The Bee-Line – Westchester: Analysis of Proposed Route Elimination

NYSAMPO Shared Transit Service Planning and Analytics Initiative

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Executive Summary

The BxM4C is an express bus service run by the Westchester County Bee-Line System between White Plains and Midtown Manhattan. The route has seen continually declining ridership over the last 10 years along with higher-than-average operating costs. This pilot project seeks to determine what impact the removal or truncation of the BxM4C service would have, and how existing service can meet the needs of current ridership.

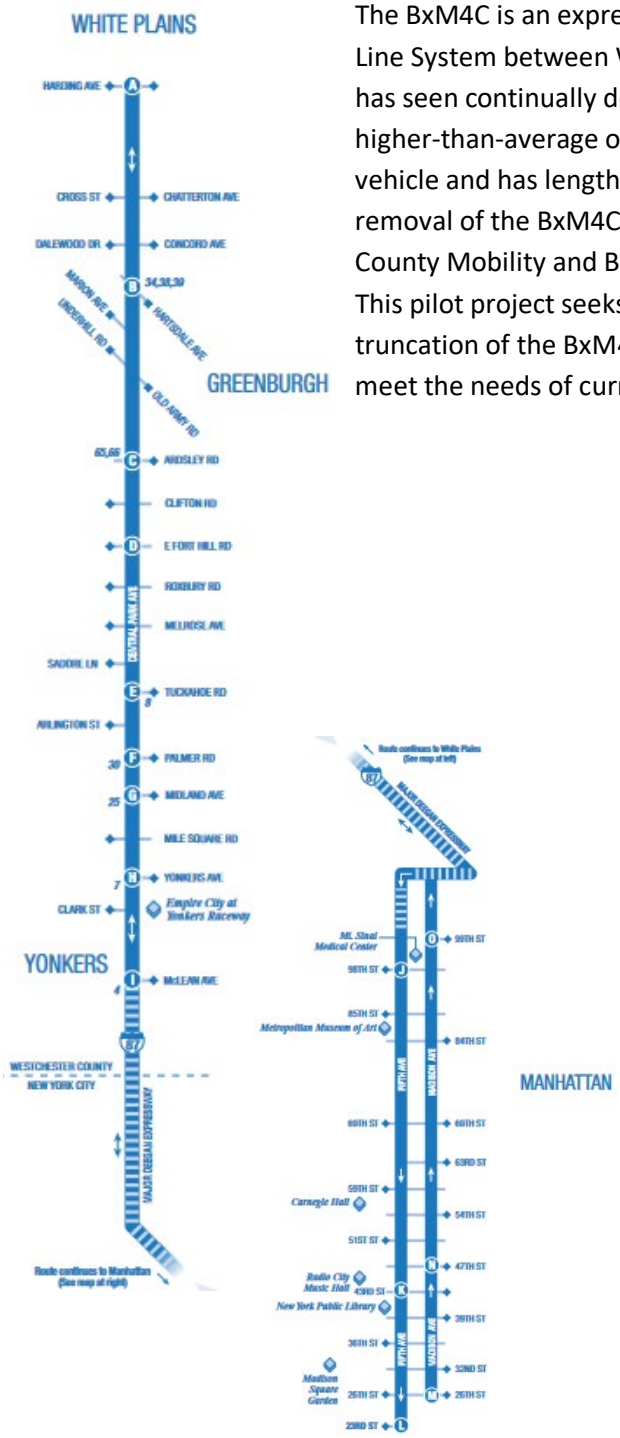
The project design tested the value of the BxM4C using origin-destination (O-D) matrices from a variety of open-source software tools to analyze travel time for BxM4C riders in a variety of service scenarios. The Research Team chose the Conveyal software due to its ability to batch run and export complex and detailed outputs in a useful format for post-processing in Excel. The Research Team compared travel times of BxM4C riders from origins in Westchester County to destinations in Manhattan in scenarios where BxM4C is providing normal service, where BxM4C is removed, and where the service is truncated at various locations in Manhattan.

The Research Team also reviewed boarding and alighting data for the BxM4C. The high boarding data in lower Westchester and the high alighting data along Central Park (stops 2968, 1942, and 1943) strongly suggests that the BxM4C ridership is also the geographic/demographic being most served by the BxM4C.

Based on the outcomes of the analysis, it is determined that removal of the BxM4C would most severely impact the people living in lower Westchester who work in upper Manhattan. Removal of the BxM4C would most severely impact this demographic by increasing inbound travel times by anywhere from 20-50minutes depending on commute start time and route schedule optimization by those riders.

Based on these findings the Research Team recommends conducting a cost/benefit analysis on the cost of truncating the service at 2 potential stop locations – at 1942 at the lower corner of Central Park, and at 1943 near Rockefeller Center. The Research Team also recommends the Conveyal software for further exploration for shared-use in New York State but notes that it would require purchase of support services from either Conveyal or from a third-party to support transit planners in designing analyses and in producing meaningful outcomes.

Problem Statement



The BxM4C is an express bus service run by the Westchester County Bee-Line System between White Plains and Midtown Manhattan[1]. The route has seen continually declining ridership over the last 10 years along with higher-than-average operating costs. The route requires a custom coach vehicle and has lengthy travel times along congested streets. The service removal of the BxM4C has been proposed as part of Westchester County's County Mobility and Bus Redesign Study[2] to optimize network efficiency. This pilot project seeks to determine what impact the removal or truncation of the BxM4C service would have, and how existing service can meet the needs of current ridership.

[1] *Bee-Line Bus Schedules and Maps*. (n.d.). Retrieved December 22, 2022, from https://transportation.westchestergov.com/bee-line-bus/index.php?option=com_content&view=article&id=1176&Itemid=123

[2] *Westchester Mobility*. (n.d.). Westchester. Retrieved December 22, 2022, from https://www.westchestermobility.org

Solution

Design

The project design will test the value of the BxM4C using origin-destination (O-D) matrices to analyze travel time for BxM4C riders in a variety of service scenarios. The Research Team will compare travel time of BxM4C riders from origins in Westchester County to destinations in Manhattan in scenarios where BxM4C is providing normal service, where BxM4C is removed, and where the service is truncated at various locations in Manhattan. The origin and destination locations are all within the greater New York City transit network shed. The Research Team will test all O-D pairs to locate pairs in which travel time is significantly impacted by reduction in service and make recommendations based upon the outcomes.

Selection of Open-Source Software

This pilot was organized and implemented through the NYSAMPO Shared Transit project which tasked the Research Team with testing open-source software for transit network analysis. "Open-source" is a designation for software whose original source code is freely available for users to view, modify, or redistribute. These software are often free to use, modify, and do not contain proprietary components that cannot be accessed.

The Research Team looked for an available open-source solution that could perform travel time matrices. As part of the Shared Transit project, the Research Team conducted a transit software market analysis and identified several potential software solutions that supported travel time matrix functionality. The team formulated a Preliminary Software Assessment through the research of Lahoorpoor et al., *The Transit Travel Time Machine: Comparing Three Different Tools for Travel Time Estimation*[3], and hands-on experience.

Preliminary Software Assessment				
	Conveyal[4]	Open Trip Planner (OTP)[5]	Google API[6]	Esri Network Analyst[7]
Ease of Use	Provides a user interface (UI) that allows for detailed analysis modification.	Simple UI that is easy to use but lacks customization and features.	Simple UI that is easy to use but lacks customization.	Can perform detailed analyses but requires user to be proficient with Esri tools.

[3] Lahoorpoor, B., & Levinson, D. M. (2019). *The Transit Travel Time Machine: Comparing Three Different Tools for Travel Time Estimation* [Working Paper]. https://ses.library.usyd.edu.au/handle/2123/21351

[4] *Conveyal—Evaluate changes to your public transportation system*. (n.d.). Retrieved December 23, 2022, from https://conveyal.com/

[5] *OpenTripPlanner 2*. (n.d.). Retrieved December 23, 2022, from https://docs.opentripplanner.org/en/v2.2.0/

[6] *Google Transit*. (n.d.). Google Developers. Retrieved December 23, 2022, from https://developers.google.com/transit

[7] *ArcGIS Network Analyst | Vehicle Routing Problem & Spatial Network Analysis*. (n.d.). Retrieved December 23, 2022, from https://www.esri.com/en-us/arcgis/products/arcgis-network-analyst/overview

Accessibility	Runs as a webhosted application—easy to access once established.	Runs as a webhosted application—easy to access once established.		An extension of the ArcGIS desktop software.
Potential for Shared Use	One webhosted instance could be a centralized access point for many users (with sufficient server hardware).	One webhosted instance could be a centralized access point for many users.		Analyses and outputs are performed on the user's computer and must be shared manually.

Figure 1 - Preliminary Software Assessment

After evaluating Conveyal, OTP, Google API, and Esri's Network Analyst extension, Conveyal appeared to be the most effective solution. Esri's Network Analyst was a potential solution, but the client did not have access to the software. OTP and Google API would have required custom software code to perform the analysis and to extract and compile the results. Conveyal offered several advantages over the other software evaluated. Its user interface (UI) and output design allows a user to run a single analysis for all origins and destinations at once. Conveyal is also a webhosted instance making it a viable open-source solution for shared use by one or more agencies needing multiple users to access the software concurrently.

origin	destination	percentile	time
1941	1941	5	0
1941	1942	5	11
1941	1943	5	13
1941	1944	5	15

Figure 2 - Conveyal CSV Output

How Conveyal Works

To conduct a Conveyal regional travel time matrix a user must first set up a market area based on Open Street Map and GTFS. Then the user must choose a specific day from within the GTFS time-period and select a time range for the analysis. Finally, the user selects parameters for the travel time matrix regional analysis such as total walk distance, maximum number of transfers, distance from bus-stops, and the number of trips to run. The trips represent the number of synthetic riders that Conveyal will randomly place within the specified distance from the origin and destination locations within the time-period. Synthetic riders are determined to access and egress all types of available transit by walking.

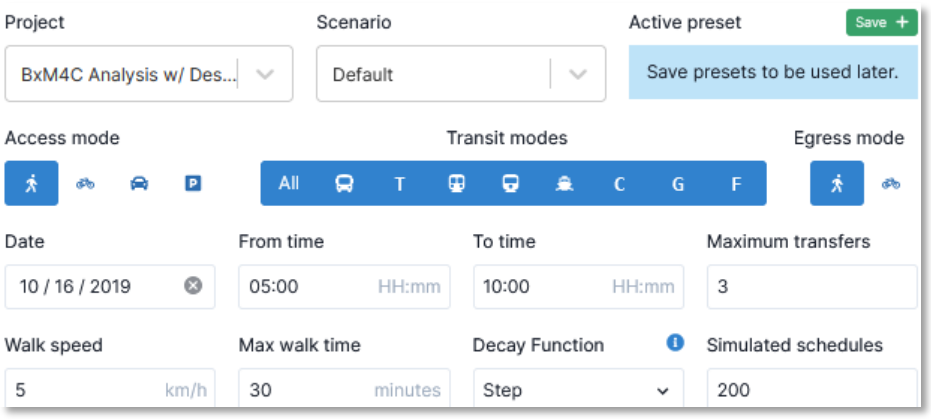


Figure 3 - Conveyal Parameter Menu

The regional travel time matrix analysis then calculates a CSV file with a row for each origin point, destination point, and travel time percentile. In travel time CSV results, a time of -1 indicates the destination is unreachable within the maximum cutoff specified when the regional analysis was created.

Conveyal produces a second type of CSV file that includes path information such as the transit lines, boarding and alighting stops, number of transfers, walk times and Iterations which provides the number of departure minutes in the departure time window at which a given transit/walk path is the most optimal in the system for a given O-D pair.

When a route is removed from service, Conveyal reroutes synthetic riders through the remaining transit network ecosystem to get them to their destination. Since the fastest routing is no longer available, new routes utilizing more transfers are required.

Case Study Methodology

In order to conduct an analysis that identifies the impacts of route removal, a New York City regional transit network ecosystem was developed using Conveyal, OpenStreetMap, Socioeconomic data (ACS and LODES), and multiple General Transit Feed Specification (GTFS) packages. The Research Team added a list of Origins and Destination which included all of the BxM4C stops and a collection of other locations that could be possible Westchester origins and possible high gravity locations in Manhattan and the Bronx. Some of the high gravity locations included points of interest and parking lots along the route that were known to be used informally as park and rides for the BxM4C. The individual stops along the route are less important to riders than the destinations they are trying to reach, which was penalizing the No-BxM4C and truncated service scenarios in the analysis.

After completing this setup, Conveyal was able to generate travel times from origin locations on or near the BxM4C to select destinations within the ecosystem for each scenario. Conveyal's output provided the travel times for each O-D pairing and any transfers that a rider would need to take to get from destinations within Westchester County to Manhattan.

origin	destination	percentile	bxm time	no bxm4c	difference
1941	1941	5	0	0	0
1941	1942	5	8	11	3
1941	1943	5	10	13	3
1941	1944	5	12	15	3

Figure 4 - Combined Conveyal Outputs

Outputs were generated for each of the three primary scenarios:

BxM4C In-Service (Existing Conditions)
BxM4C Is Removed from Service
BxM4C Is Truncated
At Stop 3069 - 5TH Avenue and 98TH Street
At Stop 1941 - 5TH Avenue and 85TH Street
At Stop 2968 - 5TH Avenue and 69TH Street
At Stop 1942 - 5TH Avenue and 59TH Street
At Stop 1943 - 5TH Avenue and 51ST Street

Using Microsoft Excel, outputs from Conveyal were post-processed into matrices showing travel times (in minutes) from each origin to each destination. The BxM4C and No-BxM4C scenario matrices were compared to assess the impact the removal of service would have. Each of the truncation matrices were compared to each other to identify optimal locations for service truncation.

Stop ID	1941	2968	1942	1943
1941	0	6	8	10
2968	15	0	4	6
1942	17	10	0	4
1943	20	17	8	0
1944	20	19	13	8
1945	25	23	16	14
1946	25	23	15	17

Figure 5 - Matrix Detail

Origin and destination matrices were manually created in Excel and indexed travel time value from Conveyal into cells corresponding to their respective origin and destination combinations. A red to green color gradient was applied to the cells to show each value relative to the others. The outcome was a series of matrices that could be analyzed independently or compared with each other:

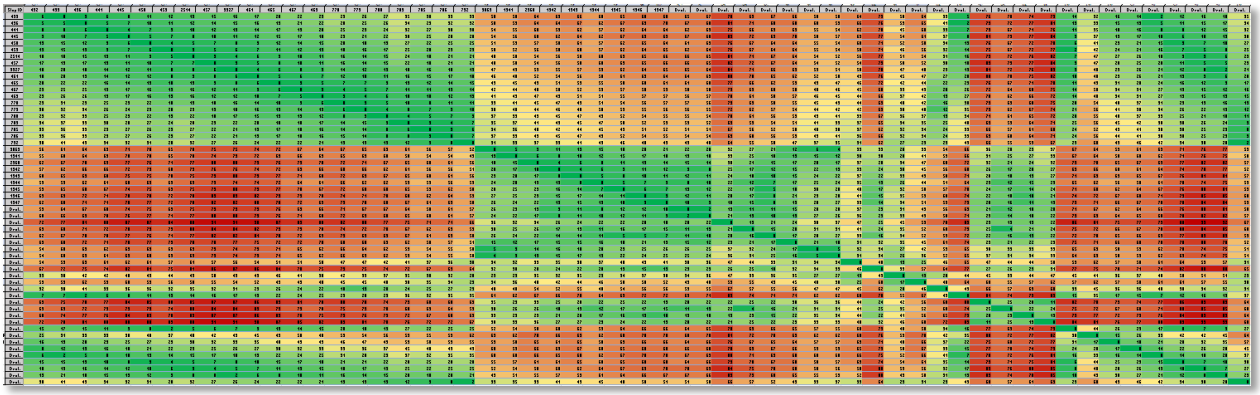


Figure 6 - Full Matrix

BxM4C Ridership Profile

The BxM4C boarding and alighting values indicate that the route is predominantly used as a commuter bus for getting from lower Westchester to upper Manhattan.

Figure 7 shows the distribution of boardings on the Westchester portion of the bus route. 10 riders, an above average amount, board at the first stop—presumably this stop attracts all riders north of it as it is the first on the line. There is a large spike of boardings that occur in the middle of the Westchester portion at stops 461, 467, and 469. The amount of boardings spike again towards the end of the route at stops 783, 785, and the last stop before Manhattan; 792.

Once the bus has collected the majority of its ridership boarding in Westchester, it heads south into Manhattan where the majority of the route's alightings occur. The first Manhattan stop, 3069 at 5th Ave @ 98th St, has the most alightings and then alightings are generally evenly distributed across the subsequent Manhattan stops, but decrease just after stop 1945 at 5th Ave @ 35th St.

Rider behavior indicates that most people board at the middle/lower portions of Westchester and alight at the upper/middle of Manhattan. This ridership profile provided the foundation for constructing truncation scenarios.

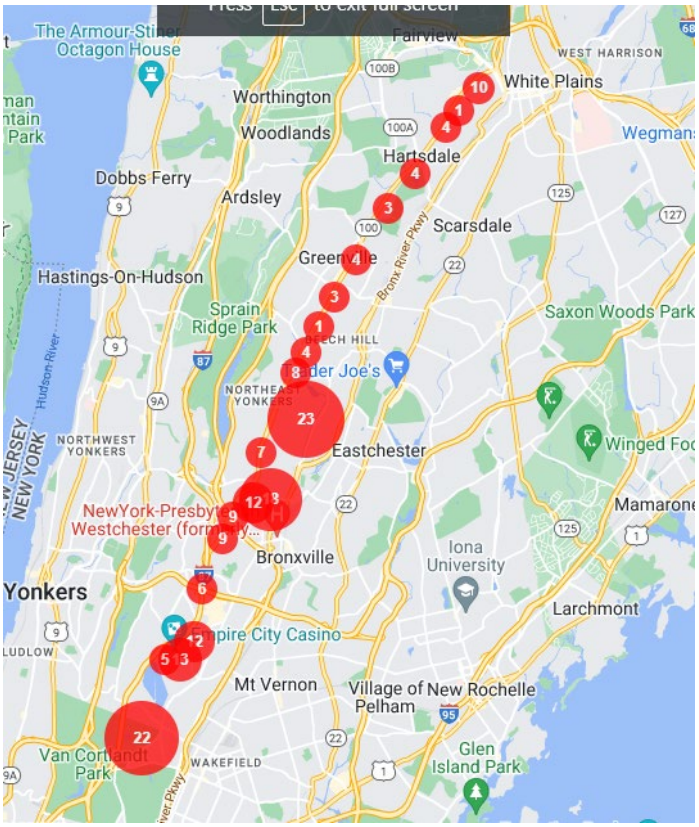


Figure 7 - BxM4C Distribution of Westchester Boardings

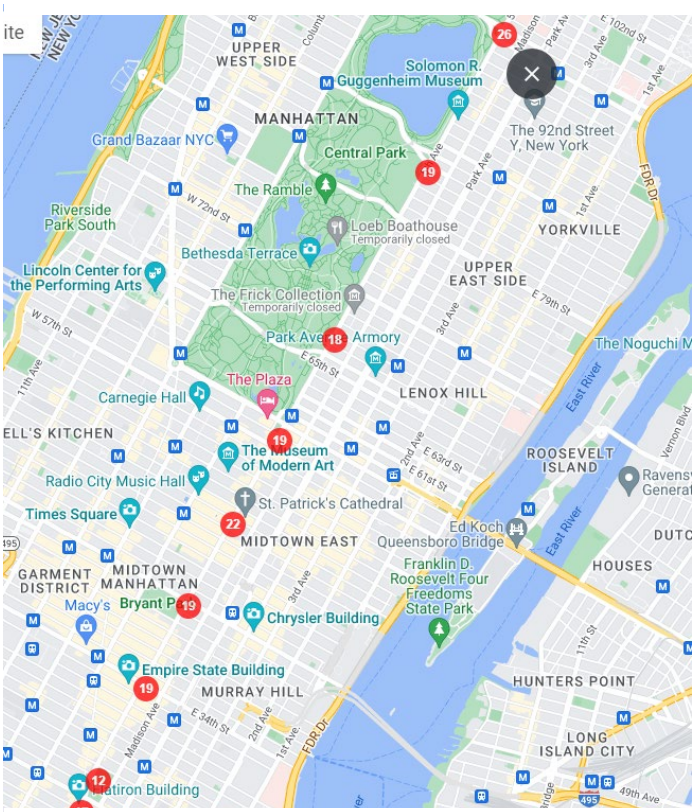


Figure 8 - BxM4C Distribution of Manhattan Alightings

Outcomes

With and Without BxM4C

Figure 9 displays the ten O-D pairs with the largest travel time differences between the current BxM4C service and the elimination of the BxM4C scenarios run in Conveyal (see Appendix X for full list). Comparison of these two scenarios reveals that the largest impact is when leaving Stop 779 (Central Park Ave. @ Palmer Rd.) bound for Stop 2968 (5th Ave. @ 69th St.). Under current service levels, travel time is 44 minutes, which jumps to 68 minutes if the BxM4C is removed—a 24-minute difference. The "Counts W" and "Count W/O" columns display how many different optimal pathways Conveyal sends a rider from an origin to a destination during the timeframe. The "Transfer" related columns calculate how many transfers occur **in total across all counts**. The increase in counts and transfers with the removal of the BxM4C is misleading due to an underlying data issue. When the BxM4C is removed from service, Conveyal reroutes synthetic riders through the transit network ecosystem to get them to their destination. Since the fastest routing is no longer available, new routes utilizing more transfers are required, resulting in the higher count and transfer values.

Origin Stop	Origin Desc	Destination Stop	Destination Desc	Time W	Time W/O	W-W/O Dif Time	Counts W	Counts W/O	Dif Counts	Transfers W	Transfers W/O	Transfers Diff	Avg Transfers W	Avg Transfers W/O	Avg Transfers Dif
779	CENTRAL PARK AVE @ PALMER RD	2968	5TH AVE @ 69TH ST	44	68	24	13	16	3	24	33	9	1.846154	2.0625	0.2163462
457	CENTRAL PARK AV @ JEFFREY PK SOUTH	2968	5TH AVE @ 69TH ST	54	77	23	15	18	3	35	44	9	2.333333	2.4444444	0.1111111
779	CENTRAL PARK AVE @ PALMER RD	3069	5TH AVE @ 98TH ST	38	61	23	10	17	7	18	35	17	1.8	2.0588235	0.2588235
792	CENTRAL PARK AVE @ MCLEAN AVE	3069	5TH AVE @ 98TH ST	31	54	23	11	29	18	24	70	46	2.181818	2.4137931	0.2319749
Grocery Store	Grocery Store near Central/McLean	3069	5TH AVE @ 98TH ST	33	56	23	11	30	19	24	72	48	2.181818	2.4	0.2181818
457	CENTRAL PARK AV @ JEFFREY PK SOUTH	3069	5TH AVE @ 98TH ST	48	70	22	13	20	7	30	49	19	2.307692	2.45	0.1423077
792	CENTRAL PARK AVE @ MCLEAN AVE	2968	5TH AVE @ 69TH ST	37	59	22	12	20	8	24	42	18	2	2.1	0.1
Grocery Store	Grocery Store near Central/McLean	2968	5TH AVE @ 69TH ST	39	61	22	12	22	10	24	46	22	2	2.0909091	0.0909091
778	CENTRAL PARK AVE @ ARLINGTON ST	2968	5TH AVE @ 69TH ST	45	66	21	10	16	6	17	33	16	1.7	2.0625	0.3625
778	CENTRAL PARK AVE @ ARLINGTON ST	3069	5TH AVE @ 98TH ST	39	60	21	8	14	6	13	27	14	1.625	1.9285714	0.3035714

Figure 9 - O-D Pair Difference Table

This matrix subtracts the travel time values of each cell in the No-BxM4C scenario from the corresponding cell in the BxM4C scenario. Like the previous matrices, green is “0” and the highest value is red. Since Conveyal calculates the fastest way to get from an origin to a destination within the entire transit network ecosystem, a value of “0” is displayed in this matrix if there is no time impact due to the removal of BxM4C service or another route could get the rider from their origin to the same destination with no time difference. Origin stops 457-792 traveling to destination stops 3069, 1941, and 2968 form red a rectangle in the matrix indicating that if the BxM4C is completely removed from service, these are the most heavily impacted origin-destination pairs according to the parameters set. Removal of the BxM4C would most severely impact the people in lower Westchester who work in upper Manhattan. The set of stops in upper Manhattan offer a potential range of destinations to be analyzed as service truncation locations.

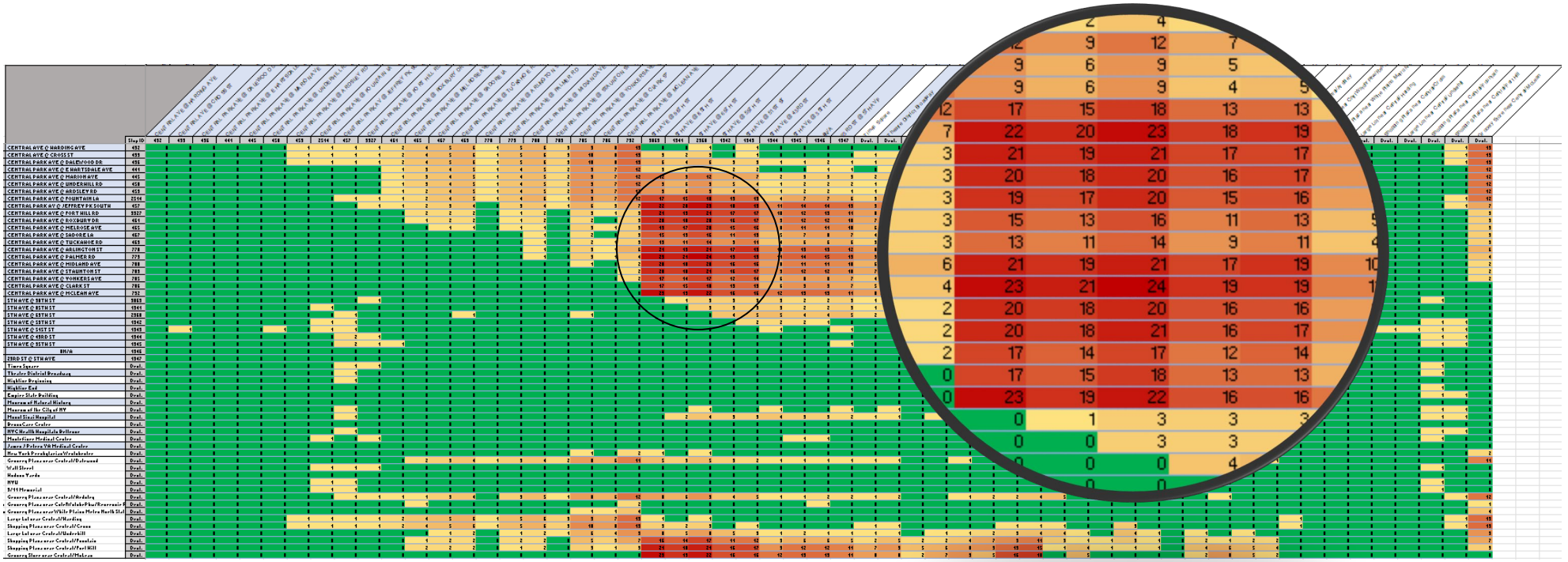


Figure 10 - Difference of Travel Time Between BxM4C and No BxM4C – Southbound, 5th Percentile

Truncation Matrices

This matrix shows the travel time difference in minutes between the BxM4C at current service levels and the BxM4C truncated at stop 3069. The four following matrices compare an additional four truncation scenarios against the current service level (truncation at 1941, 2968, 1942, and 1943, respectively). Combined, these five matrices constitute a sensitivity analysis that allowed the Research Team to identify the stop from which further truncation of the BxM4C resulted in diminishing returns of travel time savings.The shape progression of each truncation matrix tells an impact story. In the first truncation matrix, the route ends at stop 3069. All origins going to this destination have "0" difference in travel time as nothing has changed except that this is the last stop on the truncated BxM4C in this scenario. The stops immediately after are impacted greatly—about 8 minutes extra time to get to 1941, 12 minutes to 2968, and so on.

		AVE	@ CLARK ST	L PARK AVE @ MCLEAN AVE	5TH AVE @ 98TH ST	5TH AVE @ 85TH ST	5TH AVE @ 69TH ST	5TH AVE @ 59TH ST	5TH AVE @ 51ST ST	5TH AVE @ 43RD ST	5TH AVE @ 35TH ST	#N/A	23RD ST @ 5TH AVE	Times Square	Theatre District Broadway	Highline Beginning	Highline End	Empire State Building	Museum
	Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.		
CENTRAL AVE @ HARDING AVE	432	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0		
CENTRAL AVE @ CROSS ST	433	0	1	3	0	1	0	0	0	0	0	0	0	0	0	0	0		
CENTRAL PARK AVE @ DALEWOOD DR	436	0	3	5	2	2	0	1	1	0	0	1	0	0	1	0	0		
CENTRAL PARK AVE @ E HARTSDALE AVE	441	0	2	4	2	2	0	0	1	1	0	1	0	0	1	0	0		
CENTRAL PARK AVE @ MARION AVE	445	0	6	9	6	6	2	3	3	3	2	2	1	2	2	0	0		
CENTRAL PARK AVE @ UNDERHILL RD	450	0	4	7	4	4	1	2	2	2	1	1	0	1	1	0	0		
CENTRAL PARK AVE @ ARDSLEY RD	453	0	5	8	4	5	1	2	2	1	1	1	0	0	1	0	0		
CENTRAL PARK AVE @ FOUNTAIN LA	2514	0	8	12	11	12	4	6	7	6	3	5	1	2	4	0	0		
CENTRAL PARK AV @ JEFFREY PK SOUTH	457	0	8	12	12	13	9	11	11	10	7	8	2	6	8	0	0		
CENTRAL PARK AVE @ FORT HILL RD	3327	0	8	12	12	13	8	10	10	9	6	7	1	5	7	0	0		
CENTRAL PARK AVE @ ROXBURY DR	461	0	8	12	11	13	8	10	10	8	6	7	1	4	7	0	0		
CENTRAL PARK AVE @ MELROSE AVE	465	0	8	12	11	12	7	9	9	8	5	6	1	4	6	0	0		
CENTRAL PARK AVE @ SADORE LA	467	0	8	11	9	10	5	6	7	6	4	4	1	3	4	0	0		
CENTRAL PARK AVE @ TUCKAHOE RD	469	0	7	10	7	9	4	5	5	5	3	3	1	3	3	0	0		
CENTRAL PARK AVE @ ARLINGTON ST	778	0	8	12	12	13	8	10	10	8	6	7	1	5	7	0	0		
CENTRAL PARK AVE @ PALMER RD	779	0	8	12	12	13	10	12	11	10	8	8	1	6	8	0	0		
CENTRAL PARK AVE @ MIDLAND AVE	780	0	8	12	11	12	7	10	10	8	5	6	1	4	6	0	0		
CENTRAL PARK AVE @ STAUNTON ST	783	0	8	12	12	13	8	10	10	9	6	7	1	5	7	0	0		
CENTRAL PARK AVE @ YONKERS AVE	785	0	8	12	10	11	5	7	7	6	4	5	0	3	5	0	0		
CENTRAL PARK AVE @ CLARK ST	786	0	8	12	10	11	5	7	7	6	4	4	1	3	4	0	0		
CENTRAL PARK AVE @ MCLEAN AVE	792	0	8	12	12	13	10	11	11	9	7	6	1	6	7	0	0		
5TH AVE @ 98TH ST	3069	0	1	3	3	3	3	2	2	3	1	1	0	2	1	0	0		
5TH AVE @ 85TH ST	1941	0	0	3	3	3	3	2	2	3	1	2	0	2	1	0	0		
5TH AVE @ 69TH ST	2968	0	0	0	4	5	5	4	4	5	2	2	3	5	2	0	0		
5TH AVE @ 59TH ST	1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0	0		
5TH AVE @ 51ST ST	1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0		
5TH AVE @ 43RD ST	1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
5TH AVE @ 35TH ST	1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0		

Figure 11 - Truncation at Stop 3069 Matrix

The difference values gradually decrease as the BxM4C truncation is extended to stops farther down the line. There is a noticeable reduction of difference when the route is truncated at stop 1942 after which nearly all the remaining stops are only a 4-minute increase in travel time. It is the analysts' interpretation that at this stop, there are sufficient additional transit options available to connect riders with their destinations. The last matrix was constructed showing the BxM4C stopping at 1943. The impact of adding this stop is negligeable—most subsequent stops maintain the 4-minute increase. This marks the point of diminishing returns leading the final interpretation of the analysis as a recommendation that if the BxM4C were selected for truncation, that 1942 being the last stop would cause the least travel time increases.

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
433	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0
436	0	0	5	2	2	0	1	1	0	0	1	0	0	1	0
441	0	0	4	2	2	0	0	1	1	0	1	0	0	1	0
445	0	0	9	6	6	2	3	3	2	2	2	1	2	2	0
450	0	0	7	4	4	1	2	2	2	1	1	0	1	1	0
453	0	0	8	4	5	1	2	2	1	1	1	0	0	1	0
2514	0	0	11	11	12	4	6	7	5	3	5	1	2	4	0
457	0	0	11	12	13	9	11	11	8	6	8	2	5	8	0
3327	0	0	11	11	13	7	10	10	8	5	7	1	4	7	0
461	0	0	11	11	13	7	10	10	7	5	7	1	3	7	0
465	0	0	11	11	12	6	9	8	6	4	6	1	3	6	0
467	0	0	10	9	10	4	6	6	4	3	4	1	2	4	0
469	0	0	9	7	9	3	5	5	4	3	3	1	2	3	0
778	0	0	11	11	13	7	10	9	7	5	7	1	3	7	0
779	0	0	11	12	13	9	12	11	9	7	8	1	5	8	0
780	0	0	11	11	12	7	10	9	7	5	6	1	3	6	0
783	0	0	11	12	13	7	10	10	8	5	7	1	4	7	0
785	0	0	11	10	11	5	7	6	5	3	5	0	2	5	0
786	0	0	11	10	11	4	7	7	6	4	4	1	2	4	0
792	0	0	11	12	13	10	11	11	8	6	6	1	5	7	0
3069	0	0	3	3	3	3	2	2	3	1	1	0	2	1	0
1941	0	0	3	3	3	3	2	2	3	1	2	0	2	1	0
2968	0	0	0	4	5	5	4	4	5	2	2	3	5	2	0
1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Figure 15 - Truncation at Stop 1941 Matrix

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
433	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
436	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
441	0	0	0	0	2	2	0	1	1	0	0	1	0	0	0
445	0	0	0	0	3	1	1	2	1	0	0	0	2	1	0
450	0	0	0	0	3	1	1	1	0	0	0	0	0	0	0
453	0	0	0	0	3	1	1	1	0	0	0	0	0	0	0
2514	0	0	0	0	4	3	3	3	4	0	0	0	2	1	0
457	0	0	0	0	4	5	4	4	4	0	0	1	4	2	0
3327	0	0	0	0	4	4	4	4	4	0	0	0	4	2	0
461	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
465	0	0	0	0	4	3	4	4	4	0	0	0	3	1	0
467	0	0	0	0	4	2	2	3	3	0	0	0	2	1	0
469	0	0	0	0	4	1	2	2	2	0	0	0	2	0	0
778	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
779	0	0	0	0	4	5	4	4	4	0	0	0	4	2	0
780	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
783	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
785	0	0	0	0	4	3	3	3	3	0	0	0	2	2	0
786	0	0	0	0	4	3	3	3	3	0	0	0	2	1	0
792	0	0	0	0	4	5	4	4	4	0	0	0	4	2	0
3069	0	0	0	0	3	3	2	2	3	0	0	0	1	1	0
1941	0	0	0	0	3	3	2	2	3	0	0	0	1	1	0
2968	0	0	0	0	4	5	4	4	4	0	0	2	3	1	0
1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Figure 13 - Truncation at Stop 1942 Matrix

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
436	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
441	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
445	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
453	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2514	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
457	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3327	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
465	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
467	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
469	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
778	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
779	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
783	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
785	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
786	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
792	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3069	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1941	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2968	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 12 - Truncation at Stop 1943 Matrix

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
433	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
436	0	0	0	2	2	0	1	1	0	0	1	0	0	1	0
441	0	0	0	2	2	0	0	1	1	0	1	0	0	1	0
445	0	0	0	5	6	2	3	3	2	2	2	1	2	2	0
450	0	0	0	3	4	1	2	2	2	1	1	0	1	1	0
453	0	0	0	3	5	1	2	2	1	1	1	0	0	1	0
2514	0	0	0	9	12	4	6	7	5	3	5	1	2	4	0
457	0	0	0	9	13	9	11	11	8	6	8	2	5	8	0
3327	0	0	0	9	13	7	10	10	8	5	7	1	4	7	0
461	0	0	0	9	13	7	10	10	7	5	6	1	3	7	0
465	0	0	0	8	12	6	9	8	6	4	6	1	3	6	0
467	0	0	0	7	10	4	6	6	4	3	4	1	2	4	0
469	0	0	0	6	9	3	5	5	4	3	3	1	2	3	0
778	0	0	0	9	13	7	10	9	7	5	7	1	3	7	0
779	0	0	0	9	13	9	12	11	9	7	7	1	5	8	0
780	0	0	0	9	12	7	10	9	7	5	6	1	3	6	0
783	0	0	0	9	13	7	10	10	8	5	6	1	4	7	0
785	0	0	0	8	11	5	7	6	5	3	5	0	2	5	0
786	0	0	0	8	11	4	7	7	6	4	4	1	2	4	0
792	0	0	0	9	13	10	11	11	8	6	6	1	5	7	0
3069	0	0	0	3	3	3	2	2	3	1	1	0	2	1	0
1941	0	0	0	3	3	3	2	2	3	1	2	0	2	1	0
2968	0	0	0	4	5	5	4	4	5	2	2	3	5	2	0
1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Figure 14 - Truncation at Stop 2968 Matrix

Discussion

Limitations

At several points during the pilot project, the Research Team had to narrow the focus of analysis and maximize output efficacy. The first decision was made at the beginning of the pilot that all synthetic trips, both through OTP and Conveyal, were to be restricted to the middle of October of 2019 for three reasons:
Universities and other education facilities are in session marking the likely high point for ridership in a given year.
Seasonal travel and transit trip deviations are minimized. Mid-October has relatively mild weather and does not have major travel-impacting holidays. Traveler behavior is most likely to be typical and fall under predictable patterns.
Travel behavior was changed dramatically with the onset of the COVID-19 pandemic, leaving 2019 to be considered the last "normal" year in the transportation community.

Initially, Conveyal was configured to use the following parameters for output:
Both the AM and PM Peak Times (and South- and Northbound Directionality)
5^{th}, 50^{th}, and 95^{th} Percentiles
90 Minute Cut-Offs

The first several analyses using these parameters produced an unwieldy quantity of data to analyze. Six matrices were produced during the first iteration of post-processing:
Southbound, AM, 5%
Southbound, AM, 50%
Southbound, AM, 95%
Northbound, PM, 5%
Northbound, PM, 50%
Northbound, PM, 95%

The Research Team decided to focus primarily on the Southbound AM portion of the BxM4C, providing the opportunity for deeper analyses. The AM time-period was expanded to encompass 5:00am to 10:00am with the maximum 120-minute cutoff allowed by Conveyal to address concerns that the initial AM time-period selected would be insufficient for the synthetic riders to reach their destinations due to the length and duration of the route.

The Research Team chose to focus on the 5^{th} percentile ridership because of the assumption that it best represents actual ridership behavior. Most of the BxM4C ridership is utilizing the bus as a means to commute to work in the city and therefore it is mostly the case the riders are planning to arrive at the bus stop at the optimal time. The matrices in this report are all 5^{th} percentile results. The 50^{th} percentile

results show a higher differential between the BxM4C truncated service scenarios and normal service. The 95th percentile results show the greatest differentials.

At the conclusion of the project The Research Team received on-time service data that shows cumulative delay of the bus service as it moves from north to south. The bus arrives on average 5-10 minutes later than the GTFS schedule in the Bronx and up to 15 minutes late to the bus stops at the southern end of the service in Midtown Manhattan. Therefore, the Research Team concludes that utilizing the 5th percentile most likely underestimates the impact of removal or truncation of the BxM4C specifically in the areas above stop 1942 where riders have fewer service options.

Lessons Learned

Conveyal Analysis - Travel Parameters Should be All-Encompassing
As noted in the Interpretation section above, initial analyses indicated that some trips were not being accounted for based on overly restrictive time parameters. Time constraints in future similar analyses should be closely aligned with the schedules of the routes being analyzed.

Excel Matrix Processing- Hardware Matters
Origin-Destination matrices generated with the Excel INDEX methodology described in the Technical Analysis section are highly computer processor intensive. Excel's INDEX function scans through all data defined by the user, checks against the user's specified parameters, and then returns the matching value. The initial Conveyal output was a comma separated value (CSV) file with 23,232 entries (88 Origins * 88 Destinations * 3 [5th, 50th, 95th percentiles]). Each cell in the matrix is calculated individually. The CPU used to process the matrices for this project was a higher-end processor that performs, on average, above the 97th percentile of user-benchmarks compared to other processors at the time of this research[8]. With a higher-end processor, full matrix calculations were processed in approximately 13 minutes, while single-direction matrices (i.e., southbound only) were processed in approximately 7 minutes.

Excel Matrix Processing - Duplicate Matrices as "Values Only" Sheets
Due to the long processing times needed to construct the matrices, the team recommends copying a matrix and pasting it as "Values Only" to a new sheet. Doing so removes all the calculations and recreates the matrices using only the values that were indexed to each cell. This eliminates unnecessary processing time that can occur if the user attempts to make any changes to the matrix (e.g., removing unnecessary entries).

[8] *UserBenchmark: AMD Ryzen 7 5800X 100-100000063WOF*. (n.d.). UserBenchmark. Retrieved December 23, 2022, from https://cpu.userbenchmark.com/AMD-Ryzen-7-5800X/Rating/4085

Software Assessment

Open Trip Planner (OTP)

The Research Team began the route removal analysis outlined in the initial pilot project workplan using OTP. Setting up a webhosted instance of OTP required an in-house software engineer using a bundle of regionally relevant GTFS files compiled by the analysts.

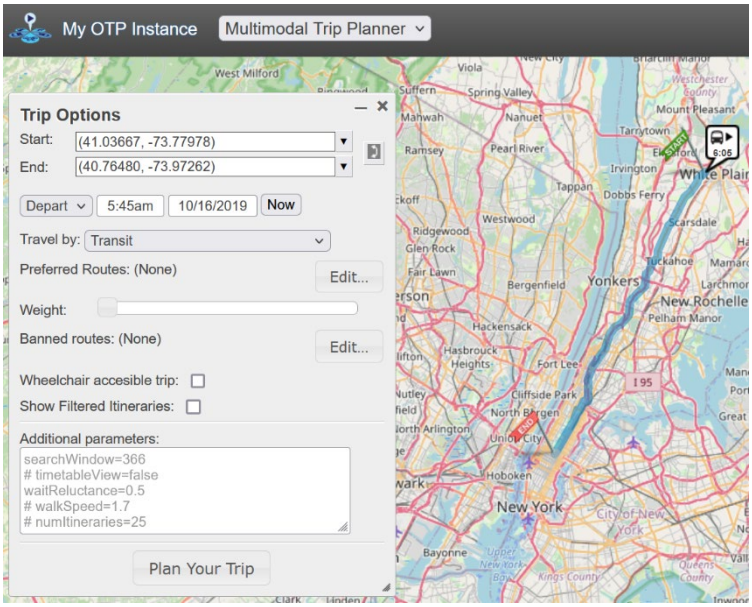


Figure 16 - OTP User Interface

Once the instance was up and running, the user interface was simple and intuitive. The analyst selects the start and end locations with coordinates or by clicking the map. The user sets a simple set of parameters—which can be slightly flexible if the analyst is comfortable coding their own parameters in the proper OTP syntax.

OTP was determined to be insufficient to generate origin and destination matrices efficiently. Itinerary outputs provided the travel time, but only for one origin-destination pair per analysis in the format shown in Figure 15. To generate the matrices required by the work plan, the analyst would need to perform the same analysis for each O-D pair of interest and manually construct an output table. The Research Team instead opted to use an alternate software.

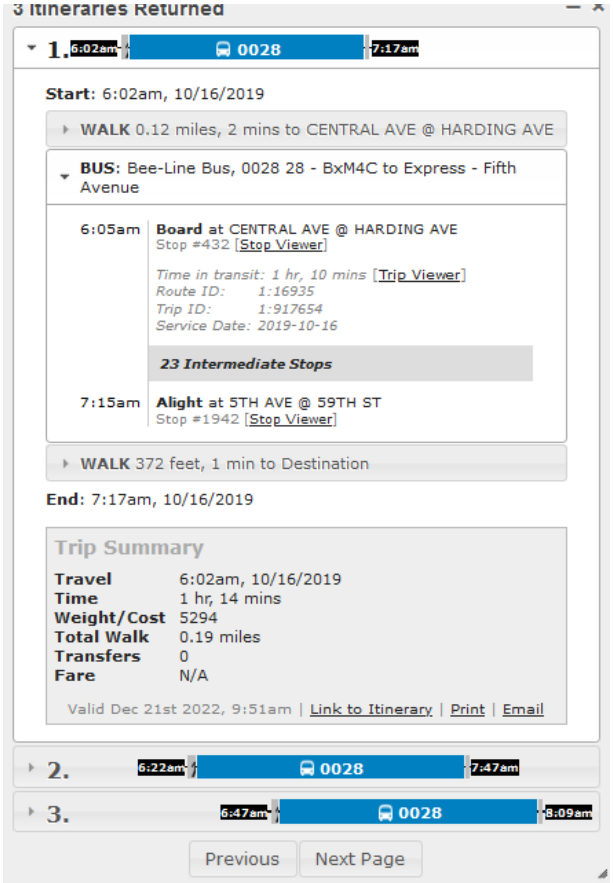


Figure 17 - OTP Output

Conveyal

The first major hurdle with Conveyal was establishing an instance. Setting up an instance of Conveyal required an in-house software engineer to establish the webhosted instance and then guide the Research Team through the process of building a network bundle to create the transit network ecosystem.

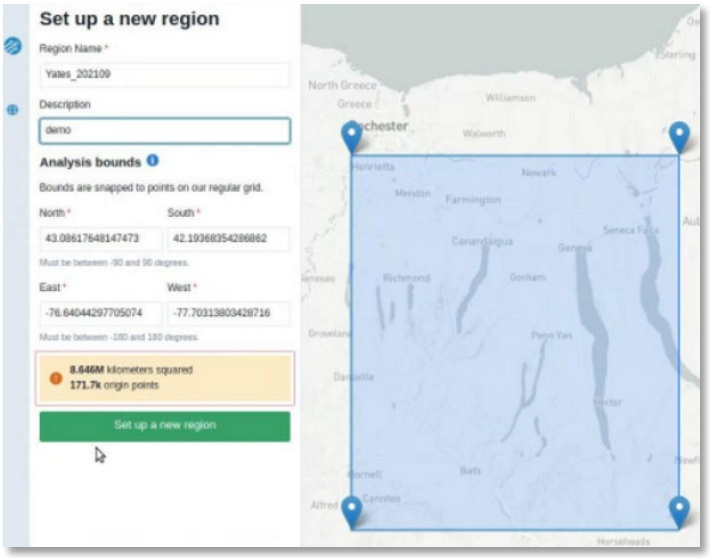


Figure 18 - Conveyal Region Setup

The setup process required the analysts to clone a GitHub repository constructed by the software engineer to their local machine. The repository served as a centralized location to store region bundle dependent files and as the software compiler. The analyst and the software engineer together gathered all the regionally relevant GTFS files and OpenStreetMap data to create the region bundles and save them to the Github repository. The analysts then used the repository to compile and generate the files necessary to set up the transit network ecosystem in the Conveyal user interface. All this setup is highly technical and would likely require software support for transit agency and MPO staff to complete.

Once the ecosystem was finished, the Research Team had to review and modify the list of stop locations desired in the analysis. This list can be found in the appendix under the title, "**Full List of Origins and Destinations Selected for Analyses**". After all components were established, the first analyses could be run.

Based on the analysts' initial interactions with the Conveyal user interface, the Research Team determined that the software was not necessarily intuitive. After progressive and repetitive usage, the "Analyze" pane where parameters are set became more approachable but navigating a workflow remained unintuitive.

Conveyal's value is in the software's flexibility in designing analyses. The parameter interface allows the user to customize many major parameters a transit analyst would expect to be present.

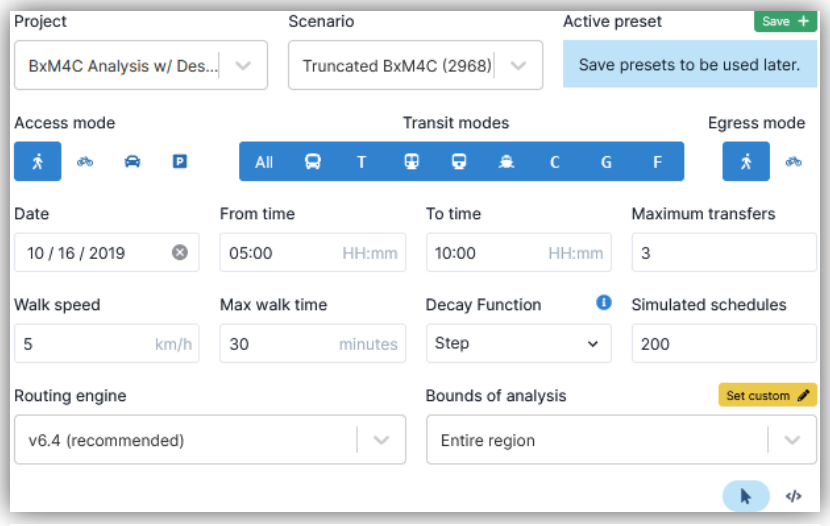


Figure 19 - Conveyal Parameters Menu

Additionally, the software supports a custom analysis request through an integrated configuration component accessible by clicking the "</>" button in the bottom right of the parameters interface. This custom analysis configuration request JSON editor allows the analyst to enter and define additional supported variables providing the analyst with deeper customization options and flexibility.

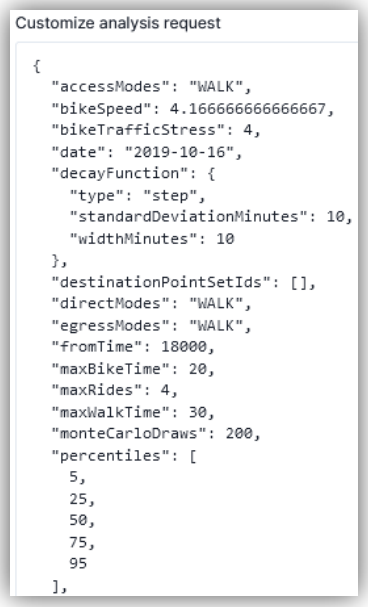


Figure 20 - Conveyal JSON Editor

Replicability

Conveyal's back-end setup and configuring required a collaborative effort between the software developer and analysts—a resource intensive process. Post-processing the output data required a robust technological environment, both hardware and expertise. Subsequently, replicating this project would require third party.

Recommendations

The high boarding data in lower Westchester and the high alighting data along Central Park (stops 2968, 1942, and 1943) strongly suggests that the BxM4C ridership is also the geographic/demographic being most served by the BxM4C. Based on the outcomes of the analysis, it is determined that removal of the BxM4C would most severely impact the people living in lower Westchester who work in upper/middle Manhattan. Removal of the BxM4C would most severely impact this demographic by increasing inbound travel times by anywhere from 20-50minutes depending on commute start time and route schedule optimization by those riders.

Based on these findings the Research Team recommends conducting a cost/benefit analysis on the cost of truncating the service at 2 potential stop locations – at 1942 at the lower corner of Central Park, and at 1943 near Rockefeller Center.

The Research Team also recommends the Conveyal software for further exploration for shared use in New York State but notes that it would require purchase of support services from either Conveyal or from a third-party to support transit planners in designing analyses and in producing meaningful outcomes.

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Appendix A: Technical Analysis

Initially, the workplan proposed the following:

"The Research Team will be using TBEST, Open Trip Planner, and/or ESRI Network Analyst to review the local bus service versus the current express route. Using travel times, comparisons will be made to the Metro North Station. Additionally, overall travel time to New York City with and without the express bus service will be compared."

The Research Team began conducting this pilot using the outlined methodology, but quickly deviated for a few reasons. Primarily, the Conveyal software had yet to be selected for assessment in any of the pilot studies and could provide an appropriate test environment for this analysis. Additionally, the Conveyal software's support for this discrete analysis was determined to be more efficient than utilizing up to three other software tools.

A transit network ecosystem was established in the back end to set up an instance of Conveyal, which is addressed in detail in the "Software Assessment" section. Establishing a "transit network ecosystem" involves selecting and formatting all GTFS files that the software will attempt to transport a synthetic rider on. The following GTFS systems were packaged together to create the ecosystem:

MTA New York City Transit
Long Island Railroad
Metro-North Railroad
MTA Bus Company
Suffolk County Transit
Bee-Line Bus
***Note**: Nassau County GTFS was initially included in the package but was removed due to a processing conflict.*

Next, the software required a list of locations formatted as a CSV file with three columns: stop_id (name of the location), stop_lat (location latitude), and stop_lon (location longitude). During the preliminary stages of the pilot project, the list of locations consisted solely of stops along the BxM4C, but as the project progressed, it was revised several times. A full list of the origins and destinations can be found in the appendix.

	A	B	C
1	stop_id	stop_lat	stop_lon
2	1941	40.78059	-73.9612
3	1942	40.76435	-73.9735
4	1943	40.75927	-73.9772
5	1944	40.75398	-73.9806
6	1945	40.7496	-73.9843
7	1946	40.74334	-73.9884
8	1947	40.74128	-73.9891

Figure 21 - O-D CSV

After the transit network ecosystem is established and the final list of relevant locations is selected, parameters need to be defined to determine the behavior and priorities.

The Conveyal software provides a user interface for defining parameters. This image depicts the final selection of parameters that were modeled.

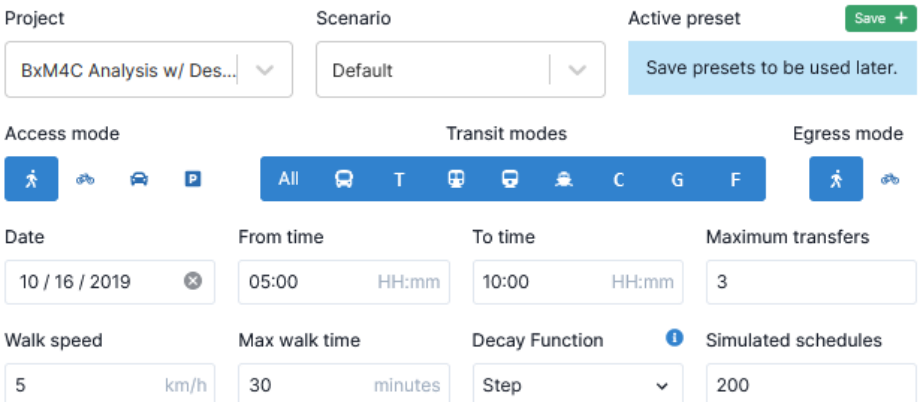

Figure 22 - Conveyal Parameter Menu

Synthetic riders were determined to access and egress all types of available transit by walking. Two-hundred simulated schedules were generated to take place between 5:00am and 10:00am. Synthetic riders were defined as having a walk speed of 5 km/h and only willing to walk for 30 minutes and make 3 transfers at most.

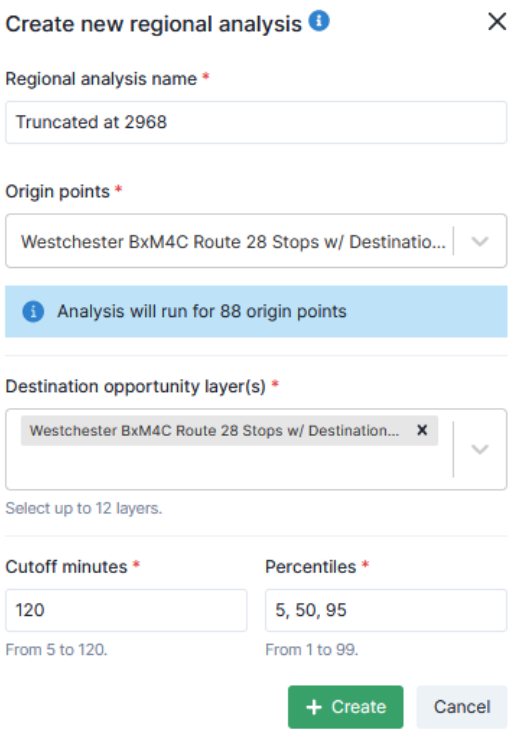

Figure 23 - Conveyal Regional Analysis Menu

The final set of parameters are defined when the analysis is converted into a regional analysis. At this phase, the analyst defined both the origin and destination points as the same set of points. The intent was to create a matrix assessing travel time from each origin point to each destination point. Cutoff Minutes, or the total duration that a synthetic trip could take before being determined invalid, was set to 120 minutes.

Finally, the percentiles Conveyal was to output were determined. If all the travel times from every trip possible within all other parameters were mapped on a bar graph, the graph would have a normal distribution. The 5th percentile indicates the travel times under the top 5% performing circumstances (i.e., as though a synthetic rider arrived at the bus stop just as the bus was arriving at the stop). The 50th percentile shows the average circumstances. Finally, the 95th percentile shows the worst-case scenario—the synthetic rider sees the bus they intended to catch drive away as they arrive at the stop and now must wait for the next bus.

Using the outlined parameters, outputs were generated for both existing conditions and a scenario in which the BxM4C was completely removed from service. Additionally, Conveyal supports the use of scenario modifications that allow the user to adjust a transit system and perform analyses on the adjusted scenario. The screenshot below depicts the "Remove Stops" modification in which all the red-highlighted stops were removed from the line.

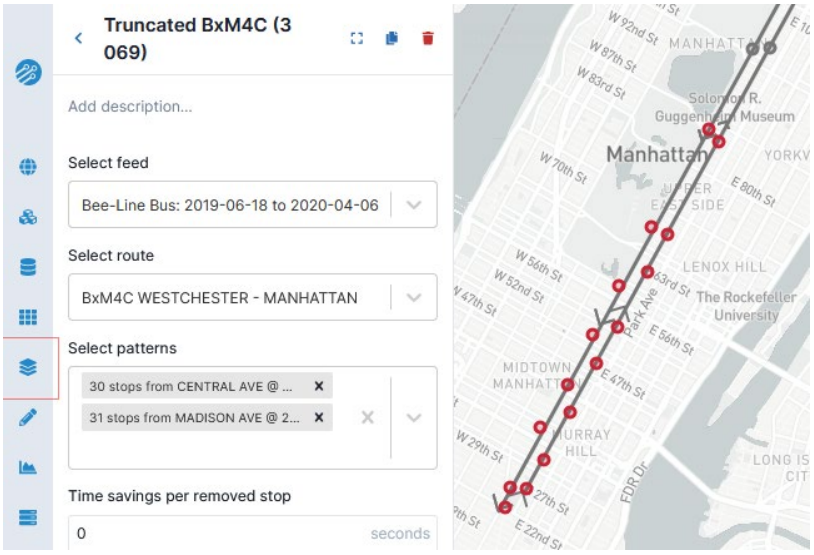

Figure 24 - Conveyal Scenario Modification Menu

The Research Team performed multiple variations of this modification, each truncating the BxM4C at different stops. After each modification, the network analysis was run, the travel time CSV output was downloaded, and the data was converted into one or more matrices following the indexing process outlined further in this section. The following stops were selected for truncation analyses:

3069 - 5TH AVE @ 98TH ST
1941 - 5TH AVE @ 85TH ST
2968 - 5TH AVE @ 69TH ST
1942 - 5TH AVE @ 59TH ST
1943 - 5TH AVE @ 51ST ST

Conveyal provides five potential outputs from an analysis: GeoTIFF, Scenario and Modification JSON, Paths CSV, Times CSV, Access CSV. The majority of our analyses utilized Times CSV outputs like the example below:

origin	destination	percentile	time
1941	1942	5	11
1941	1943	5	13
1941	1944	5	15
1941	1945	5	17
1941	1946	5	19

Figure 25 - Conveyal CSV Output

These spreadsheets depict the travel time from an origin to a destination for the selected percentile. The first row indicates that if a rider is within the 5th percentile of trip travel time, then going from stop

1941 to 1942 will be 11 minutes. The multiple scenarios and modifications outlined in the Analysis Design section were exported, combined, and compared to each other:

origin	destination	percentile	BxM4C time	no BxM4C	difference	diff values
1941	1942	5	8	11	3	3
1941	1943	5	10	13	3	3
1941	1944	5	12	15	3	3
1941	1945	5	15	17	2	2

Figure 26 - Conveyal CSV Outputs Combined

The first row in this comparison indicates that, in the fifth percentile, it takes 8 minutes to travel from stop 1941 to 1942 with the BxM4C and 11 minutes if the route were removed from service. This results in an increase of 3 minutes of travel time as shown in the "difference" column. ***Note**: Since the contents of the "diff" column were calculated using an Excel equation (=[@[no bxm4c]]-[@[bxm time]]), they could not be indexed correctly into the matrices—so they were duplicated as "values only" into a new column—"diff values".*

The final outputs of the team's analyses were a series of matrices. These matrices were initially constructed manually, but as it became an iterative process, a formula was developed so the analyst could make use of a matrix template with the equations. The equation uses the 'INDEX' function to copy information from the Conveyal output and the 'MATCH' function to identify which information to index. The colors in the full equation shown below are coordinated with their respective cells in the table screenshot below.

=INDEX('Conveyal Output'!$D:$D, MATCH(1, ('SB, 5% 5-10AM, TT BxM4C'!D$1='Conveyal Output'!$B:$B)*('SB, 5% 5-10AM, TT BxM4C'!$A4='Conveyal Output'!$A:$A)('SB, 5% 5-10AM, TT BxM4C'!A1='Conveyal Output'!$C:$C),0)*

Each time travel cell in the matrix contains the equation above that matches the associated origin (light orange), destination (blue), and percentile (purple) with the corresponding columns on the Conveyal output CSV. The green highlighted cell can be dragged across the spreadsheet to duplicate the equation for each destination, then the entire row is highlighted and dragged down to perform the index/match with all origin/destination pairs on the sheet. This method was faster and easier than manually creating the matrices but still requires a substantial amount of uninterrupted processing time—approximately 7 to 13 minutes.

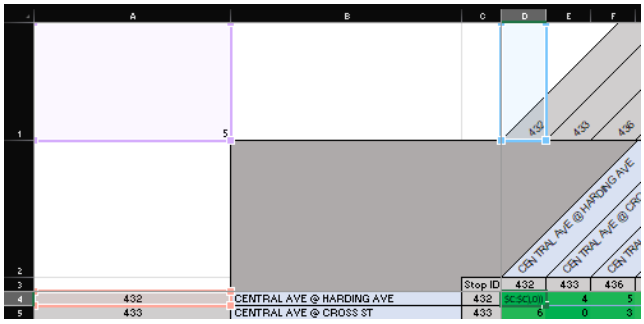

Figure 27 - Matrix Layout

Once the INDEX function has completed processing for all cells, the matrix fills in the values from the output data corresponding with each origin/destination/percentile combination.

To facilitate analysis interpretation, the data was highlighted and "Conditional Formatting" of "Red – Yellow – Green Scale" was selected. This made all 0 travel time valued cells green, the highest travel time value cell red, and then range between scaling yellow to orange from smallest to largest. The result is a color-coded origin-destination matrix showing travel times from each origin to each destination under the analyses' conditions.

Stop ID	432	433	436	441
432	0	4	5	8
433	6	0	3	6
436	5	5	0	5
441	8	8	6	0
445	9	10	7	5
450	13	15	12	9
453	13	15	13	9
2514	18	18	15	13
457	17	19	17	13
3327	18	20	18	14
461	18	20	19	14

Figure 28 - Matrix Conditional Formatting

For the first scenario, 9 total matrices were constructed—the 5th, 50th, and 95th percentile each had a matrix with three versions: All Stops, Northbound Stops Only, and Southbound Stops Only. During analysis interpretation, the Research Team agreed to concentrate their efforts to focus on Southbound Stops Only at the 5th percentile.

Travel Time – Southbound, 5th Percentile, BxM4C (Existing Conditions)

This matrix shows the travel time from and to all southbound stops and destinations for the 5th percentile with the BxM4C as it is. Conveyal calculates the fastest way to get from an origin to a destination within the entire transit network ecosystem. The "Stop ID" column and row are both listed in route beginning-to-end sequential order. The darkest green values are "0" travel time (i.e., same origin as destination). A diagonal line of these non-travel values can be seen through the spreadsheet. Since this portion of the route is one-directional and linear, a rider cannot arrive at a destination before their origin. Subsequently, all values below the "0" line can be disregarded. All values are colored on a gradient scale of green to red indicating lowest to highest travel times.

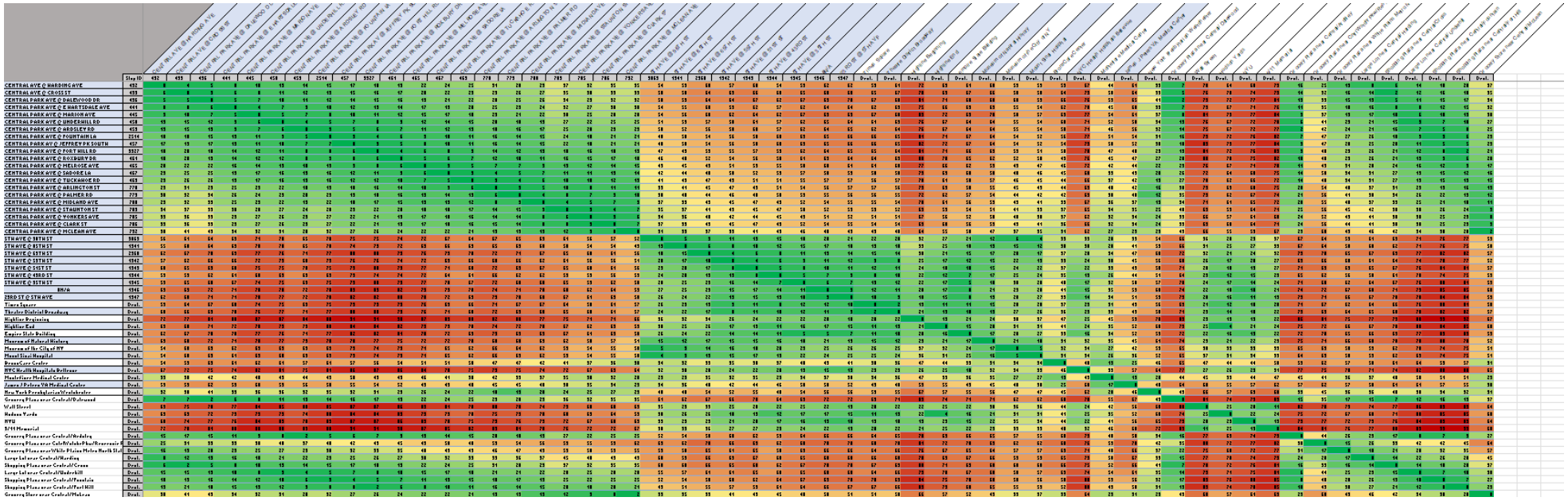

Figure 29 - Travel Time – Southbound, 5th Percentile, BxM4C (Existing Conditions)

Travel Time – Southbound, 5th Percentile, No BxM4C

This matrix shows the travel time from and to all southbound stops and destinations for the 5th percentile if the BxM4C were completely removed from service. At a glance, these two matrices are very similar, so a new type of matrix was constructed to highlight the differences in the scenarios (next page).

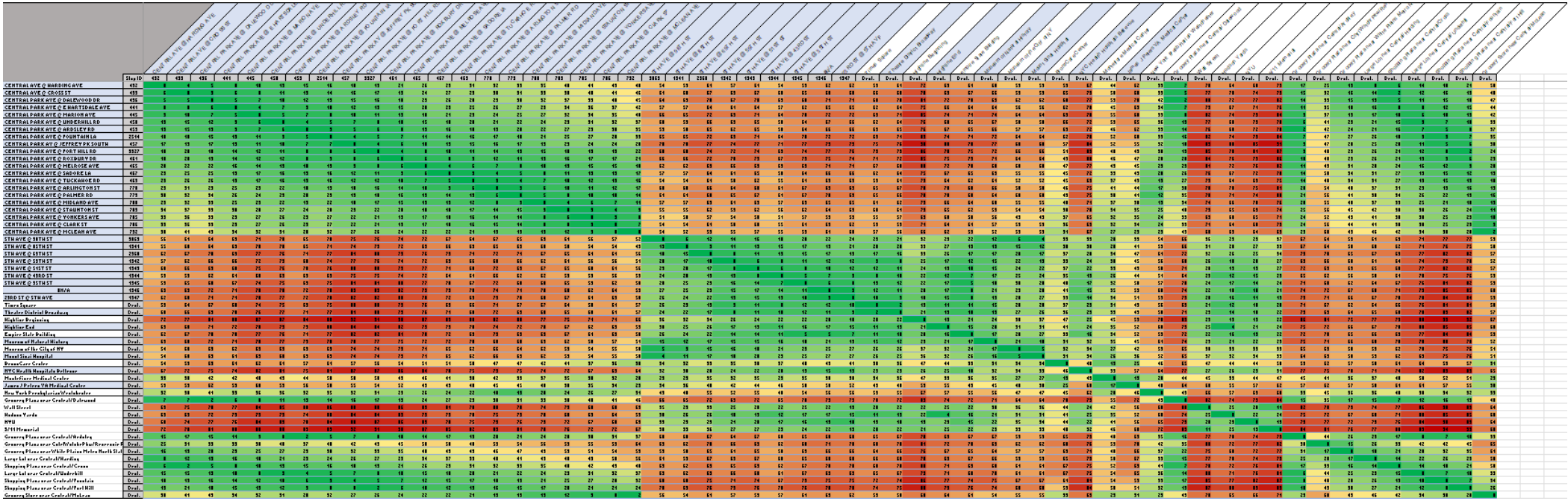

Figure 30 - Travel Time – Southbound, 5th Percentile, No BxM4C

Difference of Travel Time Between BxM4C and No BxM4C – Southbound, 5th Percentile

Generating the difference matrix used an excel formula where the travel time value of the "BxM4C" scenario matrix cell was subtracted from the same cell location on the "No BxM4C" scenario matrix (*='SB, 5% 5-10AM, TT NoBxM4C'!D4-'SB, 5% 5-10AM, TT BxM4C'!D4*). Like the previous matrices, green is "0" and the highest value is red. Since Conveyal calculates the fastest way to get from an origin to a destination within the entire transit network ecosystem, if the BxM4C is removed and there is no impact or another route could get the rider from their origin to the same destination with no time difference, then the time travel value will be a "0" in this matrix. Within this difference matrix, a very clear problem area emerges: Origin stops 457-792 traveling to destination stops 3069, 1941, and 2968.

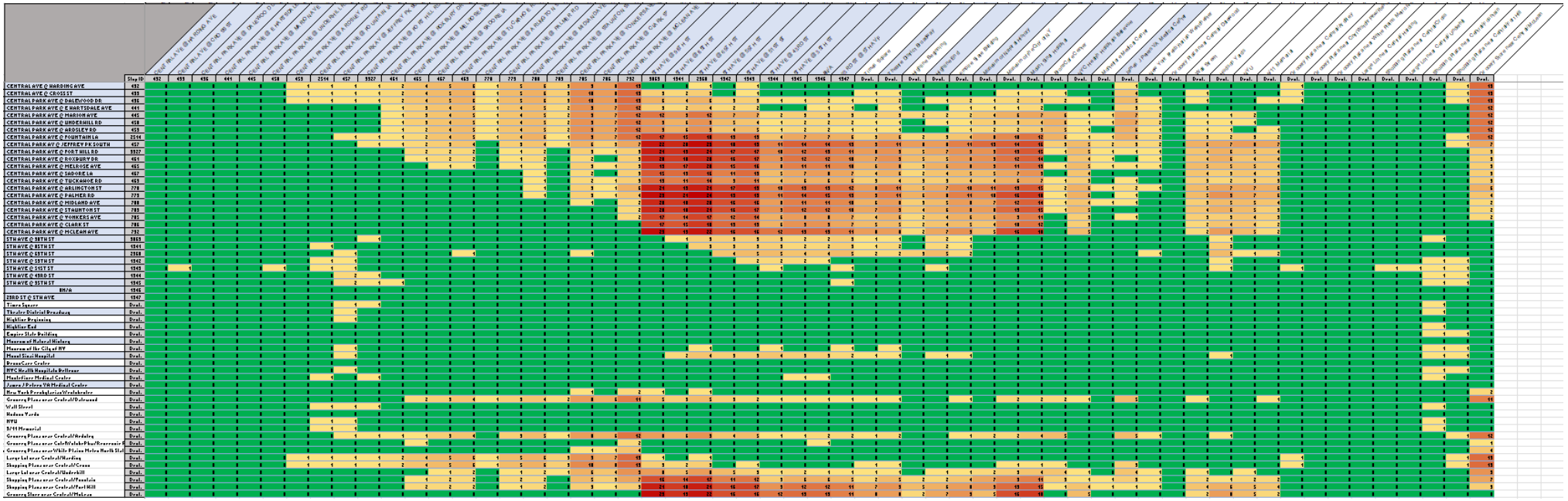

Figure 31 - Difference of Travel Time Between BxM4C and No BxM4C – Southbound, 5th Percentile

O-D Pair Difference Table

Using two outputs from Conveyal, the TIMES and PATHS .CSV files, the Research Team constructed a table (using the same INDEX/MATCH methodology as in the matrices) to sort and compare BxM4C to No-BxM4C outputs. The "Counts" related columns detail how many different pathways a rider could take to make it from that origin to that destination. Count values were generated with the equation "=COUNTIFS('Paths Output BxM4C (Values)'!$A:$A,A2,'Paths Output BxM4C (Values)'!$B:$B,B2)", with A2 being the origin and B2 being the destination. The equation scans through the PATHS .CSV output file and returns the number of times that the specified O-D pair is found together. The "Transfer" related columns calculate how many transfers occur in **total across all counts**. Calculating number of transfers requires a new column in the PATHS output with the equation "=LEN([@routes])-LEN(SUBSTITUTE([@routes],"|",""))". Since Conveyal distinguishes when a transfer occurs using the "|" symbol, this equation counts the occurrences of that symbol within the "routes" column and returns a numerical value of the times that the symbol appeared. Then, in the O-D Difference Table, the Transfers column uses "=SUMIFS(Table7[Number of Transfers], Table7[origin], [@origin],Table7[destination], [@destination])" to search the PATHS file for the O-D combination and then sum together all values returned by the former equation (aggregating the transfers for all counts).

Origin Stop	Origin Desc	Destination Stop	Destination Desc	Time W	Time W/O	W-W/O Dif Time	Counts W	Counts W/O	Dif Counts	Transfers W	Transfers W/O	Transfers Diff	Avg Transfers W	Avg Transfers W/O	Avg Transfers Dif
779	CENTRAL PARK AVE @ PALMER RD	2968	5TH AVE @ 69TH ST	44	68	24	13	16	3	24	33	9	1.846154	2.0625	0.2163462
457	CENTRAL PARK AV @ JEFFREY PK SOUTH	2968	5TH AVE @ 69TH ST	54	77	23	15	18	3	35	44	9	2.333333	2.4444444	0.1111111
779	CENTRAL PARK AVE @ PALMER RD	3069	5TH AVE @ 98TH ST	38	61	23	10	17	7	18	35	17	1.8	2.0588235	0.2588235
792	CENTRAL PARK AVE @ MCLEAN AVE	3069	5TH AVE @ 98TH ST	31	54	23	11	29	18	24	70	46	2.181818	2.4137931	0.2319749
Grocery Store	Grocery Store near Central/McLean	3069	5TH AVE @ 98TH ST	33	56	23	11	30	19	24	72	48	2.181818	2.4	0.2181818
457	CENTRAL PARK AV @ JEFFREY PK SOUTH	3069	5TH AVE @ 98TH ST	48	70	22	13	20	7	30	49	19	2.307692	2.45	0.1423077
792	CENTRAL PARK AVE @ MCLEAN AVE	2968	5TH AVE @ 69TH ST	37	59	22	12	20	8	24	42	18	2	2.1	0.1
Grocery Store	Grocery Store near Central/McLean	2968	5TH AVE @ 69TH ST	39	61	22	12	22	10	24	46	22	2	2.0909091	0.0909091
778	CENTRAL PARK AVE @ ARLINGTON ST	2968	5TH AVE @ 69TH ST	45	66	21	10	16	6	17	33	16	1.7	2.0625	0.3625
778	CENTRAL PARK AVE @ ARLINGTON ST	3069	5TH AVE @ 98TH ST	39	60	21	8	14	6	13	27	14	1.625	1.9285714	0.3035714

Figure 32 - O-D Pair Difference Table

Truncation Matrices

This matrix shows the difference of travel times in minutes between two scenarios; one where BxM4C is the full route and one where the route is truncated at stop 3069. The next page contains four other matrices comparing different truncation scenarios to the full route (truncation at 1941, 2968, 1942, and 1943). These five matrices combined constitute a sensitivity analysis that allowed the Research Team to identify at which stop truncating the BxM4C will result in diminishing returns of travel time savings.

		@ CLARK ST	L PARK AVE @ MCLEAN AVE	5TH AVE @ 98TH ST	5TH AVE @ 85TH ST	5TH AVE @ 69TH ST	5TH AVE @ 59TH ST	5TH AVE @ 51ST ST	5TH AVE @ 43RD ST	5TH AVE @ 35TH ST	#N/A	23RD ST @ 5TH AVE	Times Square	Theatre District Broadway	Highline Beginning	Highline End	Empire State Building	Museum
	Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.	
CENTRAL AVE @ HARDING AVE	432	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	
CENTRAL AVE @ CROSS ST	433	0	1	3	0	1	0	0	0	0	0	0	0	0	0	0	0	
CENTRAL PARK AVE @ DALEWOOD DR	436	0	3	5	2	2	0	1	1	0	0	1	0	0	1	0		
CENTRAL PARK AVE @ E HARTSDALE AVE	441	0	2	4	2	2	0	0	1	1	0	1	0	0	1	0		
CENTRAL PARK AVE @ MARION AVE	445	0	6	9	6	6	2	3	3	3	2	2	1	2	2	0		
CENTRAL PARK AVE @ UNDERHILL RD	450	0	4	7	4	4	1	2	2	2	1	1	0	1	1	0		
CENTRAL PARK AVE @ ARDSLEY RD	453	0	5	8	4	5	1	2	2	1	1	1	0	0	1	0		
CENTRAL PARK AVE @ FOUNTAIN LA	2514	0	8	12	11	12	4	6	7	6	3	5	1	2	4	0		
CENTRAL PARK AV @ JEFFREY PK SOUTH	457	0	8	12	12	13	9	11	11	10	7	8	2	6	8	0		
CENTRAL PARK AVE @ FORT HILL RD	3327	0	8	12	12	13	8	10	10	9	6	7	1	5	7	0		
CENTRAL PARK AVE @ ROXBURY DR	461	0	8	12	11	13	8	10	10	8	6	7	1	4	7	0		
CENTRAL PARK AVE @ MELROSE AVE	465	0	8	12	11	12	7	9	9	8	5	6	1	4	6	0		
CENTRAL PARK AVE @ SADORE LA	467	0	8	11	9	10	5	6	7	6	4	4	1	3	4	0		
CENTRAL PARK AVE @ TUCKAHOE RD	469	0	7	10	7	9	4	5	5	5	3	3	1	3	3	0		
CENTRAL PARK AVE @ ARLINGTON ST	778	0	8	12	12	13	8	10	10	8	6	7	1	5	7	0		
CENTRAL PARK AVE @ PALMER RD	779	0	8	12	12	13	10	12	11	10	8	8	1	6	8	0		
CENTRAL PARK AVE @ MIDLAND AVE	780	0	8	12	11	12	7	10	10	8	5	6	1	4	6	0		
CENTRAL PARK AVE @ STAUNTON ST	783	0	8	12	12	13	8	10	10	9	6	7	1	5	7	0		
CENTRAL PARK AVE @ YONKERS AVE	785	0	8	12	10	11	5	7	7	6	4	5	0	3	5	0		
CENTRAL PARK AVE @ CLARK ST	786	0	8	12	10	11	5	7	7	6	4	4	1	3	4	0		
CENTRAL PARK AVE @ MCLEAN AVE	792	0	8	12	12	13	10	11	11	9	7	6	1	6	7	0		
5TH AVE @ 98TH ST	3069	0	1	3	3	3	3	2	2	3	1	1	0	2	1	0		
5TH AVE @ 85TH ST	1941	0	0	3	3	3	3	2	2	3	1	2	0	2	1	0		
5TH AVE @ 69TH ST	2968	0	0	0	4	5	5	4	4	5	2	2	3	5	2	0		
5TH AVE @ 59TH ST	1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0		
5TH AVE @ 51ST ST	1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0		
5TH AVE @ 43RD ST	1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
5TH AVE @ 35TH ST	1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0		

Figure 33 - Truncation at Stop 3069 Matrix

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
433	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0
436	0	0	5	2	2	0	1	1	0	0	1	0	0	1	0
441	0	0	4	2	2	0	0	1	1	0	1	0	0	1	0
445	0	0	9	6	6	2	3	3	2	2	2	1	2	2	0
450	0	0	7	4	4	1	2	2	2	1	1	0	1	1	0
453	0	0	8	4	5	1	2	2	1	1	1	0	0	1	0
2514	0	0	11	11	12	4	6	7	5	3	5	1	2	4	0
457	0	0	11	12	13	9	11	11	8	6	8	2	5	8	0
3327	0	0	11	11	13	7	10	10	8	5	7	1	4	7	0
461	0	0	11	11	13	7	10	10	7	5	7	1	3	7	0
465	0	0	11	11	12	6	9	8	6	4	6	1	3	6	0
467	0	0	10	9	10	4	6	6	4	3	4	1	2	4	0
469	0	0	9	7	9	3	5	5	4	3	3	1	2	3	0
778	0	0	11	11	13	7	10	9	7	5	7	1	3	7	0
779	0	0	11	12	13	9	12	11	9	7	8	1	5	8	0
780	0	0	11	11	12	7	10	9	7	5	6	1	3	6	0
783	0	0	11	12	13	7	10	10	8	5	7	1	4	7	0
785	0	0	11	10	11	5	7	6	5	3	5	0	2	5	0
786	0	0	11	10	11	4	7	7	6	4	4	1	2	4	0
792	0	0	11	12	13	10	11	11	8	6	6	1	5	7	0
3069	0	0	3	3	3	3	2	2	3	1	1	0	2	1	0
1941	0	0	3	3	3	3	2	2	3	1	2	0	2	1	0
2968	0	0	0	4	5	5	4	4	5	2	2	3	5	2	0
1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Figure 37 - Truncation at Stop 1941 Matrix

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
433	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
436	0	0	0	2	2	0	1	1	0	0	1	0	0	1	0
441	0	0	0	2	2	0	0	1	1	0	1	0	0	1	0
445	0	0	0	5	6	2	3	3	2	2	2	1	2	2	0
450	0	0	0	3	4	1	2	2	2	1	1	0	1	1	0
453	0	0	0	3	5	1	2	2	1	1	1	0	0	1	0
2514	0	0	0	9	12	4	6	7	5	3	5	1	2	4	0
457	0	0	0	9	13	9	11	11	8	6	8	2	5	8	0
3327	0	0	0	9	13	7	10	10	8	5	7	1	4	7	0
461	0	0	0	9	13	7	10	10	7	5	6	1	3	7	0
465	0	0	0	8	12	6	9	8	6	4	6	1	3	6	0
467	0	0	0	7	10	4	6	6	4	3	4	1	2	4	0
469	0	0	0	6	9	3	5	5	4	3	3	1	2	3	0
778	0	0	0	9	13	7	10	9	7	5	7	1	3	7	0
779	0	0	0	9	13	9	12	11	9	7	7	1	5	8	0
780	0	0	0	9	12	7	10	9	7	5	6	1	3	6	0
783	0	0	0	9	13	7	10	10	8	5	6	1	4	7	0
785	0	0	0	8	11	5	7	6	5	3	5	0	2	5	0
786	0	0	0	8	11	4	7	7	6	4	4	1	2	4	0
792	0	0	0	9	13	10	11	11	8	6	6	1	5	7	0
3069	0	0	0	3	3	3	2	2	3	1	1	0	2	1	0
1941	0	0	0	3	3	3	2	2	3	1	2	0	2	1	0
2968	0	0	0	4	5	5	4	4	5	2	2	3	5	2	0
1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Figure 36 - Truncation at Stop 2968 Matrix

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
436	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0
441	0	0	0	0	1	0	0	1	1	0	0	0	0	1	0
445	0	0	0	0	3	1	1	2	1	0	0	0	2	1	0
450	0	0	0	0	2	1	1	0	1	0	0	0	1	0	0
453	0	0	0	0	3	1	1	1	0	0	0	0	0	0	0
2514	0	0	0	0	4	3	3	3	4	0	0	0	2	1	0
457	0	0	0	0	4	5	4	4	4	0	0	1	4	2	0
3327	0	0	0	0	4	4	4	4	4	0	0	0	4	2	0
461	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
465	0	0	0	0	4	3	4	4	4	0	0	0	3	1	0
467	0	0	0	0	4	2	2	3	3	0	0	0	2	1	0
469	0	0	0	0	4	1	2	2	2	0	0	0	2	0	0
778	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
779	0	0	0	0	4	5	4	4	4	0	0	0	4	2	0
780	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
783	0	0	0	0	4	4	4	4	4	0	0	0	3	2	0
785	0	0	0	0	4	3	3	3	3	0	0	0	2	2	0
786	0	0	0	0	4	3	3	3	3	0	0	0	2	1	0
792	0	0	0	0	4	5	4	4	4	0	0	0	4	2	0
3069	0	0	0	0	3	3	2	2	3	0	0	0	1	1	0
1941	0	0	0	0	3	3	2	2	3	0	0	0	1	1	0
2968	0	0	0	0	4	5	4	4	4	0	0	2	3	1	0
1942	0	0	0	0	2	2	2	1	0	0	0	0	0	0	0
1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Figure 35 - Truncation at Stop 1942 Matrix

Stop ID	3069	1941	2968	1942	1943	1944	1945	1946	1947	Dest.	Dest.	Dest.	Dest.	Dest.	Dest.
432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
436	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
441	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0
445	0	0	0	0	0	1	1	2	1	0	0	0	2	1	0
450	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0
453	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
2514	0	0	0	0	0	3	3	3	4	0	0	0	2	1	0
457	0	0	0	0	0	5	4	4	4	0	0	0	4	2	0
3327	0	0	0	0	0	4	4	4	4	0	0	0	4	2	0
461	0	0	0	0	0	4	4	4	4	0	0	0	3	2	0
465	0	0	0	0	0	3	4	4	4	0	0	0	3	1	0
467	0	0	0	0	0	2	2	3	3	0	0	0	2	1	0
469	0	0	0	0	0	1	2	2	2	0	0	0	2	0	0
778	0	0	0	0	0	4	4	4	4	0	0	0	3	2	0
779	0	0	0	0	0	5	4	4	4	0	0	0	4	2	0
780	0	0	0	0	0	4	4	4	4	0	0	0	3	2	0
783	0	0	0	0	0	4	4	4	4	0	0	0	3	2	0
785	0	0	0	0	0	3	3	3	3	0	0	0	2	2	0
786	0	0	0	0	0	3	3	3	3	0	0	0	2	1	0
792	0	0	0	0	0	5	4	4	4	0	0	0	4	2	0
3069	0	0	0	0	0	3	2	2	3	0	0	0	1	1	0
1941	0	0	0	0	0	3	2	2	3	0	0	0	1	1	0
2968	0	0	0	0	0	5	4	4	4	0	0	1	3	1	0
1942	0	0	0	0	0	2	2	1	0	0	0	0	0	0	0
1943	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Figure 34 - Truncation at Stop 1943 Matrix

Appendix B: Analysis Origins and Destinations

stop_id	stop_description	stop_lat	stop_lon
1941	5TH AVE @ 85TH ST	40.780586	-73.961179
1942	5TH AVE @ 59TH ST	40.764347	-73.973484
1943	5TH AVE @ 51ST ST	40.759274	-73.977178
1944	5TH AVE @ 43RD ST	40.753982	-73.9806
1945	5TH AVE @ 35TH ST	40.749603	-73.984287
1946	#N/A	40.743338	-73.988381
1947	23RD ST @ 5TH AVE	40.74128	-73.989067
1962	MADISON AVE @ 26TH ST	40.743225	-73.986151
1963	MADISON AVE @ 32ND ST	40.746208	-73.983825
1964	MADISON AVE @ 39TH ST	40.751124	-73.980153
1965	MADISON AVE @ 47TH ST	40.756242	-73.976634
1966	MADISON AVE @ 54TH ST	40.760056	-73.97373
1967	MADISON AVE @ 63RD ST	40.765755	-73.969543
1968	MADISON AVE @ 84TH ST	40.779305	-73.959709
2514	CENTRAL PARK AVE @ FOUNTAIN LA	40.987596	-73.824515
2938	MADISON AVE @ 99TH ST	40.788964	-73.952768
2968	5TH AVE @ 69TH ST	40.770414	-73.969123
2969	MADISON AVE @ 69TH ST	40.769651	-73.966865
3069	5TH AVE @ 98TH ST	40.788923	-73.955098
3327	CENTRAL PARK AVE @ FORT HILL RD	40.978725	-73.830773
432	CENTRAL AVE @ HARDING AVE	41.035792	-73.781011
433	CENTRAL AVE @ CROSS ST	41.031541	-73.787578
436	CENTRAL PARK AVE @ DALEWOOD DR	41.027894	-73.79092
441	CENTRAL PARK AVE @ E HARTSDALE AVE	41.018653	-73.798793
445	CENTRAL PARK AVE @ MARION AVE	41.011656	-73.806916
450	CENTRAL PARK AVE @ UNDERHILL RD	41.001282	-73.814744
453	CENTRAL PARK AVE @ ARDSLEY RD	40.993413	-73.820476
457	CENTRAL PARK AV @ JEFFREY PK SOUTH	40.982705	-73.828554
461	CENTRAL PARK AVE @ ROXBURY DR	40.973696	-73.834318
465	CENTRAL PARK AVE @ MELROSE AVE	40.962165	-73.840298
467	CENTRAL PARK AVE @ SADORE LA	40.956148	-73.842018
469	CENTRAL PARK AVE @ TUCKAHOE RD	40.952873	-73.843792
470	CENTRAL PARK AVE @ TUCKAHOE RD	40.953458	-73.842492
471	CENTRAL PARK AVE @ SADORE LA	40.95613	-73.841527
472	CENTRAL PARK AVE @ MELROSE AVE	40.962442	-73.839674
477	CENTRAL PARK AVE @ ROXBURY DR	40.974198	-73.833524
479	CENTRAL PARK AVE @ E FORT HILL RD	40.979858	-73.829983
480	CENTRAL PARK AV @ BURLINGTON COAT	40.982657	-73.82805

481	CENTRAL PARK AV @ CENTRAL PLAZA SC	40.9856	-73.825583
482	CENTRAL PARK AVE @ CLIFTON RD	40.988213	-73.823634
484	CENTRAL PARK AVE @ ARDSLEY RD	40.993066	-73.82055
488	CENTRAL PARK AVE @ OLD ARMY RD	41.002487	-73.813765
493	CENTRAL PARK AVE @ MARION AVE	41.011674	-73.806603
495	CENTRAL PARK AVE @ E HARTSDALE AVE	41.018735	-73.798311
501	CENTRAL PARK AVE @ CONCORD AVE	41.027821	-73.790625
504	CENTRAL AVE @ CHATTERTON AVE	41.033418	-73.785091
505	CENTRAL AVE @ HARDING AVE	41.035583	-73.781223
778	CENTRAL PARK AVE @ ARLINGTON ST	40.949446	-73.847976
779	CENTRAL PARK AVE @ PALMER RD	40.944907	-73.850633
780	CENTRAL PARK AVE @ MIDLAND AVE	40.934779	-73.856631
783	CENTRAL PARK AVE @ STAUNTON ST	40.924992	-73.859266
785	CENTRAL PARK AVE @ YONKERS AVE	40.921716	-73.863283
786	CENTRAL PARK AVE @ CLARK ST	40.920716	-73.866166
792	CENTRAL PARK AVE @ MCLEAN AVE	40.90895	-73.877962
793	CENTRAL PARK AVE @ MCLEAN AVE	40.908943	-73.877254
797	CENTRAL PARK AVE @ CLARK ST	40.920383	-73.865489
798	CENTRAL PARK AVE @ YONKERS AVE	40.921533	-73.862333
801	CENTRAL PARK AVE @ MILE SQUARE RD	40.924583	-73.858133
804	CENTRAL PARK AVE @ MIDLAND AVE	40.934808	-73.855739
805	CENTRAL PARK AVE @ PALMER RD	40.944806	-73.850338
806	CENTRAL PARK AVE @ ARLINGTON ST	40.94934	-73.847496
Dest.	Times Square	40.757974	-73.985544
Dest.	Theatre District Broadway	40.759456	-73.985149
Dest.	Highline Beginning	40.73952	-74.008184
Dest.	Highline End	40.756336	-74.003613
Dest.	Empire State Building	40.748441	-73.985665
Dest.	Museum of Natural History	40.78083	-73.972832
Dest.	Museum of the City of NY	40.792505	-73.951899
Dest.	Mount Sinai Hospital	40.789933	-73.952419
Dest.	BronxCare Center	40.843376	-73.910073
Dest.	NYC Health Hospitals Bellevue	40.739691	-73.976209
Dest.	Montefiore Medical Center	40.860691	-73.890126
Dest.	James J Peters VA Medical Center	40.867533	-73.906437
Dest.	New York Presbytarian Westchester	40.942383	-73.837006
Dest.	Grocery Plaza near Central/Dalewood	41.026697	-73.791973
Dest.	Wall Street	40.70615	-74.00904
Dest.	Hudson Yards	40.754279	-74.002306
Dest.	NYU	40.729521	-73.996461
Dest.	9/11 Memorial	40.711415	-74.012482

Dest.	Grocery Plaza near Central/Ardsley	40.992413	-73.821639
Dest.	Grocery Plaza near CntrlWstchrPkw/Reservoir Rd) (MetroNorth)	41.054875	-73.765752
Dest.	Grocery Plaza near White Plains Metro North Station	41.032305	-73.765018
Dest.	Large Lot near Central/Harding	41.037941	-73.782483
Dest.	Shopping Plaza near Central/Cross	41.030752	-73.788926
Dest.	Large Lot near Central/Underhill	40.999428	-73.815023
Dest.	Shopping Plaza near Central/Fountain	40.985623	-73.825369
Dest.	Shopping Plaza near Central/Fort Hill	40.977647	-73.829985
Dest.	Grocery Store near Central/McLean	40.908932	-73.876803

Figure 38 - Full List of Origins and Destinations Selected for Analyses