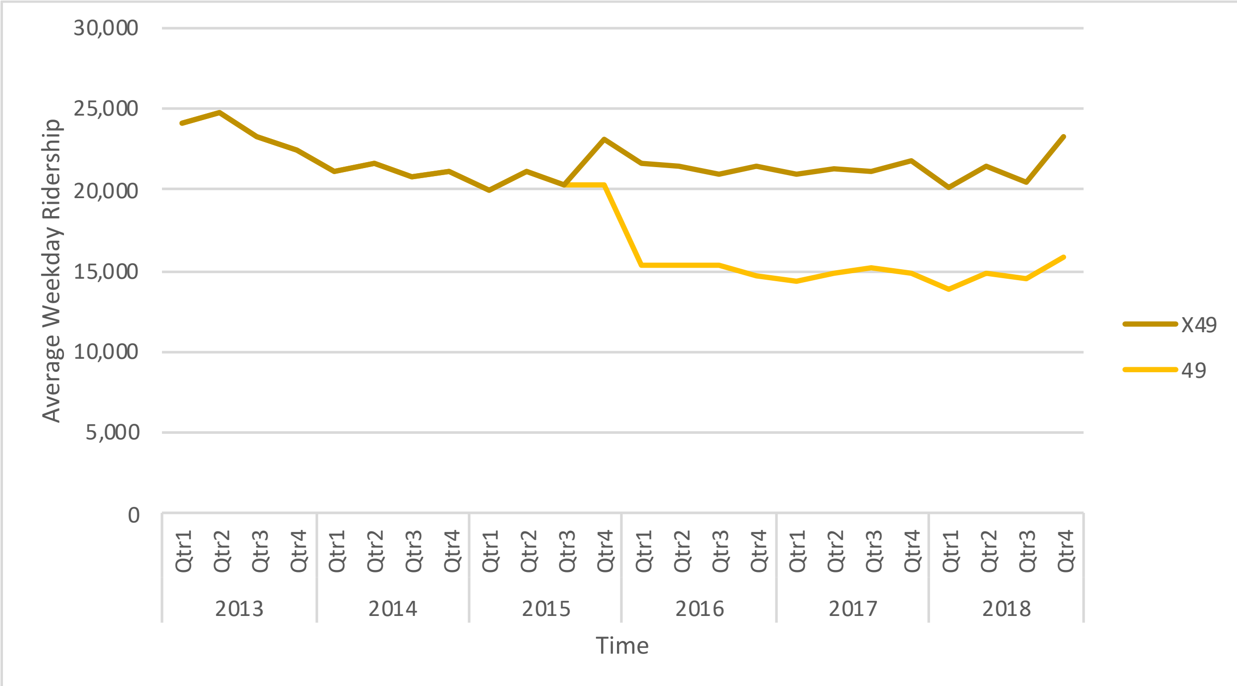

Figure 16 Cumulative Average Weekday Ridership on Western Avenue

5. Discussion

Stop spacing is a major component in public transportation service planning. It can lead to reduced operation costs and allocation of the excessive funds towards service improvements, but at the same time it may lead to longer dwell times and loss of ridership due to the longer walking distance to bus stops. Changing the stop spacing along a route requires acknowledgement of the social impacts and strong arguments in favor.

An analysis of parallel corridors in Chicago showed that the consolidation of bus stops improved travel times without decreasing ridership. Ashland and Western avenues were also positively affected by the introduction of the express bus routes #X9 and #X49 during peak hours. However, it is not easily recognizable if the consolidation only could improve service, as the two event happened simultaneously. #50 Damen shows the lowest ridership of all, mostly due to the fact that it is located half mile apart from Ashland and Western avenues. However, it may also be partly due to having the shortest stop spacing of all examined routes, which leads to more delays and discomfort for riders.

This paper is an introductory analysis on the issues of stop spacing and its impact on travel times and ridership. There is a lot of room for improvement in the level of detail and the size of the experiment. First, more detailed stop-level data can be used to enhance the accuracy and precision of the data analyzed. Second, more routes can be examined and more route characteristics can be discussed, such as demographics, purpose of travel, and traffic conditions along the selected corridors. Last, a study can be made to define the optimal stop spacing for Chicago, based on the function of the route and the other characteristics, forming an argument in favor of stop consolidation and the social benefits that outweigh the minor discomfort costs.

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