The Immediate Performance Impacts of Implementing Select Bus Service at New York City Transit: A Case Study of the Bx41 Route

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Abstract:
Select Bus Service (SBS) is New York City's version of bus rapid transit (BRT). On June 30, 2013, New York City Transit (NYCT) launched its fifth SBS line, SBS Bx41 on Webster Avenue in the Bronx. The SBS Bx41 features dedicated offset bus lanes, off board fare collection, station and bus branding, three-door low-floor buses, and pedestrian safety improvements. While existing data supports the effectiveness of SBS, past SBS launches have been accompanied by limited examination of performance impacts. This study looks at a variety of performance indicators before and after the launch of SBS Bx41 to carefully quantify the immediate impacts of SBS improvements. One component of this report is a study of reductions in dwell times. Dwell times and passenger boardings and alightings were measured at four en-route time points along the Bx41 route before and after the implementation of SBS. Data were collected in each direction and during selected times both peak and off-peak, and a multivariate regression model of dwell time was developed to quantify the time savings from all-door boarding and off-board fare payment, as well as the negative impacts of customer confusion about fare payment. Dwell time per passenger boarding decreased from an estimated 3.52 seconds before the implementation of SBS to only 1.12 seconds after. The introduction of SBS on the Bx41 has also led to substantial improvements in wait assessment (NYCT's measure of headway regularity), on-time performance, running time, and bus bunching on the Bx41 for both the SBS and local buses. On the SBS route, weekday wait assessment improved by 8.9 percent, on-time performance by 27.9 percent, running time by 15 percent, and bus bunching by 63 percent compared to the Bx41 Limited service. Performance on the SBS line is likely to continue to improve in the longer term, yet even these immediate short-term impacts are sizable. This study supports the implementation of BRT upgrades in New York City and elsewhere as a cost-effective way to improve bus performance.

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New York City Transit

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OVERVIEW OF STUDY

New York City Transit (NYCT) launched Select Bus Service (SBS) on the Bx41 route on June 30, 2013. The 5.3-mile route SBS features 4 miles of dedicated offset bus lanes, off board fare collection, station and bus branding, three-door low-floor buses, and pedestrian safety improvements; later in 2013 the line will add bus bulbs and transit signal priority.

This study measures the immediate impact of SBS by examining a number of indicators for 30 days before and after the SBS launch (April 28 to May 27 and July 14 to August 12, which excludes time during which bus lanes were painted as well as a two week adjustment period after SBS launch). Dwell time per passenger is analyzed in a regression model of manually collected data. Wait Assessment (WA), On-Time Performance (OTP), Running Time, and Bus Bunching are already reported daily by NYCT System Data and Research using MTA Bus Time data.

Summary of Weekday Performance Indicators

		Pre-Launch	Post-Launch	Unit Change	% Change
Bx41 Limited/ SBS	Dwell Time per Pax Boarding	3.52 sec	1.12 sec	-2.4 sec	-68.2%
	WA (Absolute, +3/+5)	74.9%	81.6%	6.7%	8.9%
	WA (Relative, +25%)	69.9%	69.3%	-0.6%	-0.9%
	OTP	65.6%	83.9%	18.3%	27.9%
	Running Time (End-to-end)	40.9 min	34.8 min	-6.1 min	-15.0%
	Running Time (Bus Lane)	18.3 min	15.2 min	-3.1 min	-17.1%
	Bus Bunching	2.7%	1.0%	-1.7%	-63.0%
Bx41 Local	WA (Absolute, +3/+5)	78.3%	88.1%	9.8%	12.5%
	WA (Relative, +25%)	68.8%	81.3%	12.5%	18.2%
	OTP	66.7%	79.5%	12.8%	19.2%
	Running Time (End-to-end)	46.1 min	43.0 min	-3.0 min	-6.6%
	Running Time (Bus Lane)	20.5 min	18.8 min	-1.7 min	-8.4%
	Bus Bunching	6.2%	0.8%	-5.4%	-87.1%

	Seasonally Adjusted Change	
	Ridership	Revenue
Bx41 Corridor	9.2%	19.4%
Bx41 Limited/SBS	131.8%	165.0%

The study also finds that dwell times for customers confused about fare payment and boarding policies were almost four times longer than for others, high-lighting the importance of customer communications.

The SBS upgrade has already clearly had a substantial, positive impact on performance for both the SBS and local routes, particularly on dwell times, OTP, running time, and bus bunching. Performance is expected to continue to improve as customers gain familiarity with SBS and more improvements are implemented, such as transit signal priority and bus bulbs. The results of this study suggest that bus lanes, low-floor buses, and clear off-board fare payment and all-door boarding policies lead to improved bus performance, and also that performance improves for local routes on the same corridor as an SBS route. This study supports that the SBS program is effective at improving bus performance on key corridors in New York City.

BACKGROUND ON BX41 SBS

New York City Transit (NYCT) launched Select Bus Service (SBS) on the Bx41 route on June 30, 2013. SBS is New York City's version of Bus Rapid Transit (BRT), and was first launched on the Bx12 in June 2008 (*1*). The Bx41 SBS route replaces the existing Bx41 Limited service and expands its operations from weekday-only service to 7 days a week. The 5.3-mile route connects The Hub at East 149th St/3rd Avenue with Gun Hill Intermodal Terminal at East Gun Hill Road/White Plains Road. The route has connections to the 2 and 5 subway lines at both terminals and the Bx12 SBS and Metro-North Railroad along the route (see Figure 1). The Bx41 SBS features 4 miles of dedicated offset bus lanes, off board fare collection, station and bus branding, three-door low-floor buses, and pedestrian safety improvements; later in 2013 the line will add bus bulbs (sidewalk extensions at bus stations) and transit signal priority, and a new transit plaza at the Hub is planned for 2015 (*2*).

The key project goals are improving the speed and reliability of buses in the corridor, improving safety for all corridor users, and supporting community needs. Manually collected data from 2012 indicate that Bx41 buses are stopped 51% of the time, 24% of the time at bus stops and 26% of the time due to red lights (*2*). One-way travel time on the Bx41 Limited varies substantially throughout the day, typically between 37 to 57 minutes.

This study measures the immediate impact of SBS with regards to improvements in travel times, reliability, and overall performance by examining a number of indicators before and after the SBS launch. This study examines pre-SBS launch data from April 28 to May 27, 2013 and post-SBS launch data from July 14 to August 12, 2013. These time intervals are both 30 days, beginning on a Sunday. These intervals are chosen to exclude bus lane painting as well as the first two weeks of the new bus service, which are considered an adjustment period for customers and bus operators. Data are also evaluated for a 90-day period before launch (February 27 to May 27, 2013) to take advantage of available data, and the data from this extended baseline period is presented in the Appendix.

Figure 1. Bx41 Select Bus Service and Webster Avenue Bus Lane

PERFORMANCE INDICATORS (PIs)

The performance indicator (PI) program at NYCT was established in 1994 following the recommendations of research by the Office of the Inspector General for performance metrics other than terminal on-time performance (*3*). These PIs can be compared before and after the SBS launch, as well as segmented by time of day, direction, and time point. This study uses the following PIs and other metrics to measure performance before and after the SBS Bx41 launch:

- **Dwell Time per Passenger:** Many of the enhancements associated with SBS are focused on reducing delays at bus stops (e.g. three-door low-floor buses with all-door boarding, off board fare collection). Dwell times and passenger boardings/alightings will be measured to determine if dwell time per passenger improves as a result of SBS. Dwell time will be defined as only the amount of time for which it is necessary for doors to remain open to allow passengers to board, pay, and alight. This limited version of dwell time is sometimes referred to as "passenger service time." This PI requires manual data collection and is not one of NYCT's routinely measured PIs.
- **Wait Assessment (WA):** NYCT's primary performance measure, WA measures customers' maximum wait time while waiting to board and compares it to scheduled headways.
    - **Absolute WA**: WA for buses is currently assessed on a "+3/+5" absolute basis. It is reported as the percentage of headway intervals that are within the scheduled headway +3 minutes during the peak period, or the scheduled headway +5 minutes during the off-peak period. WA is a particularly important indicator of customer experience on routes with short headways (ten minutes or less) since customers are less concerned with the specific bus schedule and more concerned with the duration of their wait.
    - **Relative WA:** In addition to the standard, absolute WA, a relative measure of WA will also be examined. Subways currently define "passing" WA as headway plus 25%, and this standard will be applied to SBS in this study.
- **On-Time Performance (OTP):** On-Time Performance for buses is defined as being between 1 minute before to 5 minutes after the scheduled time. OTP is measured at en-route time points, which are intermediate stops on a route that are assigned a scheduled departure; for instance, the Bx41 has 5 time points.
- **Running Time:** Running time is the time for a bus to travel between two points, be they the origin and destination of a route or en-route time points. It can be used to measure reductions in average travel time as well as its variability. Along with WA, running time is an important measure of customer experience on frequent routes where customers are often less aware of the actual schedule but are still concerned about their travel time.
- **Bus Bunching:** Bus bunching at NYCT is currently defined as two buses on the same route heading in the same direction departing a common time point within 90 seconds of each other. Bunching is reported for NYCT buses as the percentage of bus pairs that are bunched.
- **Ridership and Revenue:** Average daily ridership and revenue are available from automated fare collection (AFC) data. While not a performance indicator per se, ridership and revenue are important metrics for measuring the success of a new bus service.

In addition, a weighted measure of WA is considered in this paper as a potential future PI that is being developed and tested at NYCT System Data and Research:

- **Weighted WA:** The current measure of WA does not consider volumes of passengers, but instead examines the percentage of headway intervals that are passing, treating all headways equally. NYCT System Data and Research is exploring the possibility of a weighted WA measure that more highly rewards headway adherence during periods with more passengers by weighting headways by their ridership. An algorithm for weighted WA has not yet been fully developed and tested, but underlying assumptions of such a measure will be explored in this study.

RELEVANT LITERATURE

Performance Indicators and Underlying Data Sources

This study focuses on the immediate impact of SBS on performance indicators. Most of the performance indicators examined in this study are already routinely reported by NYCT, and have been documented in a 2009 Transportation Research Record paper on NYCT's performance indicator program (*4*). Three main performance indicators in particular are discussed: en-route schedule adherence, headway regularity, and wait assessment (WA). Headway regularity is no longer reported as a PI since it is similar to WA, which is a simpler metric; en-route schedule adherence is now referred to as on-time performance (OTP). The article outlines the methodology used to collect a statistically valid sample of data throughout the system using field surveyors. At the time of this paper, efficiencies had recently been introduced into the PI program through the use of personal digital assistants (PDAs) to replace paper data collection forms for bus performance.

The efficiency and availability of data for bus performance has increased dramatically since the introduction of MTA Bus Time technology (*5*, *6*). MTA Bus Time is an automatic vehicle location (AVL) system that uses GPS to wirelessly transmit the location of equipped buses every 30 seconds. Before the introduction of Bus Time, weekday running times for bus routes would be measured for any given line every two to three years, and PIs were reported twice a year for 42 of the 224 NYCT bus routes through the aforementioned sampling methodology. By contrast, PIs based on Bus Time data are available on a next-day basis for all equipped buses, rather than a sample. Bus Time was first introduced in February 2011, and was installed on nearly all Staten Island and Bronx buses by the end of 2012. All buses in the city will be equipped with Bus Time by early 2014. Bus Time allows for richer data analyses and visualizations. Detailed data visualizations have been developed to take advantage of Bus Time data, such as comparisons of actual to scheduled running times and stringline diagrams that convey performance and bunching for bus service in one direction over a day.

AVL data allows for profoundly more reliable and in-depth information on schedule adherence, headway regularity, and passenger waiting time (*7*). In addition, running time analyses are much more meaningful when based on complete data rather than smaller samples. Complete data allows for reliable measurement of the distribution of running times over different time periods, which is particularly useful for scheduling, and can also help identify problem areas and times of day that might justify capital improvements, such as transit signal priority and bus lanes. AVL data can also be matched with automated fare collection (AFC) or automatic passenger counter (APC) data, which provides ridership information, to estimate bus ridership by location and bus load factors, which is informative for transit service planning.

Bus Rapid Transit (BRT)

SBS is New York City's version of bus rapid transit (BRT). Typically, BRT involves some form of bus priority, all-door low-floor passenger boarding, off-board fare collection, and unique branding (*8*, *9*, *10*). BRT ideally combines attractive and accessible stations and vehicles, frequent service, dedicated running ways, and Intelligent Transportation Systems (ITS) such as transit signal priority to cost-effectively increase the speed and reliability of bus service within an integrated public transportation network. Capital costs for construction of BRT are lower than for a corresponding light rail line, and operating costs are usually similar (*8*). BRT also has the distinct advantage of being a flexible technology that can be incrementally expanded or upgraded, and some components such as dedicated running ways can serve other bus lines for portions of the corridor.

BRT systems with arterial bus lanes, such as the SBS Bx41, have a level of service similar to light rail transit (*8*). However, offset or curb-running bus lanes, like those of the SBS Bx41, confer less travel time savings than median-running bus lanes and are more susceptible to conflicts with right-turning traffic and pedestrians (*11*). One study found that re-striped bus lanes like those on the SBS Bx41 offer roughly a third of the time savings per mile of completely separated at-grade busways, but are significantly less expensive. Re-striped bus lanes can cost on average a fiftieth of the cost per mile of separated at-grade busways, and curb-running or offset lanes typically have capital costs of $2 to $3 million per lane mile in comparison to median transitways with costs of $5 to $10 million per lane mile (*10*). Enforcement of bus lanes is essential for the lanes to impact performance.

BRT is essentially a suite of technological upgrades, each of which has impacts on performance indicators:

- **Bus lanes'** effectiveness varies with their level of separation from other traffic. Separated busways, which are a higher-performing form of running way than arterial bus lanes, led to 20 to 44 percent reductions in travel time on a selection of BRT systems in the US, Australia, and Brazil (*10*). Arterial bus lanes in New York City (Madison Avenue), San Francisco, and Los Angeles have reduced travel times by 34 to 43 percent and increased reliability (as measured by the coefficient of variation) by 12 to 57 percent (*10*). The same study suggests that a typical arterial may experience travel time reductions of 30 to 60 seconds per mile from arterial bus lanes. Another study finds that transit lanes for trams in Melbourne, Australia have reduced route level running times by 28 percent and running time variability by 40 percent (*12*).
- **Transit signal priority** (TSP), in which a green light may start earlier or last longer to reduce bus delay, has reduced running time by 2 to 18 percent on bus systems in the US, Canada, and Germany, with a typical range of 8 to 12 percent; in Seattle, TSP reduced intersection delay by 13 percent and increased reliability by 35 percent (*10*). In Melbourne, Australia, TSP reduced variability of running times by 21 percent (*12*).
- **Curb extensions and bus bulbs** eliminate "clearance time" in which buses must wait to pull back into a traffic lane, typically saving 9 to 20 seconds and also improving pedestrian safety while boarding and alighting (*10*).
- **Low-floor buses** can reduce boarding times by about 20 percent (*13*).
- **Off-board fare payment** can significantly reduce dwell time by reducing per-passenger boarding times. Dip cards, such as the MetroCard used by the MTA, are associated with per-passenger service times of about 4.2 seconds, and exact change takes roughly 3.6 to 4.3 seconds; prepayment (including off-board fare payment, passes, free transfers, and pay-on-exit) reduces this to 2.25 to 2.75 seconds per passenger (*10*).
- **All-door boarding** combined with **off-board fare payment** significantly reduce dwell times. One study in Changzhou, China found that BRT dwell times per passenger were 22 percent less than non-BRT dwell times per passenger (*14*).

- **Branding** and modern vehicle styling may have a positive impact on ridership since components like distinctive stations, larger windows, higher roofs, and improved aesthetics make customers feel safe and comfortable. Styling and branding in some cases have corresponded to ridership increases of 35 to 100 percent (*10*), though it may be difficult to isolate their effects.

Dwell Time

Dwell time is a particular focus of this study. Dwell time is conventionally defined as the amount of time a bus is stopped at the curb to allow for passenger boarding and alighting, including the time for doors to open and close, whereas "passenger service time" is used to refer to the portion of dwell time during which buses are serving passengers (*13*, *15*). Dwell time typically represents up to 26 percent of total bus travel time (*16*). It is impacted by a number of factors, including the passenger demand at the highest-volume doors, fare payment methods, vehicle types (particularly if a bus has low-floors), use of lifts or ramps, bus operator behavior, and the load factor of the bus which affects how easily passengers are able to move past the doors and farebox if applicable (*14*, *15*, *17*, *18*). Time of day and route type can also have an impact on dwell time through their effects on passenger demand, and peak period passengers may be more likely to use pre-paid passes and ask fewer questions. In addition, if demand is primarily in one direction, there may be less conflicts between passengers boarding and alighting.

The Transit Capacity and Quality of Service Manual (TCQSM) provides guidance on performing dwell time analyses, and suggests that it is important to measure boardings, alightings, and the number of passengers on board the bus. The dwell time and passenger counts are most accurate if measured directly in the field, and should not include "time for stragglers to board or exit" (*13*). Wheelchairs can also strongly affect dwell time, though this varies by the type of bus. Traditional high-floor buses typically take 60 to 200 seconds to serve a wheelchair, whereas ramps on low-floor buses are able to serve a wheelchair in 30 to 60 seconds according to the TCQSM (*13*), similar to findings from a study in Vancouver that found that wheelchairs add 38 seconds to dwell time (*17*). Other "atypical users" associated with extended per passenger dwell times have been analyzed separately in some studies (*18*).

As outlined above, off-board fare payment and all-door boarding reduce dwell time. In Changzhou, China, dwell time per passenger decreased by 22 percent as a result of these technological improvements. A study in Vancouver found that while dwell time per passenger was higher in crowded conditions on conventional buses, buses with all-door boarding had less dwell time per passenger in crowded conditions, likely because the efficiencies of all-door boarding make the most difference when demand is high, and because rear-door boardings took less time due to crowding at the front door (*17*). Likewise, fare media had an impact on dwell time: "flash passes" added only 2.2 seconds to dwell time per passenger, whereas magnetic swipe tickets added 3.0 seconds and cash fares added 4.2 seconds. Passengers who did not present a pass or pay at the farebox had the least impact on dwell time at only 1.6 seconds per passenger, suggesting the potential dwell time savings of off-board fare payment. As stated earlier, the BRT Practitioner's Guide finds that prepayment of fares reduces boarding times per passenger to about 2.25 to 2.75 seconds, in comparison to 4.2 seconds with a dip card such as the MetroCard (*10*).

Traditional models of dwell time treat dwell as a linear function of passenger boardings and alightings. Other studies have created more complex, non-linear models of dwell time (*14*, *16*, *17*). For instance, some models consider the natural log or square of boardings and alightings, or consider the volumes of passengers boarding and alighting through the highest volume door, since the highest volume door may be the only one to have a binding effect on dwell times. Some models also include measures of the load factor on buses, the number of people on a BRT platform, or even a "conflict factor" or "friction factor" of boardings multiplied by alightings and indicates which bus dwells have the most passengers going in both directions. Information on the payment method of customers can also refine dwell time models. While including a variety of independent variables can improve the explanatory power of dwell time models, passenger boarding and alightings are the most important determinants of dwell time, and even models with relatively few independent variables can provide satisfactory results (*16*).

Previous Studies by MTA of SBS in New York City

Bx12 Select Bus Service One Year Report

A report was completed in October 2009 on the first year of service on the Bx12 SBS (*19*). The report found that after its first year:

- **Ridership** increased for the Bx12 SBS and Local routes by 6.7 percent for weekdays and 6.3 percent overall; by comparison, all other local routes experienced decreases of 0.9 percent and 0.4 percent respectively.
- **Revenue** increased on the Bx12 SBS and Local routes by 9.9 percent for weekdays and 8.8 percent overall; by comparison, all other local routes experienced increases of 1.5 percent and 1.4 percent respectively.
- **Travel time** decreased by 19 percent overall with respect to the previous Bx12 Limited service. Pre-SBS running time was 58 minutes on average, which was reduced to 47 minutes with SBS.
- **Dwell times** decreased from 27 percent of travel time to 21 percent of travel time with the introduction of off-board fare payment.
- **Time stopped at traffic signals** decreased from 21 percent of travel time to 16 percent of travel time with the use of TSP installed at 20 intersections.
- **In motion time** increased from 49 percent of travel time to 61 percent of travel time as a result of reductions in dwell time and traffic signal delays.
- **Customer satisfaction** was very high; a survey of customers found that 95 percent were satisfied or very satisfied with their wait times, and 96 percent with the speed of their ride. The survey also found that 30 percent were riding more frequently than before, and 69 percent found off-board fare payment more convenient.
- **Mode share** for buses increased among those shopping on Fordham Road: in 2007, 37 percent of shoppers arrived by bus, and in 2008 42 percent arrived by bus. At the same time, the proportion of shoppers who drove to and parked on Fordham Road fell from 11 percent to 2 percent.

M15 Select Bus Service Evaluation

NYCT Operations Planning evaluated baseline performance before the October 2010 launch of the M15 Select Bus Service (*20*). The evaluation included a basic dwell time analysis with a simple linear regression of dwell times on a single variable of combined passenger boarding and alightings. At baseline before SBS, it was found that boarding took roughly 4.0 seconds per passenger, with a constant of 25.7 seconds, and an R^2 of 0.60 for this model. The model did not consider boardings and alightings separately, nor separately measure wheelchairs or bus characteristics (high-floor or low-floor).

Aside from dwell time, baseline measurements were captured for average point-to-point running times along the M15 Limited route, from which a speed profile of the Limited route was constructed. Load factors on the M15 Limited service were also calculated by analyzing data from November 2007 that had been collected for schedule making purposes.

DATA AND METHODOLOGY

Data Sources

This study taps into a number of existing and recently developed data sources at NYCT and also relies on some manual data collection. MTA Bus Time data, as detailed in the literature review, is the underlying data source for most of the performance indicators. PIs that are regularly reported by NYCT, as well as a variety of other data analyses and visualizations, are readily available internally at NYCT through the Operations Research & Computational Analysis (ORCA) web-based reporting and data visualization platform.

Table 1. Data Sources for Performance Indicators

Metric	Source
Dwell Time per Passenger	Manual data collection of boardings, alightings, and dwell times
WA (Absolute, Relative)	Reported by NYCT based on Bus Time data
OTP	Reported by NYCT based on Bus Time data
Running Time	Reported by NYCT based on Bus Time data
Bunching	Reported by NYCT based on Bus Time data
Ridership and Revenue	Automated fare collection (AFC) data

In addition, while it is not a performance metric, the randomness of passenger arrivals is an underlying assumption for formulation of a passenger-weighted WA. This would not be a reasonable assumption if many passengers were arriving immediately before the bus, for instance by using Bus Time to minimize their wait times. To test the reasonability of the assumption of randomness of passenger arrivals on the Bx41, manual data collection was conducted on passenger and bus arrivals at Bx41 Limited/SBS stops, and the results are presented later in this study.

The dates for the evaluation of the performance metrics before the launch of SBS were chosen to avoid bus lane painting. The NYC Department of Transportation began painting the 4 miles of red offset bus lanes on the Bx41 route on May 28, 2013. While a road segment is being painted, buses are likely slowed around lane closures. Conversely, though the dedicated bus lanes were not technically in effect until June 30, private vehicles tended to avoid driving in the completed segments of the bus lanes during the month of June, possibly decreasing travel times for buses in the painted portions of the corridor. Likewise, the post-launch data starts two weeks after the launch of SBS to allow for an adjustment period for customers and bus operators during which performance may be more variable.

The performance metrics are presented both before and after the launch of SBS. Pre-SBS metrics are presented from April 28 to May 27, 2013 and post-SBS launch data from July 14 to August 12, 2013, which are both 30-day periods starting on a Sunday. Data are also analyzed for a 90-day period before launch (February 27 to May 27) to take advantage of available data, and presented in the Appendix. The greatest confounding factors between the pre- and post-SBS time periods would likely be weather and the change in student ridership due to the school year ending on June 26.

Table 2. Bx41 Key Performance Indicators, School Year vs. Summer (Summer 2008-2012)

	School Year [1]		Summer [2]		Change	
School Year	**OTP**	**WA**	**OTP**	**WA**	**OTP**	**WA**
2007-2008	60.4%	77.2%	58.1%	75.5%	**-2.3%**	**-1.7%**
2008-2009	62.7%	76.5%	60.3%	75.3%	**-2.4%**	**-1.3%**
2009-2010	64.9%	74.6%	68.8%	78.1%	**3.9%**	**3.5%**
2010-2011	60.8%	72.6%	67.6%	78.8%	**6.8%**	**6.2%**
2011-2012	71.0%	78.9%	69.0%	79.2%	**-2.0%**	**0.4%**

Notes:
[1] "School Year" measures service on the Bx41 Local and Limited for the last 60 calendar days of the school year.
[2] "Summer" measures service on the Bx41 Local and Limited for the first 60 calendar days after the school year.
[3] Performance indicators based on a manually collected sample of bus service.

Table 2 presents the OTP and WA for the Bx41 Local and Limited routes for 60-day periods before and after the end of the school year over the previous five school years. Sixty-day periods were chosen to increase reliability of the estimates due to the limited sample available. OTP and WA across the end of the school year are unpredictable; they have alternately increased or decreased in past years, and the change has usually been relatively small. It is also worth noting that these data are based on samples of bus performance, and are therefore not as precise as the complete Bus Time data that is now available. The performance indicators from the last five years suggest that for this particular route the end of the school year and the seasonal changes in ridership during summer are not likely to have a strong or predictable impact on key performance indicators such as OTP and WA over the study period around the launch of SBS. It is not surprising that OTP and WA would not vary substantially by season – in theory, if running times for instance vary systematically by season then this would be built into the schedule, and a well-formulated schedule could have similar performance across seasons.

Weather is also unlikely to be a confounding factor in this analysis. All three time periods examined for PIs (90-day pre-launch period, 30-day pre-launch period, and 30-day post-launch period) had precipitation between 40 and 43 percent of the days during the time period (*21*). The 30-day pre- and post-launch time periods both had 12 days of precipitation, and both had 8 days with more than 0.1 inches of precipitation.

Methodology

The majority of the performance metrics analyzed in this report are already automatically collected and reported daily by NYCT System Data & Research, and are available on demand on the ORCA platform. Only two components of this report require manual data collection in the field: dwell time per passenger, and randomness of passenger arrivals.

Dwell Time per Passenger

The dwell time per passenger is the only metric analyzed that is not available from data already collected by NYCT. For this metric, dwell times and total passenger boardings and alightings were measured at four en-route time points along the Bx41 route before and after the implementation of SBS. Data was collected for Bx41 Limited and Local buses before the launch of SBS for four hours at each location: one hour in each direction during the peak, and one hour in each direction during the off-peak. After the SBS launch, the data collection was repeated in the same way for SBS buses only. Thus, the data collected represents 32 hours total of data collection, during which 255 bus dwells and 3,656 passenger boardings or alightings were measured.

Stops were considered only if they existed on the Bx41 Limited route and continued to be in use with the Bx41 SBS which replaced the Limited service. Internally within NYCT, data was readily available on estimated boardings and alightings by bus stop for the week of March 6-12, 2013. The four sampled stops selected for the dwell time analysis were chosen based on high passenger boarding and alighting counts and geographic coverage of a substantial portion of the route. Origins and terminals of the route were not considered, since various other factors affect their dwell time.

The bus stops for the dwell time analysis data collection are:

1) Melrose Avenue & East 161st Street
2) Webster Avenue & East 167th Street
3) Webster Avenue & East Tremont Avenue
4) Webster Avenue & East Fordham Road (connections to Bx12 SBS and Metro-North Railroad)

Data was collected by two individuals: one counting passenger alightings, and one counting passenger boardings and measuring the dwell time of the bus. Wheelchair boarding and alightings were also separately counted, and bus numbers were recorded to allow the data to be matched to Bus Time and automated fare collection (AFC) data if needed. NYCT buses are not equipped with bicycle racks and no bicyclists were observed boarding buses.

For the purposes of this study, dwell time is defined as only the amount of time for which it is necessary for doors to remain open to allow passengers to board, pay, and alight, plus the time for doors to open and close. If a bus operator stays at a stop longer than necessary for passenger boarding and alighting, for instance to avoid bunching with another bus ahead, this time is not counted toward dwell time. This is consistent with the advice of the TCQSM, as mentioned in the literature review, to avoid counting stragglers or other such events in dwell time analyses. By consistently measuring dwell time in this way, this study is able to isolate the dwell time effects of the technological improvements of SBS (in particular, off-board fare collection and the use of only low-floor buses).

During the post-launch data collection in particular, there were many instances in which the full dwell time at the bus stop was delayed, often due to customer confusion. Despite the deployment of Customer Ambassadors at all SBS stops for the first two weeks of the service, many passengers were still confused about how to use the new SBS, extending bus dwells either by asking questions of the bus operator or paying at the fare machines after the bus's arrival, often very slowly. Initially, data collection was structured to measure only the "efficient" boardings and dwell times. In other words, passengers were counted if they were prepared to board the bus when it arrived or if they arrived at the stop at the same time as the bus but understood how to use the fare machines relatively quickly; their corresponding dwell time was recorded. This information was captured consistently throughout the entire post-launch data collection effort. As such, the analysis of this data indicates the full technological potential of SBS to reduce dwell times, but will understate the currently achieved per-passenger dwell time.

However, due to observations of the impact of customer confusion on dwell time, data collection was expanded during the course of the post-launch field work. The latter portion of the post-launch data collection also includes data on the number of additional passengers who boarded after the "efficient" boardings, and their corresponding marginal contribution to dwell time. While this additional data is limited in size, it allows for a basic analysis of the impact of customer confusion on dwell times, and sheds some light on the connection between customer communications and bus performance.

Randomness of Passenger Arrivals

Randomness of passenger arrivals is an important assumption in structuring a weighted measure of WA. To verify the assumption of randomness of passenger arrivals within actual bus headways, data collection was conducted at Bx41 Limited/SBS stops. Passenger and bus arrivals at the stops were recorded within 15 second intervals. To be able to compare across headways, each passenger observation is normalized to the percentage of actual bus headway elapsed when the passenger arrived at the bus stop. For instance, if a passenger arrives two minutes into an eight-minute actual headway, that passenger has arrived at 25% elapsed of the headway. This data collection was conducted for 200 minutes of passenger and bus arrivals, during which 103 passengers waited for 24 bus arrivals. This data is analyzed to determine if it is reasonable to assume that passenger arrivals can be treated as a random variable, which would support the future development of a weighted WA metric.

ANALYSIS AND FINDINGS

The analysis compares the PIs and other metrics before and after the launch of SBS. Dwell time per passenger is based on data that was manually collected on June 19-24 and July 17-22, 2013. Unless otherwise noted, all other PIs presented in this section are for the 30-day pre- and post-launch periods of April 28-May 27 and July 14-August 12, 2013. The Appendix includes many of the PIs presented with a 90-day pre-launch period as well (February 27-May 27). In the tables in this section, "percentage points change" represents the numerical increase in the PI, *e.g.*, from 4 percent to 5 percent is a 1 percentage point increase, while "percent change" would indicate the same as a 25 percent increase.

In addition, Bx41 Limited service operated only during weekday peak periods, whereas SBS operates 7 days a week and is not limited to peak periods. For PIs of SBS weekend service, percent changes shown in this section use local service as a baseline since local service was the pre-existing weekend service. These percent changes are italicized to indicate that they include both the effect of SBS technological upgrades as well as weekend service expansions from local-only to local and SBS service.

Dwell Time per Passenger

Dwell time per passenger was modeled based on data collected before and after the launch of SBS. Pre-launch data reflects bus dwells for both the Bx41 Local and Limited, which had identical fare and boarding policies, while post-launch data is for the SBS Bx41 only. The dwell time was modeled using linear regressions in Stata. The regression models do not include indicator variables for direction or peak/off-peak since in all cases these variables were insignificant.

Scatter charts of dwell time on boardings and alightings (Figures 2 and 3) confirm the literature's suggestion that boardings are the strongest determinant of dwell times. It is also clear that this relationship is strongest for the Local and Limited buses, when each boarding passenger pays at the farebox as they enter the bus, creating a very systematic relationship between passenger boardings and necessary dwell time. Fare pre-payment and all-door boarding weaken the strength of the relationship between boardings, alightings, and dwell times. On a Local or Limited bus, every passenger will necessarily add at least a few seconds to dwell time, whereas on SBS it is possible for many passengers to board and alight simultaneously, and conflicts between passengers boarding and alighting can vary substantially, even at the same passenger volumes.

Figure 2. Scatter of Dwell Times by Number of Boardings/Alightings, Bx41 Local & Limited (Pre-Launch)

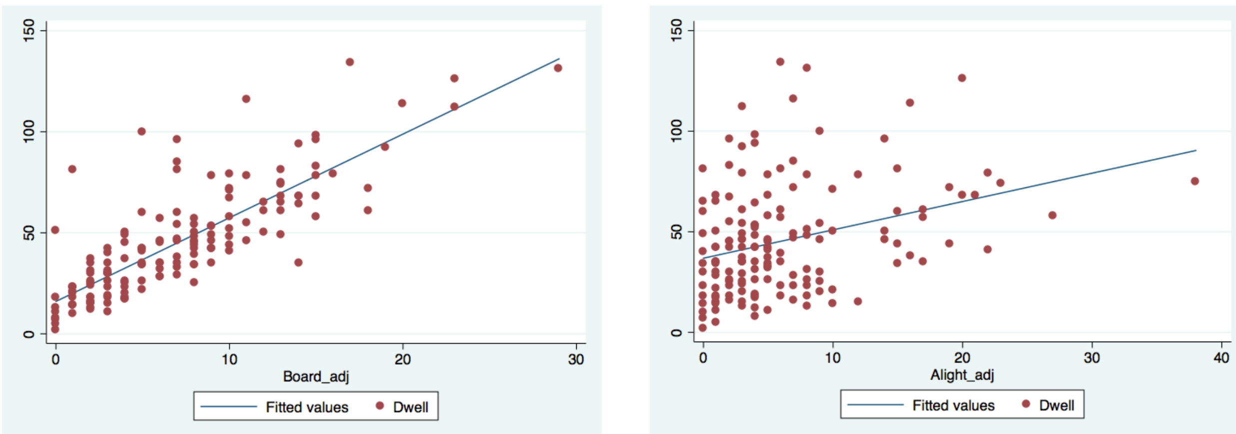


Figure 3. Scatter Chart of Dwell Times by Number of Boardings/Alightings, Bx41 SBS (Post-Launch)

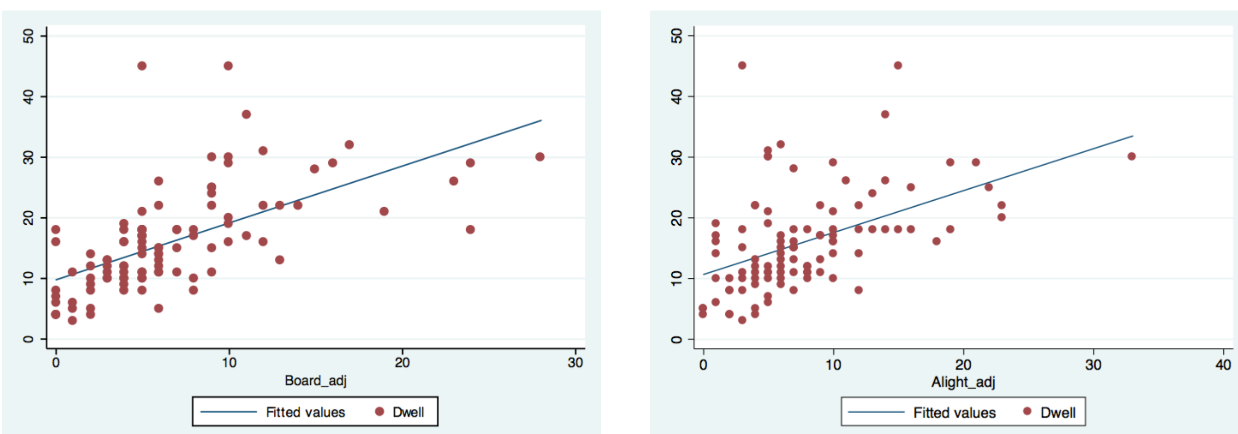


Table 3. Dwell Time Models, Pre-Launch

	Model 1			Model 2 (Preferred)			Model 3		
	Coeff.	*Std. Err.*	*p-value*	*Coeff.*	*Std. Err.*	*p-value*	*Coeff.*	*Std. Err.*	*p-value*
Constant	14.45 *	1.51	0.000	14.42 *	1.48	0.000	11.17 *	2.12	0.000
Boardings	3.88 *	0.18	0.000	3.52 *	0.20	0.000	3.91 *	0.27	0.000
Alightings	0.04	0.16	0.785	0.02	0.15	0.912	0.63	0.32	0.053
Wheelchairs	44.15 *	4.69	0.000	35.62 *	6.30	0.000	37.50 *	6.29	0.000
High Floor * Boardings	---	---	---	0.85 *	0.20	0.000	0.83 *	0.19	0.000
High Floor * Wheelchairs	---	---	---	10.02	7.45	0.180	7.51	7.45	0.315
Friction factor	---	---	---	---	---	---	-0.06	0.03	0.035
Observations	151			151			151		
R-squared	0.8394			0.8645			0.8686		

Notes:
[1] Model 1 has been corrected for heteroskedasticity and uses robust standard errors. White's test for Models 2 and 3 did not find evidence of heteroskedasticity.
[2] Coefficients with an asterisk next to them are statistically significant at the 5% level.
[3] The friction factor is equal to boardings * alightings.

Table 3 presents the results of three different pre-launch dwell time models, which measure the effects of the primary determinants of dwell time for local and limited buses. Model 1 is the simplest model, examining only boardings, alightings, and wheelchairs. Model 2 additionally considers whether buses were high-floor, and Model 3 includes a friction factor to examine how dwell time changes when high volumes of passengers are boarding and alighting simultaneously. The models all have very high explanatory power, explaining between 84 and 87 percent of the observed variation in dwell time based on their R^2 statistics, even in the simplest model.

Model 2, the preferred model, accounts for the effects of high floors through two interaction variables: an interaction between an indicator variable for whether the observed bus was a high-floor bus multiplied by the number of boardings, and an interaction of high-floor times the number of wheelchairs. By introducing these interaction variables, the preferred model is able to measure the extra dwell time per boarding passenger or per wheelchair with respect to low-floor buses. High-floor buses are older, with wheelchair ramps that operate more slowly, and the extra steps required to board high-floor buses increase boarding times for all passengers.

The preferred model finds that the baseline dwell times for buses include a 14 second constant to serve a bus stop, which captures components of dwell time such as the time for doors to open and close, or the extra time for customers to walk to the bus doors when it is unable to stop directly in front of the sign for the bus stop. Each passenger boarding adds 3.5 seconds to dwell time, or 4.4 seconds if the bus is high-floor, while each wheelchair takes 35.6 seconds to board or alight, or 45.6 seconds if the bus is high-floor. These results are consistent with the literature: the TCQSM suggests that low-floor buses can reduce boarding times by 20 percent. These model results suggest that low-floor buses reduce marginal boarding times for able passengers and passengers in wheelchairs by 19 and 22 percent respectively. The marginal effect of passenger alightings on dwell times is extremely weak and insignificant. This finding is not surprising: passenger alighting is much quicker than boarding, which on a limited or local bus includes time for fare payment. Alighting may not even impact dwell time at all in circumstances where all passengers alight from rear doors and complete their alighting before all customers have boarded at the front door. However, the coefficient on alightings has a standard error much larger than its estimate because there is a great deal of variation in passenger behavior, and many passengers do alight out of front doors, extending dwell time as passengers must wait to board. The only other variable besides alightings that is not significant at the 1 percent level is the interaction of high-floor times wheelchairs. This estimate is only significant at an 18 percent level, though this is likely because of the limited number of observations. A total of 11 wheelchairs were observed to board or alight during the 151 bus dwells, 8 of which were on high-floor buses. The estimate presented here is likely a reasonable one, which could be made more precise with a larger sample.

A third model was examined which includes a friction factor as suggested by the literature, calculated as the number of boardings times the number of alightings. Introducing this variable increased the model's explanatory power by very little, and while the friction factor was significant at the 5 percent level, it is very small, indicating that for every 1-unit increase in the product of boardings and alightings dwell time decreases by 0.06 seconds. It is interesting however to observe how the coefficients change between the second and third models. The coefficients for boardings and alightings increase, while the friction factor is negative and the constant term has decreased by 3.3 seconds. The net changes in estimated dwell times at various volumes of boarding and alighting passengers are presented in the Appendix, but overall estimated dwell times decrease at low passenger volumes (7 or less passengers boarding and 5 or less passengers alighting) and high passenger volumes (at least 13 passengers boarding and at least 9 passengers alighting), but estimated dwell times increase between these bounds. Thus, there is likely a friction effect that gives an advantage to small passenger volumes, but there may also be efficiencies at high passenger volumes that exert a greater influence than the passenger "friction" on dwell times.

Three models were also considered for the post-launch period (Table 4). The simplest model (Model 1) once again looks only at boardings, alightings, and wheelchairs, while Model 2 adds in a friction factor and Model 3 considers the dwell time impacts of customer confusion about fare payment and boarding policies.

Table 4. Dwell Time Models, Post-Launch

	Model 1 (Preferred)			Model 2			Model 3 (Customer Confusion)		
	Coeff.	*Std. Err.*	*p-value*	*Coeff.*	*Std. Err.*	*p-value*	*Coeff.*	*Std. Err.*	*p-value*
Constant	5.75 *	1.56	0.000	4.17 *	1.83	0.025	-13.23	7.50	0.101
Boardings ("efficient")	1.12 *	0.28	0.000	1.37 *	0.38	0.001	2.07 *	0.71	0.012
Alightings	0.34	0.23	0.134	0.57	0.34	0.099	1.66	0.94	0.100
Wheelchairs	47.26 *	13.57	0.001	47.12 *	13.80	0.001	27.41	19.20	0.177
Friction factor	---	---	---	-0.03	0.05	0.515	---	---	---
Delayed Boardings	---	---	---	---	---	---	7.72 *	1.61	0.000
Observations	104			104			18		
R-squared	0.6736			0.6748			0.8821		

Notes:
[1] Models 1 and 2 have been corrected for heteroskedasticity and use robust standard errors. There was not evidence of heteroskedasticity for Model 3.
[2] Coefficients with an asterisk next to them are statistically significant at the 5% level.
[3] The friction factor is equal to boardings * alightings.

The results from the post-launch data collection show that the implementation of SBS fundamentally transformed the relationship between dwell times and passenger activity. The scatter charts shown previously (Figures 2 and 3) show that boardings are still a stronger determinant of dwell time than alightings but the relationship has weakened. No high-floor buses were in use on the SBS line, so high-floors do not contribute to dwell time in the post-launch period.

As outlined in the methodology, Models 1 and 2 present only the "efficient" boardings of passengers who boarded without delay due to confusion, and use a larger sample than Model 3. These efficient boardings took only 1.12 seconds per passenger in the preferred, simpler model (Model 1). Alightings continue to have a small and statistically insignificant impact on dwell times, while the marginal dwell time per wheelchair has not changed dramatically. The introduction of a friction factor in Model 2 does very little to increase the explanatory power of the regression, and has a similar impact as in the pre-launch Model 3. The net effects of the introduction of a friction factor at different levels of passenger activity are presented in the Appendix of this report. The first model is chosen here as the preferred model due to its greater ease of interpretation and relatively strong explanatory power. For ease of comparison the preferred models from pre- and post-launch are presented side-by-side in Table 5 below.

Table 5. Comparison between Pre- and Post-Launch Dwell Models

	Pre-Launch	Post-Launch	% Change	Significant?
Constant	14.42 *	5.75 *	-60.1%	Yes
Boardings	3.52 *	1.12 *	-68.1%	Yes
Alightings	0.02	0.34	2011.6%	No
Wheelchairs	35.62 *	47.26 *	32.7%	No
High Floor * Boardings	0.85 *	---	---	---
High Floor * Wheelchairs	10.02	---	---	---
Observations	151	104		
R-squared	0.8394	0.6736		

Notes:
[1] The coefficient estimates presented are from pre-launch Model 2 and post-launch Model 1.
[2] Coefficients with an asterisk next to them are statistically significant at the 5% level.
[3] The significance in difference in coefficients is determined with the formula
$Z = (b_1 - b_2) / \mathrm{sqrt}(SEb_1^2 + SEb_2^2)$, with significance at the 5% level.

The most important finding is that dwell time per passenger boarding has decreased 68.1 percent, from 3.52 to 1.12 seconds. The constant has also decreased 60 percent, further reducing the predicted dwell times with SBS. The reduction in the constant may come partially from reconfigurations of stops that have separated SBS and Local stops, reducing bus conflicts and making it easier for buses to consistently stop directly precisely at their designated locations. In addition, by using only low-floor buses, SBS avoids 0.85 additional seconds of dwell per passenger boarding and 10.02 seconds of dwell per wheelchair boarding or alighting. Alightings and wheelchairs both show increases in their coefficient estimates, but this is misleading. The estimate for alightings is not significant in either time period, and increases by a very small amount over a baseline that is close to zero. The statistical significance of the changes in coefficients was tested (*22*). While the change in the boarding coefficient and the constant are significant, the change in the alighting coefficient is not significant, and while each wheelchair estimate is significantly different from zero, the two coefficient estimates are not statistically significantly different from each other. A much larger sample would be needed to precisely measure wheelchairs' impacts on dwell times. During the pre-launch period, a total of 11 wheelchairs were observed to board or alight during the 151 bus dwells; during the post-launch period, only 6 wheelchair boardings or alightings were observed.

Model 3 presents the analysis of the contribution of customer confusion to dwell times, as outlined in the methodology. Within the subset of observations that had full data for Model 3, efficient boardings took 2.07 seconds per passenger, while boardings of passengers who were confused took on average 5.7 seconds longer (7.72 seconds). When buses wait for passengers to pay, this is a very substantial delay when even a small number of passengers are confused about fare payment. For example, in the data collection underlying this model, on one occasion 24 people boarded efficiently in 18 seconds, and the next 6 passengers boarded in 1 minute and 25 seconds. In another case, 5 people boarded efficiently in 17 seconds, and 1 additional passenger boarded in 8 seconds. This underscores the connection between customer communications and bus performance. According to this data, passengers who are confused about fare payment on average increase dwell times almost four times as much as other customers, delaying buses en route.

Wait Assessment (WA: Absolute and Relative)

WA is the primary performance indicator for NYCT, and is an important measure of reliability of bus service. Absolute WA (using a standard of scheduled headway +3/+5 minutes during the peak/off-peak) and relative WA (using a standard of 25% of scheduled headway) give somewhat different results, since the relative WA is a stricter standard for routes with frequent service such as the SBS Bx41.

It is also important to keep in mind when interpreting all the PIs reported on by day type (weekday, Saturday, Sunday) that the Saturday and Sunday PIs are based on only one month of Saturdays or Sundays, and thus represent one fifth the number of observations underlying the weekday PIs. As such, particularly good or bad performance on a single day is more likely to exert a strong influence on PIs for Saturdays and Sundays than on weekdays in this report.

Table 6. Absolute WA (Within Scheduled Headway +3/+5 minutes)

		Pre-Launch	Post-Launch	% Pts Change	% Change
Bx41 Limited/SBS	Weekday	**74.9%**	**81.6%**	**6.7%**	**8.9%**
	Saturday	---	84.6%	*5.5%*	*7.0%*
	Sunday	---	77.5%	*-1.6%*	*-2.0%*
Bx41 Local	Weekday	**78.3%**	**88.1%**	**9.8%**	**12.5%**
	Saturday	79.1%	80.4%	1.3%	1.6%
	Sunday	79.1%	86.6%	7.5%	9.5%

Table 7. Relative WA (Within Scheduled Headway +25%)

		Pre-Launch	Post-Launch	% Pts Change	% Change
Bx41 Limited/SBS	Weekday	**69.9%**	**69.3%**	**-0.6%**	**-0.9%**
	Saturday	---	80.4%	*14.3%*	*21.6%*
	Sunday	---	73.0%	*1.7%*	*2.4%*
Bx41 Local	Weekday	**68.8%**	**81.3%**	**12.5%**	**18.2%**
	Saturday	66.1%	73.3%	7.2%	10.9%
	Sunday	71.3%	80.9%	9.6%	13.5%

The absolute WA standard shows significant improvement to both the SBS and Local service for the Bx41. Absolute WA on weekdays increased by 6.7 percentage points for the Bx41 SBS (and by 9.7 percent over the 90-day baseline period presented in the Appendix). The weekend period for the SBS is not directly comparable to the pre-launch time period, which had only local bus service. However, the reliability of weekend SBS service in the first month represents a significant improvement over the reliability of the local service in the pre-launch period, particularly on Saturdays. The lower performance of the SBS Bx41 on Sundays may be partially because of the fewer data points from looking at only one month of Sundays in both the pre- and post-launch periods. While Absolute WA on the SBS Bx41 was 1.6 percentage points lower than on the previous Sunday local service when compared to the 30-day pre-launch period, a comparison to the 90-day pre-launch period (presented in the Appendix) shows instead a 0.8 percentage point increase.

The local service has also improved dramatically with the introduction of the new SBS service. On weekdays, the Absolute WA for the Bx41 Local increased by 9.8 percentage points, and weekend service also improved by 1.3 to 7.5 percentage points. The improvements in local service are expected, since the local service also benefits from many of the corridor upgrades such as the bus lane and bus stop enhancements.

Relative WA is a stricter standard for the Bx41 SBS than absolute WA, and as such shows less dramatic improvement. SBS scheduled headways are at most 10 minutes, and are 7-9 minutes during peak periods, meaning that 25 percent of scheduled headway is always stricter than even the +3 minutes peak period standard of Absolute WA. The Relative WA is also a stricter standard for the SBS than it was for the Limited route, since headways on the Limited route were longer (10-15 minutes during peak periods). As such, the stability of Relative WA for weekday SBS obscures actual performance improvements, since increased reliability is offset by the stricter standards created by shorter headways under SBS. Conversely, the Relative WA standard became less strict for the local bus with the new schedule after the SBS launch. With the shifting priority toward SBS service on the corridor, headways on the Bx41 Local were increased from 7-10 minutes throughout the day to 12 minutes under the new schedule. Performance improvements thus may be overstated for the Bx41 Local when comparing across the schedule change. Relative WA is thus a useful PI, but should be interpreted with care when compared across schedule changes that alter headways.

Relative WA for SBS weekday service dropped slightly (0.6 percentage points) in comparison to the 30-day pre-launch period, although it increased by 2 percentage points over the 90-day baseline for weekday service, presented in the Appendix. Saturday SBS service under the Relative WA improved by 14.3 percentage points in comparison to the baseline local service, and Sunday SBS service improved by

1.7 percentage points. For the Bx41 Local, the Relative WA shows similar patterns as the absolute WA, with weekday improvements of 12.5 percentage points, and weekend improvements of 7.2 to 9.6 percentage points.

Table 8. Absolute WA, Weekday Peak Periods Only

		Pre-Launch	Post-Launch	% Pts Change	% Change
Bx41 Limited/SBS	AM Peak	78.2%	90.6%	**12.4%**	**15.8%**
	PM Peak	70.0%	86.8%	**16.8%**	**24.1%**
Bx41 Local	AM Peak	81.0%	87.9%	**6.9%**	**8.5%**
	PM Peak	68.9%	83.2%	**14.2%**	**20.7%**

Notes:

[1] AM Peak is defined as trips starting between 7:00AM and 9:00AM on weekdays; PM Peak is 4:00PM to 7:00PM.

[2] The pre-launch period is April 28, 2013 - May 27, 2013. The post-launch period is July 14, 2013 - August 12, 2013.

Table 8 presents Absolute WA for weekday peak periods. Interestingly, Absolute WA for SBS was significantly higher during peak periods than overall on weekdays, at 90.6 percent for the AM peak compared to 81.6 percent overall for weekdays. The improvements in Absolute WA are greater in peak periods, with Absolute WA increasing by 12.4 percentage points for the AM peak period (15.8 percent), compared to 6.7 percentage points for weekdays overall (8.9 percent, see Table 6). While performance is lower during the congested PM peak than during the AM peak, the magnitude of improvement during the PM peak was even greater, with Absolute WA increasing by 16.8 percentage points (24.1 percent). SBS has proven particularly effective at improving WA during peak periods.

On-Time Performance (OTP)

OTP has increased noticeably for both the local and SBS service since the introduction of SBS on the Bx41 corridor, as shown in the Table 9.

Table 9. On-Time Performance (OTP)

		Pre-Launch	Post-Launch	% Pts Change	% Change
Bx41 Limited/SBS	Weekday	**65.6%**	**83.9%**	**18.3%**	**27.9%**
	Saturday	---	87.6%	*21.2%*	*31.9%*
	Sunday	---	86.5%	*18.3%*	*26.8%*
Bx41 Local	Weekday	**66.7%**	**79.5%**	**12.8%**	**19.2%**
	Saturday	66.4%	73.7%	7.3%	11.0%
	Sunday	68.2%	78.5%	10.3%	15.1%

Weekday OTP for the SBS is 83.9 percent, which represents an 18.3 percentage point increase over the Limited service (and a 27.9 percent increase), and weekend OTP is even higher for SBS. The local service also experienced significant improvements in OTP, likely for the same reasons as WA improvements on local service (the benefits of the bus lane and bus stop enhancements). OTP increased between 7.3 and 12.8 percentage points for local service over the pre-launch period. The introduction of SBS on the Bx41 corridor has dramatically improved OTP for both the local and SBS service.

Running Time

The one-way running time on the Bx41 corridor has improved substantially. The running times reported in Table 9 are the average one-way running times for all trips starting between 6:00 AM and 10:00 PM. The data for southbound running times should be interpreted with some caution, since the last southbound time point was adjusted slightly between the pre and post study periods, slightly overstating the running times in the pre period. In addition, AVL data presents difficulties in identifying the exact departure and arrival times at origins and terminals of a bus route. For this reason, NYCT uses a 1/8 mile buffer around the origin/terminal rather than the actual stop location when determining departure or arrival times, which is consistent with industry best practices and improves the reliability of running time data (*5*, *7*). As such, the actual end-to-end running times may be one or two minutes longer than those reported here. The data presented in Table 12, running time within the bus lane only, are not subject to these data issues and are thus more reliable and informative as to the potential running time improvements that can result generally from SBS.

Table 10. Average End-to-End Running Time (6:00 AM-10:00 PM)

		Pre-Launch			Post-Launch			Percent Change			Minutes
		NB	SB	Overall	NB	SB	Overall	NB	SB	Overall	Overall
Bx41 Limited/SBS	Weekday	41.5	40.3	**40.9**	35.1	34.5	**34.8**	-15.3%	-14.3%	**-15.0%**	**-6.1**
	Saturday	---	---	---	34.9	32.7	**33.8**	*-21.1%*	*-21.5%*	***-21.3%***	***-9.1***
	Sunday	---	---	---	33.2	32.3	**32.7**	*-17.3%*	*-16.8%*	***-17.0%***	***-6.7***
Bx41 Local	Weekday	47.2	45.0	**46.1**	44.6	41.4	**43.0**	-5.4%	-8.0%	**-5.4%**	**-3.0**
	Saturday	44.3	41.6	**42.9**	42.8	40.0	**41.4**	-3.3%	-3.9%	**-3.3%**	**-1.5**
	Sunday	40.1	38.8	**39.4**	40.0	38.7	**39.3**	-0.3%	-0.3%	**-0.3%**	**-0.1**

Note: Data presented are the average running times for trips starting between 6:00 AM to 10:00 PM.

Running times improved for all services on the Bx41 corridor, especially on the SBS route. Average running times improved by 6.1 minutes (15 percent) on weekdays on the Bx41 SBS in comparison to the Bx41 Limited service. The improvement in travel times on the weekends was even more substantial, since previously only local service was available. With the introduction of weekend SBS service, passengers are now able to travel on the Bx41 corridor in 17 to 21 percent less time than previously. Running time improvements were smaller on the Bx41 Local route, though weekday running times still decreased by 3 minutes (5.4 percent).

Table 11. Average End-to-End Running Time, Weekday Peak Periods Only

		Pre-Launch			Post-Launch			Percent Change			Minutes
		NB	SB	Overall	NB	SB	Overall	NB	SB	Overall	Overall
Bx41 Limited/SBS	AM Peak	38.8	38.7	**38.7**	34.9	32.3	**33.6**	-10.0%	-16.6%	**-13.3%**	**-5.2**
	PM Peak	42.1	41.1	**41.7**	36.3	35.0	**35.6**	-13.7%	-14.9%	**-14.5%**	**-6.0**
Bx41 Local	AM Peak	44.9	46.1	**45.5**	43.5	42.0	**42.8**	-3.2%	-8.8%	**-6.0%**	**-2.7**
	PM Peak	50.2	48.2	**49.2**	47.7	45.3	**46.5**	-4.9%	-6.1%	**-5.5%**	**-2.7**

Note: AM Peak is defined as trips starting between 7:00AM and 9:00AM on weekdays; PM Peak is 4:00PM to 7:00PM.

Examining the peak periods, it is clear that the changes are similar to those observed on weekdays overall, with reductions being slightly less in terms of minutes, particularly in the AM peak which is already less congested than the PM peak. This means that conversely the running times have improved more than the overall rates for off-peak periods. It is difficult to isolate how much of this pattern is due to the increased passenger volumes at peak periods versus possibly higher violations of bus lanes by private automobiles during congested peak periods.

The effects on running time are also examined for the portion of the route with painted bus lanes to isolate their impact. The data presented below is for 6,427 bus trips in the pre-launch period and 9,529 bus trips in the post-launch period.

Table 12. Running Time Between Time Points Within the Bus Lane

		Pre-Launch		Post-Launch			
		Average	Std. Dev.	Average	Std. Dev.	Change (Mins)	% Change
Bx41 Limited/SBS	Weekday	18.3	3.4	15.2	2.2	**-3.1**	**-17.1%**
	Saturday	---	---	14.5	2.4	***-5.0***	***-25.6%***
	Sunday	---	---	13.8	2.5	***-3.5***	***-20.4%***
Bx41 Local	Weekday	20.5	4.8	18.8	4.0	**-1.7**	**-8.4%**
	Saturday	19.5	3.9	18.3	3.4	**-1.1**	**-5.9%**
	Sunday	17.4	3.3	17.1	3.3	**-0.3**	**-1.7%**

In all cases, the average running time in the bus lanes as well as its reliability (where a smaller standard deviation means more consistent, reliable service) has improved. Weekday running times have improved substantially, decreasing by 17.1 percent on the SBS and 8.4 percent on the local. These improvements are greater than those on the entire length of the route, indicating that the bus lanes do make a difference for running times. In this comparison, the impact of the bus lanes on local service is apparent. The weekday improvements on the Bx41 Local were about 55 percent higher within the bus lanes than on the route as a whole including the bus lane (8.4 percent versus 5.4 percent), and weekend performance shows similar patterns. The improvements on the local route are of interest since they show what performance impacts might be expected when only bus lanes are implemented, rather than the full suite of SBS technologies. It is clear that bus lanes can improve performance, but are not singularly responsible for the time savings of SBS.

As shown in Table 13, when the running times in the bus lanes are examined during the weekday PM peak period (the most congested time period), running time reductions are still notable, but are less than overall.

Table 13. Running Time Between Time Points Within the Bus Lane, PM Peak Period

		Pre-Launch		Post-Launch			
		Average	Std. Dev.	Average	Std. Dev.	Change (Mins)	% Change
Bx41 Limited/SBS	Overall	18.6	2.6	16.4	2.0	**-2.2**	**-11.7%**
	Northbound	18.6	2.8	16.3	2.3	**-2.3**	**-12.6%**
	Southbound	18.5	2.3	16.5	1.7	**-2.0**	**-10.7%**
Bx41 Local	Overall	23.5	4.0	22.3	2.6	**-1.3**	**-5.3%**
	Northbound	23.3	3.9	22.1	2.7	**-1.1**	**-4.9%**
	Southbound	23.8	4.1	22.4	2.4	**-1.4**	**-5.8%**

The running time reductions vary somewhat by direction, but overall the weekday PM peak period running time for SBS has decreased by 11.7 percent and the local by 5.3 percent, compared with 17.1 and 8.4 percent respectively on weekdays across all time periods. The PM peak is the most congested time period, and these results show that SBS is still able to make a significant impact on running times even in the most challenging time periods, but there is room for improvement. Camera enforcement of the bus lanes has not yet begun, and increased enforcement is likely to improve the efficacy of the bus lanes. Other factors, such as the introduction of transit signal priority and increased customer familiarity with SBS, will also contribute to further decreases in running time in coming months.

Bus Bunching

Bus bunching has decreased dramatically for all service on the Bx41 corridor.

Table 14. Bus Bunching

		Pre-Launch	Post-Launch	% Pts Change	% Change
Bx41 Limited/SBS	Weekday	**2.7%**	**1.0%**	**-1.7%**	**-63.0%**
	Saturday	---	0.1%	*-9.8%*	*-99.0%*
	Sunday	---	0.4%	*-6.8%*	*-94.4%*
Bx41 Local	Weekday	**6.2%**	**0.8%**	**-5.4%**	**-87.1%**
	Saturday	9.9%	1.4%	-8.5%	-85.9%
	Sunday	7.2%	1.5%	-5.7%	-79.2%

Before the launch of SBS, 2.7 percent of bus intervals were bunched on the weekday Bx41 Limited (buses within 90 seconds of each other), and between 6 and 10 percent of bus intervals were bunched on the local. By comparison, bus bunching for the borough of the Bronx as a whole was 4.8 percent during the 30-day pre-launch period. With the introduction of SBS, bunching on the SBS fell to only 1.0 percent compared to the former Bx41 Limited, representing a 63 percent reduction in bunching (1.7 percentage points). Weekend bus bunching on the SBS line is extremely low, at only 0.1 to 0.4 percent, representing reductions of over 90 percent with respect to the pre-launch local service. Bunching on the Bx41 Local fell by 5.4 to 8.5 percentage points, translating to reductions in bunching on the Bx41 Local of more than 79 to 87 percent for all days. Bus bunching at all times is now much lower than the Bronx borough average. It is important to note however that while bus bunching likely improved substantially because of the introduction of bus lanes and reduced dwell times on SBS, the reduction in bus bunching on the local route is also partially an outcome of its increased headways.

Ridership and Revenue

Ridership and revenue have increased substantially on the Bx41 SBS route and corridor, as is shown in Table 15, which compares average daily ridership and revenue during the 2013 post-launch period to the same period in summer 2012.

Table 15. Average Daily Ridership and Revenue

		July 14-Aug 12, 2012		Post-Launch 2013		Percent Change	
		Ridership	Revenue	Ridership	Revenue	Ridership	Revenue
Bx41 Limited/SBS	Weekday	3,684	$4,929	8,538	$13,061	**131.8%**	**165.0%**
	Saturday	---	---	6,054	$9,751	---	---
	Sunday	---	---	4,715	$7,522	---	---
Bx41 Local	Weekday	13,731	$18,886	10,481	$15,379	**-23.7%**	**-18.6%**
	Saturday	13,259	$19,732	8,718	$13,888	-34.2%	-29.6%
	Sunday	9,872	$14,704	6,999	$11,075	-29.1%	-24.7%
Bx41 Corridor	Weekday	17,415	$23,815	19,019	$28,440	**9.2%**	**19.4%**
	Saturday	13,259	$19,732	14,773	$23,639	11.4%	19.8%
	Sunday	9,872	$14,704	11,713	$18,597	18.7%	26.5%
Bronx (Borough) *	Weekday	471,594	---	482,134	---	**2.2%**	---
	Saturday	303,337	---	319,487	---	5.3%	---
	Sunday	241,665	---	249,145	---	3.1%	---

Note: Borough level ridership and revenue figures are for July 1 to 31.

Average weekday daily ridership on the SBS route was 131.8 percent higher than on the limited route in 2012. However, ridership on the local route decreased as passengers shifted to SBS buses. This pattern is to be expected not only because SBS provides an experience that is preferable to many customers, but also because the launch of SBS was paired with schedule changes that increased the frequency of the SBS and decreased the frequency of the local route. In fact, before the launch of SBS on June 30, 21 percent of scheduled weekday Bx41 bus trips were for the Bx41 Limited route. After the launch of SBS, the weekday schedule became evenly split, with 50 percent of trips on SBS and 50 percent on the local route. The shifts in ridership between the two services follow the changes in service provision relatively closely. During the pre-launch time period in 2013, the Bx41 Limited carried 24 percent of the Bx41 weekday bus ridership (see Appendix Table A9); post-launch, SBS carried 45 percent of the average weekday bus ridership. It will be interesting to see if the corridor's ridership continues to shift toward SBS over time.

It is important therefore to also look at the corridor-level ridership (the sum of both the SBS and local service). On net, the Bx41 corridor ridership increased 9.2 percent from 2012 to 2013, which is in contrast to an increase in borough-level ridership of only 2.2 percent from July 2012 to July 2013. If the 2.2% captures general trends of increases in bus ridership over the time period, the 7.0 percent difference between the 9.2 percent increase on the Bx41 corridor and the 2.2 percent increase in the borough may be substantially attributable to the increased quality of service provided by SBS. Interestingly, changes in revenue are of different magnitudes than changes in ridership. A decrease in average ridership on the local route of 23.7 percent on weekdays is associated with an 18.6 percent decrease in revenue, whereas a 131.8 percent increase in average ridership on SBS is associated with a 165 percent increase in revenue. This suggests that average revenue per passenger and fare compliance may benefit from SBS.

The appendix also presents an alternative way of examining ridership and revenue by looking at the difference in difference for average daily ridership and revenue, comparing to seasonal patterns on the corridor rather than long-term trends in the borough. Instead of comparing summer 2012 to summer 2013 for the corridor and contrasting that with borough-level changes, the ridership and revenue comparison in the Appendix Table A9 compares the pre- and post-launch time periods on the Bx41 corridor in 2013 and contrasts that with the changes on the corridor during the same time periods in 2012. This alternative method assumes that the changes in seasonal patterns in 2013 compared to 2012 are attributable to the introduction of SBS. It is crucial to control for the seasonal differences by comparing to the patterns observed in 2012. The pre-launch period (April 28 to May 27) is during the school year, while the post-launch period (July 14 to August 12) is not, and summer bus ridership is substantially lower for this reason. Ridership is also lower in summer for a number of other reasons, including vacationing workers and college students (the Bx41 passes by Fordham University and is near Hostos Community College).

The results from the difference in difference comparison in Appendix Table A9 are not substantially different – instead of a 9.2 percent increase in corridor ridership, there is a 9.1 percent increase with this methodology. Weekday SBS ridership represents a 101.4 percent increase in comparison to patterns observed on the limited route in 2012, in comparison to the 131.8 percent presented in Table 15.

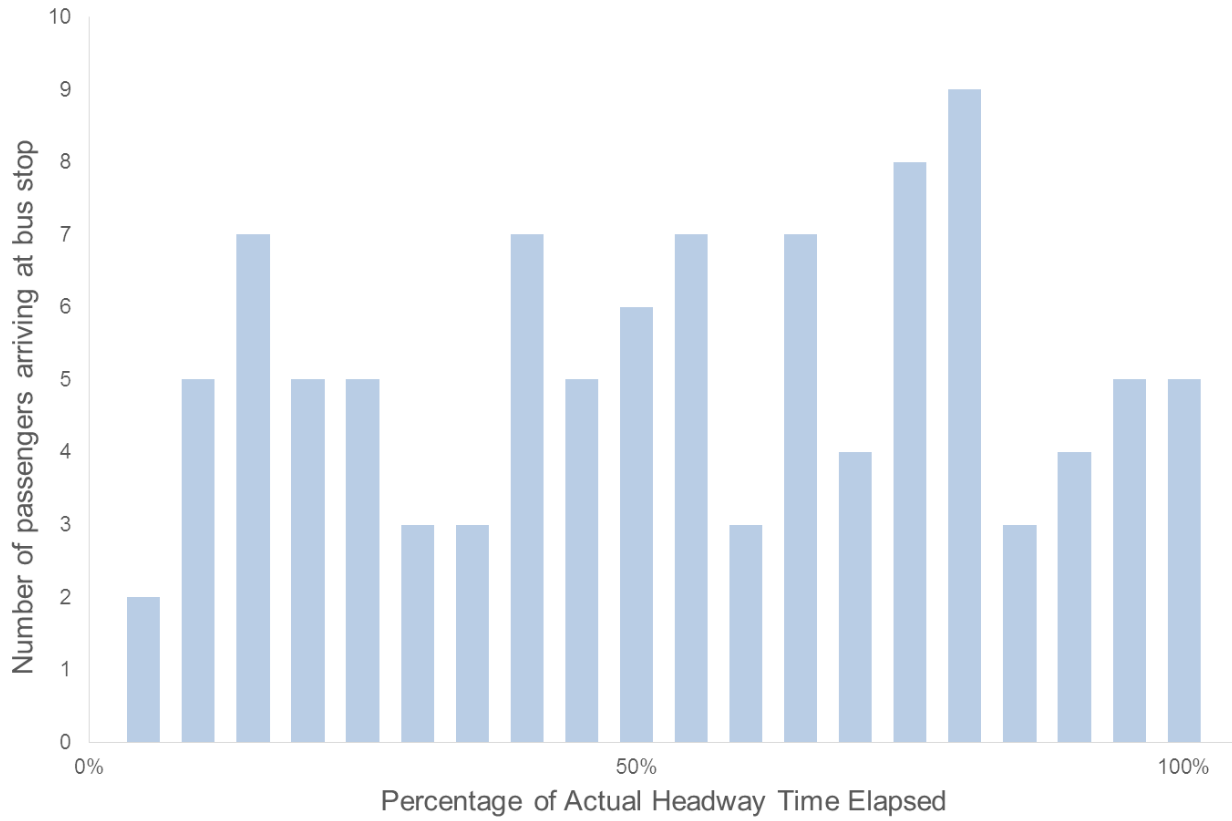
It is important to also note, however, that SBS is not the only change across these time periods that could impact the numbers reported here. With the launch of SBS also came the discontinuation of the Bx55 route, which overlapped with the Bx41 from Fordham Road to East Gun Hill Road. Some of the increase in ridership is thus likely from passengers switching to the Bx41 from the Bx55, although ridership on the overlapping segment of the Bx55 was relatively low. In addition, student transit passes are not valid in summer for students who are not enrolled in summer school, and thus a (very small) portion of the revenue increase may be due to students paying full fares rather than using free or reduced fare passes.

Randomness of Passenger Arrivals, for Use with Weighted WA

The preceding analyses examine impacts on bus performance. This analysis presents the findings of measurements of randomness of passenger arrivals, which is presented not as a performance indicator but rather to verify this assumption for the future development of a passenger-weighted WA.

Figure 2 below presents the results of the data collection on passenger arrivals. The data reflects the arrival times of 103 passengers who waited for 24 different bus arrivals. The height of each bar represents the number of passengers who arrived within that 5 percent "bucket" of elapsed headway before the next bus's arrival. For instance, the first data point indicates that out of the 24 different headways observed (before each of the 24 buses), two of the 103 people arrived during the interval from 5 percent to 10 percent of their headway elapsed.

Figure 2. Passenger Arrivals by Percentage of Headway Time Elapsed (Five Percent Buckets)



The average passenger arrived at the bus stop 52.3 percent of the way through their headway. If passenger arrivals were completely random, we would expect the average passenger to arrive halfway through a headway, and the data are close to this, suggesting that randomness of passenger arrivals may be a reasonable assumption.

In addition, a simple linear regression was run on the data presented in this chart, regressing the number of passenger arrivals in each 5 percent bucket on the percent of headway elapsed. If passengers tend to arrive right before a bus, or arrive more frequently the sooner a bus is coming, one would expect the coefficient on the percent of headway elapsed to clearly show a positive trend, and for the regression to have reasonable explanatory power.

Table 17. Regression of Passenger Arrivals on Percentage of Headway Time Elapsed

	Coeff.	*Std. Err.*	*p-value*
Constant	4.54*	1.51	0.000
% of headway elapsed	0.012	0.015	0.447
Observations	20		
R-squared	0.0325		

However, the regression coefficient on percentage of headway elapsed is small (0.012) and insignificant ($p = 0.447$). The coefficient means that in this data the rate of passenger arrivals increases by 0.012 people for every 1 percent of headway elapsed. Phrased differently, this means that each "bucket" of 5 percent of a headway is predicted to have 0.058 more people than the previous bucket (a number that is not statistically significantly different from zero). This result does not suggest a strong upward trend on passenger arrivals over time during a headway. Furthermore, the regression model has very little explanatory power ($R^2 = 0.0325$), explaining just over 3 percent of the variation in the data. The shape of the chart, average arrival of passengers, and regression results all suggest that it is reasonable to assume randomness of passenger arrivals when constructing a model of weighted WA.

When formulating a passenger-weighted WA, NYCT System Data and Research will take advantage of existing algorithms that are being continuously refined, and which use Bus Time and AFC data to report the number of boardings and alightings at each SBS stop. Passenger counts from AFC data can be matched to buses from Bus Time data, and actual headways can also be calculated from Bus Time data. Without the assumption of randomness of passenger arrivals, it would not be straightforward to translate passenger counts to total wait times of passengers during each headway. However, because this assumption is reasonable, the count of passengers arriving during any given headway can be translated into an expected total wait time of passengers by multiplying the passenger count by the expected wait time, which is one half of the actual headway. This theoretical expected wait time is quite close to the average wait time observed during data collection. The average passenger among the 103 observations arrived 52.3 percent through the headway, thus waiting 47.7 percent of the actual headway.

STUDY LIMITATIONS & FUTURE RESEARCH

The results of this study rely on post-SBS measurements taken over a 30-day period starting after a two-week adjustment period. However, there are some aspects of SBS service that were still in flux during data collection. Bus bulbs had not yet been constructed, and TSP and camera enforcement of the bus lane were not yet implemented. Thus, the post-SBS results presented here likely do not capture the full magnitude of performance improvements that will be achieved after complete implementation of the Bx41 SBS upgrade. Another limitation of the use of a 30-day period is that Saturday and Sunday PIs are based on a small number of days, so particularly good or bad performance on a single Saturday or Sunday can exert a strong influence on PIs for those day types. Weekday PIs are based on more data, and are therefore less likely to be swayed by isolated incidents.

The dwell time analysis was a unique contribution of this report, drawing on data not typically available for NYCT buses. The model used could however be further refined with greater data collection and integration. Algorithms are still being refined at NYCT to join AFC and Bus Time data to model bus boardings, alightings, and load factors. In the future, information on bus load factors could be included in the dwell time analysis, since the literature indicates that, above a certain threshold, crowding likely slows passenger boardings and alightings. Load factor would be particularly important to include in modeling dwell times for lines such as the Bx12 SBS, which is consistently at capacity for much of the day. In addition, data collection that measures each door separately could further refine dwell time analyses, especially if the highest volumes of passengers are still boarding or alighting at the front door. Lastly, with regards to the dwell time model for local and limited buses, the dwell time per passenger is potentially also affected by the overall mix of customers paying with MetroCards or coins. Including information on the share of different fare media could further increase the reliability and flexibility of the regression results to model dwell times on other routes that may have a different mix of fare media.

Another interesting insight of this research is the impact of customer communications on bus performance. Even a relatively small subset of customers confused about fare payment can have a substantial impact on bus performance. Customer communications at SBS stops could include more visually striking or detailed information. Some customers are still somewhat confused or unaware of all-door boarding policies, the location of local versus SBS stops, and fare policies (transfer policies; which SBS fare machines accept what forms of payment; where to buy MetroCards outside of subway stations; the need not only to obtain a receipt, but also to hold onto it for the entire trip). While addressing these concerns not only increases customer satisfaction, it also has the potential to increase bus performance. These impacts on performance will likely vary, and may be even greater on SBS lines such as the M34 and M15 which serve high volumes of visitors and tourists. The analysis of the impact of customer confusion here relied on a relatively small sample. A more complete study could give better information on the performance impacts of customer confusion, or of specific communications strategies.

This report presents a series of comparisons that could be useful to evaluate changes in performance on bus routes over two or more time periods. Most of the data underlying the PIs presented is based on Bus Time data, which will be available for all NYCT buses in 2014. PIs based on Bus Time data require no additional data collection efforts. NYCT can take advantage of this data to analyze the performance impacts of the upcoming launch of the B44 SBS in Brooklyn, launching November 17, 2013. In addition, the same reports presented here could be re-generated in the future after more time has elapsed in order to quantify long-term performance impacts of SBS. Furthermore, these types of reports need not be restricted only to launches of new bus services. They provide a useful framework for examining performance changes over distinct time periods, and could be used for instance to analyze the impact of long-term construction on a bus route, or to see for instance the performance impacts of new fare media or an upgraded bus fleet. These types of reports are also flexible on being able to include new PIs as they are developed. Once a passenger-weighted WA metric is developed and tested, it could be included in future reports, and depending on data availability it may even be possible to create some reports on passenger-weighted WA retroactively.

CONCLUSIONS

Performance on the Bx41 corridor has improved significantly for both the SBS and local routes.

Table 18. Summary of Weekday PIs Before and After Launch of SBS

		Pre-Launch	Post-Launch	Unit Change	% Change
Bx41 Limited/ SBS	Dwell Time per Pax Boarding	3.52 sec	1.12 sec	-2.4 sec	-68.2%
	WA (Absolute, +3/+5)	74.9%	81.6%	6.7%	8.9%
	WA (Relative, +25%)	69.9%	69.3%	-0.6%	-0.9%
	OTP	65.6%	83.9%	18.3%	27.9%
	Running Time (End-to-end)	40.9 min	34.8 min	-6.1 min	-15.0%
	Running Time (Bus Lane)	18.3 min	15.2 min	-3.1 min	-17.1%
	Bus Bunching	2.7%	1.0%	-1.7%	-63.0%
Bx41 Local	WA (Absolute, +3/+5)	78.3%	88.1%	9.8%	12.5%
	WA (Relative, +25%)	68.8%	81.3%	12.5%	18.2%
	OTP	66.7%	79.5%	12.8%	19.2%
	Running Time (End-to-end)	46.1 min	43.0 min	-3.0 min	-6.6%
	Running Time (Bus Lane)	20.5 min	18.8 min	-1.7 min	-8.4%
	Bus Bunching	6.2%	0.8%	-5.4%	-87.1%

	Seasonally Adjusted Change	
	Ridership	Revenue
Bx41 Corridor	9.2%	19.4%
Bx41 Limited/SBS	131.8%	165.0%

Notes:

[1] The pre-launch period is April 28, 2013 - May 27, 2013. The post-launch period is July 14, 2013 - August 12, 2013.

[2] The pre-launch estimate for Dwell Time per Passenger Boarding applies to both Limited and Local buses, since fare collection is the same on these buses. The post-launch estimate applies only to SBS.

[3] Fare evasion is only measured for the Bx41 in the pre-launch period, and the range of fare evasion rates for the rest of the SBS system is presented here. The post-launch fare evasion and change in fare evasion are forecasts.

[4] Change in ridership and revenue compares ridership and revenue in the post-launch period to the same dates in 2012.

Table 18 presents the overall weekday PIs from this report in one table. The only PI that does not show improvement is the Relative WA for SBS, though as discussed earlier the Relative WA is a stricter standard for the Bx41 SBS than for the Limited due to the shorter headways of SBS service. When headways are also changing, Absolute WA will provide a more directly comparable overview of reliability across schedule changes.

While all PIs show evidence of substantial performance improvements, it is clear that immediately after its implementation SBS has been particularly effective at dramatically reducing dwell time per passenger, bus bunching, and running time, and increasing OTP.

Furthermore, these are only the short-term improvements, and performance is expected to continue to improve over coming months. TSP and camera enforcement have not yet been implemented, both of which could have significant impacts on performance based on the literature. Bus bulbs are also slated for construction in late 2013, and a new transit plaza is planned for the Hub in 2015. Aside from continued technological and capital investment in the Bx41 corridor, performance is also likely to improve as more passengers become acquainted with SBS fare machines and cause less delay at bus stops. Customer communications strategies can make this transition easier.

As NYCT continues to pursue and develop SBS corridors elsewhere in the city, the results of this report strongly support the effectiveness of these investments for improving bus performance and passenger experience. The results of this data analysis as well as literature review suggest that

- **Bus lanes** should be provided for as much of the route as possible. They should be separated to the extent feasible to allow for the best bus performance, particularly during congested peak periods. Median-running alignments may further improve performance if they are feasible on future corridors. Enforcement is also key to ensuring the efficacy of bus lanes.
- The use of **low-floor buses** reduces dwell times for all buses, and contributes to the time savings of SBS.
- **Off-board fare payment** and **all-door boarding** are very effective at reducing dwell times, but they are only effective to the extent that customers clearly understand both policies. Strong customer communications and strikingly clear signage can further improve dwell times. Customers who were confused about fare payment took on average almost four times as long to board as other customers.
- **Local routes** that share the bus lane with SBS routes can also expect to see significant performance improvements.

This study demonstrates that SBS upgrades are effective at immediately improving bus service on key bus corridors in New York City.

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APPENDICES

A1. Pre-Launch, Net Change to Estimated Dwell Times from Introduction of Friction Factor

	Alightings																			
Boardings	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	-2.31	-1.75	-1.19	-0.63	-0.07	0.48	1.04	1.60	2.16	2.71	3.27	3.83	4.39	4.94	5.50	6.06	6.62	7.17	7.73	8.29
2	-1.97	-1.47	-0.97	-0.47	0.03	0.53	1.03	1.53	2.03	2.53	3.03	3.53	4.03	4.53	5.03	5.54	6.04	6.54	7.04	7.54
3	-1.64	-1.20	-0.75	-0.31	0.13	0.58	1.02	1.46	1.91	2.35	2.80	3.24	3.68	4.13	4.57	5.01	5.46	5.90	6.34	6.79
4	-1.31	-0.92	-0.53	-0.15	0.24	0.63	1.01	1.40	1.78	2.17	2.56	2.94	3.33	3.72	4.10	4.49	4.87	5.26	5.65	6.03
5	-0.97	-0.64	-0.31	0.01	0.34	0.67	1.00	1.33	1.66	1.99	2.32	2.65	2.98	3.31	3.64	3.97	4.29	4.62	4.95	5.28
6	-0.64	-0.37	-0.10	0.18	0.45	0.72	0.99	1.27	1.54	1.81	2.08	2.35	2.63	2.90	3.17	3.44	3.71	3.99	4.26	4.53
7	-0.31	-0.09	0.12	0.34	0.55	0.77	0.98	1.20	1.41	1.63	1.84	2.06	2.27	2.49	2.70	2.92	3.13	3.35	3.56	3.78
8	0.03	0.18	0.34	0.50	0.66	0.82	0.97	1.13	1.29	1.45	1.61	1.76	1.92	2.08	2.24	2.40	2.55	2.71	2.87	3.03
9	0.36	0.46	0.56	0.66	0.76	0.86	0.96	1.07	1.17	1.27	1.37	1.47	1.57	1.67	1.77	1.87	1.97	2.07	2.17	2.27
10	0.69	0.74	0.78	0.82	0.87	0.91	0.95	1.00	1.04	1.09	1.13	1.17	1.22	1.26	1.30	1.35	1.39	1.44	1.48	1.52
11	1.03	1.01	1.00	0.99	0.97	0.96	0.95	0.93	0.92	0.91	0.89	0.88	0.87	0.85	0.84	0.82	0.81	0.80	0.78	0.77
12	1.36	1.29	1.22	1.15	1.08	1.01	0.94	0.87	0.79	0.72	0.65	0.58	0.51	0.44	0.37	0.30	0.23	0.16	0.09	0.02
13	1.69	1.56	1.44	1.31	1.18	1.05	0.93	0.80	0.67	0.54	0.42	0.29	0.16	0.03	-0.09	-0.22	-0.35	-0.48	-0.60	-0.73
14	2.03	1.84	1.66	1.47	1.29	1.10	0.92	0.73	0.55	0.36	0.18	-0.01	-0.19	-0.38	-0.56	-0.75	-0.93	-1.11	-1.30	-1.48
15	2.36	2.12	1.87	1.63	1.39	1.15	0.91	0.67	0.42	0.18	-0.06	-0.30	-0.54	-0.79	-1.03	-1.27	-1.51	-1.75	-1.99	-2.24
16	2.69	2.39	2.09	1.79	1.50	1.20	0.90	0.60	0.30	0.00	-0.30	-0.60	-0.90	-1.19	-1.49	-1.79	-2.09	-2.39	-2.69	-2.99
17	3.02	2.67	2.31	1.96	1.60	1.24	0.89	0.53	0.18	-0.18	-0.54	-0.89	-1.25	-1.60	-1.96	-2.32	-2.67	-3.03	-3.38	-3.74
18	3.36	2.94	2.53	2.12	1.71	1.29	0.88	0.47	0.05	-0.36	-0.77	-1.19	-1.60	-2.01	-2.43	-2.84	-3.25	-3.67	-4.08	-4.49
19	3.69	3.22	2.75	2.28	1.81	1.34	0.87	0.40	-0.07	-0.54	-1.01	-1.48	-1.95	-2.42	-2.89	-3.36	-3.83	-4.30	-4.77	-5.24
20	4.02	3.50	2.97	2.44	1.91	1.39	0.86	0.33	-0.19	-0.72	-1.25	-1.78	-2.30	-2.83	-3.36	-3.89	-4.41	-4.94	-5.47	-6.00

This table shows the net change in estimated dwell times resulting from the introduction of a friction factor in the pre-launch dwell time model. The entries are the sum of the changes to estimated boarding and alighting times, modeled using the revised dwell time model (see Table 3 in main text).

A2. Post-SBS, Net Change to Estimated Dwell Times from Introduction of Friction Factor

	Alightings																			
Boardings	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	-1.14	-0.95	-0.75	-0.56	-0.36	-0.17	0.02	0.22	0.41	0.60	0.80	0.99	1.18	1.38	1.57	1.76	1.96	2.15	2.35	2.54
2	-0.92	-0.76	-0.59	-0.43	-0.27	-0.10	0.06	0.22	0.39	0.55	0.71	0.88	1.04	1.20	1.37	1.53	1.69	1.86	2.02	2.18
3	-0.70	-0.57	-0.44	-0.30	-0.17	-0.04	0.10	0.23	0.36	0.50	0.63	0.76	0.90	1.03	1.16	1.30	1.43	1.56	1.70	1.83
4	-0.48	-0.38	-0.28	-0.17	-0.07	0.03	0.13	0.24	0.34	0.44	0.55	0.65	0.75	0.86	0.96	1.06	1.16	1.27	1.37	1.47
5	-0.26	-0.19	-0.12	-0.05	0.03	0.10	0.17	0.24	0.32	0.39	0.46	0.54	0.61	0.68	0.75	0.83	0.90	0.97	1.05	1.12
6	-0.05	0.00	0.04	0.08	0.12	0.17	0.21	0.25	0.29	0.34	0.38	0.42	0.47	0.51	0.55	0.59	0.64	0.68	0.72	0.76
7	0.17	0.18	0.20	0.21	0.22	0.23	0.25	0.26	0.27	0.28	0.30	0.31	0.32	0.33	0.35	0.36	0.37	0.38	0.40	0.41
8	0.39	0.37	0.36	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.21	0.20	0.18	0.16	0.14	0.12	0.11	0.09	0.07	0.05
9	0.61	0.56	0.51	0.47	0.42	0.37	0.32	0.27	0.23	0.18	0.13	0.08	0.03	-0.01	-0.06	-0.11	-0.16	-0.21	-0.25	-0.30
10	0.83	0.75	0.67	0.59	0.52	0.44	0.36	0.28	0.20	0.12	0.05	-0.03	-0.11	-0.19	-0.27	-0.34	-0.42	-0.50	-0.58	-0.66
11	1.05	0.94	0.83	0.72	0.61	0.50	0.40	0.29	0.18	0.07	-0.04	-0.15	-0.25	-0.36	-0.47	-0.58	-0.69	-0.80	-0.90	-1.01
12	1.27	1.13	0.99	0.85	0.71	0.57	0.43	0.30	0.16	0.02	-0.12	-0.26	-0.40	-0.54	-0.67	-0.81	-0.95	-1.09	-1.23	-1.37
13	1.48	1.32	1.15	0.98	0.81	0.64	0.47	0.30	0.13	-0.03	-0.20	-0.37	-0.54	-0.71	-0.88	-1.05	-1.22	-1.38	-1.55	-1.72
14	1.70	1.50	1.30	1.11	0.91	0.71	0.51	0.31	0.11	-0.09	-0.29	-0.49	-0.68	-0.88	-1.08	-1.28	-1.48	-1.68	-1.88	-2.08
15	1.92	1.69	1.46	1.23	1.00	0.78	0.55	0.32	0.09	-0.14	-0.37	-0.60	-0.83	-1.06	-1.29	-1.52	-1.75	-1.97	-2.20	-2.43
16	2.14	1.88	1.62	1.36	1.10	0.84	0.58	0.32	0.06	-0.19	-0.45	-0.71	-0.97	-1.23	-1.49	-1.75	-2.01	-2.27	-2.53	-2.79
17	2.36	2.07	1.78	1.49	1.20	0.91	0.62	0.33	0.04	-0.25	-0.54	-0.83	-1.12	-1.41	-1.70	-1.98	-2.27	-2.56	-2.85	-3.14
18	2.58	2.26	1.94	1.62	1.30	0.98	0.66	0.34	0.02	-0.30	-0.62	-0.94	-1.26	-1.58	-1.90	-2.22	-2.54	-2.86	-3.18	-3.50
19	2.80	2.45	2.10	1.75	1.40	1.05	0.70	0.35	0.00	-0.35	-0.70	-1.05	-1.40	-1.75	-2.10	-2.45	-2.80	-3.15	-3.50	-3.85
20	3.01	2.63	2.25	1.87	1.49	1.11	0.73	0.35	-0.03	-0.41	-0.79	-1.17	-1.55	-1.93	-2.31	-2.69	-3.07	-3.45	-3.83	-4.21

This table shows the net change in estimated dwell times resulting from the introduction of a friction factor in the post-launch dwell time model. The entries are the sum of the changes to estimated boarding and alighting times, modeled using the revised dwell time model (see Table 4 in main text).

A3. Absolute Wait Assessment (Within Scheduled Headway +3/+5 minutes)

		Pre-Launch		Post-Launch	Percent Change (% Pts)	
		30-Day	90-Day	30-Day	Base: 30 days	Base: 90 days
Bx41 Limited/SBS	Weekday	74.9%	71.9%	81.6%	**6.7%**	**9.7%**
	Saturday	---	---	84.6%	***5.5%***	***8.5%***
	Sunday	---	---	77.5%	***-1.6%***	***0.8%***
Bx41 Local	Weekday	78.3%	76.0%	88.1%	**9.8%**	**12.1%**
	Saturday	79.1%	76.1%	80.4%	**1.3%**	**4.3%**
	Sunday	79.1%	76.7%	86.6%	**7.5%**	**9.9%**

Notes:
[1] The pre-launch 30-day period is April 28, 2013 - May 27, 2013; the 90-day period is February 27, 2013 - May 27, 2013.
[2] The "30 days" post-launch period is July 14, 2013 - August 12, 2013.
[3] The Bx41 Limited service operated only on weekdays. For the SBS, percent change uses Local service as a baseline for weekend service, since Local service was the pre-existing weekend service. These percent changes are italicized to indicate that they include both the effect of SBS technological upgrades as well as weekend service expansions from Local-only to Local and SBS service.

Absolute Wait Assessment (WA) is the percentage of headway intervals that are within the scheduled headway +3 minutes during the peak period, or the scheduled headway +5 minutes during the off-peak period.

A4. Relative Wait Assessment (Within Scheduled Headway +25%)

		Pre-Launch		Post-Launch	Percent Change (% Pts)	
		30-Day	90-Day	30-Day	Base: 30 days	Base: 90 days
Bx41 Limited/SBS	Weekday	69.9%	67.3%	69.3%	**-0.6%**	**2.0%**
	Saturday	---	---	80.4%	***14.3%***	***15.7%***
	Sunday	---	---	73.0%	***1.7%***	***4.7%***
Bx41 Local	Weekday	68.8%	66.7%	81.3%	**12.5%**	**14.6%**
	Saturday	66.1%	64.7%	73.3%	**7.2%**	**8.6%**
	Sunday	71.3%	68.3%	80.9%	**9.6%**	**12.6%**

Notes:
[1] The pre-launch 30-day period is April 28, 2013 - May 27, 2013; the 90-day period is February 27, 2013 - May 27, 2013.
[2] The post-launch period is July 14, 2013 - August 12, 2013.
[3] The Bx41 Limited service operated only on weekdays. For the SBS, percent change uses Local service as a baseline for weekend service, since Local service was the pre-existing weekend service. These percent changes are italicized to indicate that they include both the effect of SBS technological upgrades as well as weekend service expansions from Local-only to Local and SBS service.

Relative Wait Assessment (WA) is the percentage of headway intervals that are within the scheduled headway +25%.

A5. On-Time Performance (OTP)

		Pre-Launch		Post-Launch	Percent Change (% Pts)	
		30-Day	90-Day	30-Day	Base: 30 days	Base: 90 days
Bx41 Limited/SBS	Weekday	65.6%	63.4%	83.9%	**18.3%**	**20.5%**
	Saturday	---	---	87.6%	***21.2%***	***22.9%***
	Sunday	---	---	86.5%	***18.3%***	***23.0%***
Bx41 Local	Weekday	66.7%	65.4%	79.5%	**12.8%**	**14.1%**
	Saturday	66.4%	64.7%	73.7%	**7.3%**	**9.0%**
	Sunday	68.2%	63.5%	78.5%	**10.3%**	**15.0%**

Notes:
[1] The pre-launch 30-day period is April 28, 2013 - May 27, 2013; the 90-day period is February 27, 2013 - May 27, 2013.
[2] The "30 days" post-launch period is July 14, 2013 - August 12, 2013.
[3] The Bx41 Limited service operated only on weekdays. For the SBS, percent change uses Local service as a baseline for weekend service, since Local service was the pre-existing weekend service. These percent changes are italicized to indicate that they include both the effect of SBS technological upgrades as well as weekend service expansions from Local-only to Local and SBS service.

A6. Running Time Between Time Points Within the Bus Lane, AM Peak Period

		Pre-Launch		Post-Launch	Change (mins)	
		30-Day	90-Day	Average	Base: 30 days	Base: 90 days
Bx41 Limited/SBS	Overall	17.0	16.8	15.2	**-1.8**	**-1.7**
	Northbound	17.1	17.3	15.3	**-1.8**	**-2.0**
	Southbound	16.8	16.3	15.0	**-1.8**	**-1.2**
Bx41 Local	Overall	21.2	21.4	19.5	**-1.6**	**-1.8**
	Northbound	20.2	20.5	19.3	**-0.9**	**-1.2**
	Southbound	22.2	22.4	19.8	**-2.4**	**-2.6**

Notes:
[1] The pre-launch 30-day period is April 28, 2013 - May 27, 2013; the 90-day period is February 27, 2013 - May 27, 2013.
[2] The post-launch period is July 14, 2013 - August 12, 2013.

A7. Running Time Between Time Points Within the Bus Lane, PM Peak Period

		Pre-Launch		Post-Launch	Change (mins)	
		30-Day	90-Day	Average	Base: 30 days	Base: 90 days
Bx41 Limited/SBS	Overall	18.6	19.6	16.4	**-2.2**	**-3.2**
	Northbound	18.6	19.5	16.3	**-2.3**	**-3.2**
	Southbound	18.5	19.7	16.5	**-2.0**	**-3.2**
Bx41 Local	Overall	23.5	24.0	22.3	**-1.3**	**-1.7**
	Northbound	23.3	23.6	22.1	**-1.1**	**-1.5**
	Southbound	23.8	24.4	22.4	**-1.4**	**-2.0**

Notes:
[1] The pre-launch 30-day period is April 28, 2013 - May 27, 2013; the 90-day period is February 27, 2013 - May 27, 2013.
[2] The post-launch period is July 14, 2013 - August 12, 2013.

A8. Bus Bunching

		Pre-Launch		Post-Launch	Percent Change (% Pts)	
		30-Day	90-Day	30-Day	Base: 30 days	Base: 90 days
Bx41 Local	Weekday	5.9%	6.2%	0.8%	**-5.1%**	**-5.4%**
	Saturday	9.2%	9.9%	1.4%	**-7.8%**	**-8.5%**
	Sunday	6.4%	7.2%	1.5%	**-4.9%**	**-5.7%**
Bx41 Limited/SBS	Weekday	2.3%	2.7%	1.0%	**-1.3%**	**-1.7%**
	Saturday	N/A	N/A	0.1%	***-9.1%***	***-9.8%***
	Sunday	N/A	N/A	0.4%	***-6.0%***	***-6.8%***

Notes:
[1] The pre-launch 30-day period is April 28, 2013 - May 27, 2013; the 90-day period is February 27, 2013 - May 27, 2013.
[2] The post-launch period is July 14, 2013 - August 12, 2013.
[3] The Bx41 Limited service operated only on weekdays. For the SBS, percent change uses Local service as a baseline for weekend service, since Local service was the pre-existing weekend service. These percent changes are italicized to indicate that they include both the effect of SBS technological upgrades as well as weekend service expansions from Local-only to Local and SBS service.

Bus bunching is reported as the percentage of bus pairs on the same route heading in the same direction departing a common time point within 90 seconds of each other.

A9. Average Daily Ridership and Revenue, Difference-in-Difference

		Pre-Launch		Post-Launch		Percent Change	
		Ridership	Revenue	Ridership	Revenue	Ridership	Revenue
Bx41 Limited/SBS	Weekday	4,834	$5,490	8,538	$13,061	76.6%	137.9%
	Saturday	---	---	6,054	$9,751	---	---
	Sunday	---	---	4,715	$7,522	---	---
Bx41 Local	Weekday	15,088	$19,616	10,481	$15,379	-30.5%	-21.6%
	Saturday	13,820	$21,927	8,718	$13,888	-36.9%	-36.7%
	Sunday	9,973	$16,004	6,999	$11,075	-29.8%	-30.8%
Bx41 Corridor	Weekday	19,922	$25,106	19,019	$28,440	-4.5%	13.3%
	Saturday	13,820	$21,927	14,773	$23,639	6.9%	7.8%
	Sunday	9,973	$16,004	11,713	$18,597	17.5%	16.2%

		Change in 2012		Change in 2013		Difference in Difference	
		Ridership	Revenue	Ridership	Revenue	Ridership	Revenue
Bx41 Limited/SBS	Weekday	-24.8%	-3.7%	76.6%	137.9%	101.4%	141.6%
Bx41 Corridor	Weekday	-13.6%	1.8%	-4.5%	13.3%	9.1%	11.5%
	Saturday	-8.1%	-7.1%	6.0%	6.9%	14.1%	14.0%
	Sunday	-7.3%	-7.0%	17.3%	16.0%	24.6%	23.0%