NYU Marron Institute of Urban Management

Rebuilding Bus Ridership in America

A Case Study in Brooklyn, New York

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Table of Contents

Abstract

Bus ridership in cities across the United States is declining. In Brooklyn, New York, annual ridership has declined by nearly 50,000,000 rides between 2007 and 2017. While this 21% reduction in ridership is alarming, it isn't impossible to reverse. Based on experiences in other cities around the world, namely Barcelona, we have proposed a radically specific redesign of the Brooklyn bus network that translates best practices from other cities into a plan for Brooklyn that consists of new route designs, greater service frequency, revamped street configurations, and fewer stops. Furthermore, we have limited our redesign to the existing operating hours budget provided by the Metropolitan Transportation Authority so that our redesign doesn't ignore budgetary constraints. By making the bus faster, more reliable, and less vulnerable to traffic congestion, the bus can again be a mode of transit that stitches Brooklyn together and provides access to the promise of New York.

1 Introduction

Across the United States bus ridership is declining (Mallett 2018; Boisjoly et al. 2018; Alam et al. 2015). As escalating transit infrastructure costs limit the ability of American cities to build and maintain rail-based transit networks, the bus offers a cheaper alternative (Pickrell 1989). Before investing more resources in buses, however, cities need to figure out how to provide attractive service that will get people back on the bus. In this report, we provide a blueprint to rebuild bus ridership based on best practices from around the world that we have applied to Brooklyn, New York's bus network. Despite our eagerness to revitalize the bus, we recognize that changes to the built environment and the benefits ascribed to car ownership have put transit at a disadvantage (Smart and Klein 2018, Warner 1995, Sheller and Urry 2000, Gutfreund 2004).

We selected Brooklyn because much like the nation at large, it has experienced a steady decline in bus ridership for more than a decade. Between 2007 and 2017, annual ridership decreased by more than 48,000,000 rides, or a 21% drop (Figure 1). This loss of ridership represents a reduction in urban mobility by public transportation because subway ridership has not risen to compensate (in fact, subway ridership has been falling since 2016). Despite this loss of ridership, the share of workers commuting by public transit has increased: in Brooklyn, New York's most populous borough, it rose from 60.5% in 2010 to 61.8% in 2017 (United States Census Bureau n.d.). These numbers confirm that transit still matters in Brooklyn and serves as the dominant travel mode for commuters.[1] In response to this ongoing urban mobility crisis, the Metropolitan Transportation Authority (MTA), the primary transit operator in New York City, announced it would redesign the city's entire bus network borough by borough (Metropolitan Transportation Authority 2018).

1 While commuters aren't the only group of Brooklynites who travel, the census collects comparable data on this specific class of travelers.

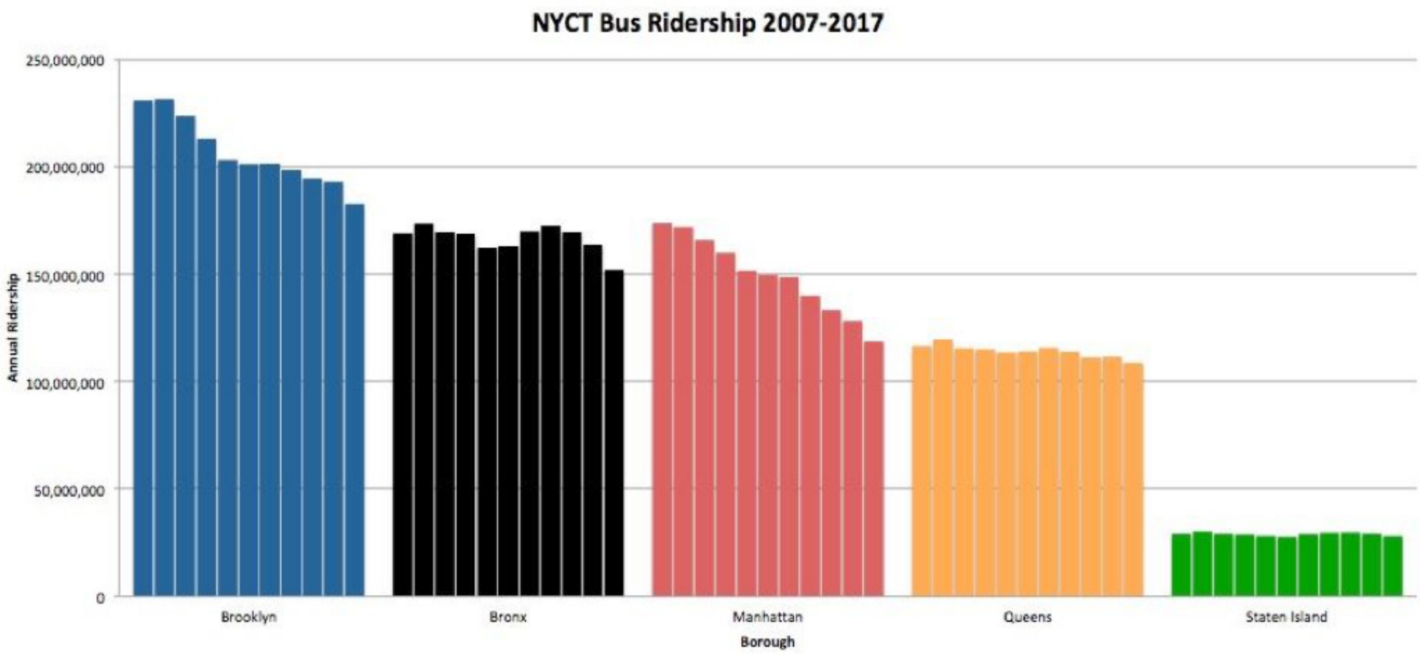


Figure 1. New York City Bus Ridership, 2007-2017 (MTA.info and Author's own data)

While the proportion of commuters driving has fallen, the total number of cars has increased, thanks to population and economic growth (United States Census Bureau n.d.). The resulting traffic has slowed down buses as well as cars, causing commute times to inch upward while degrading bus service. According to the American Community Survey 5-Year Estimates of Selected Economic Characteristics (United States Census Bureau n.d.) the average one-way commute for workers living in Brooklyn rose from 41.1 minutes in 2012 to 42.4 minutes in 2017. Relying on BusTime data provided by the MTA, we see that local and limited bus speeds in Brooklyn have fallen from 11.6 km/h in January 2015 to 10.9 km/h in January 2018, while bus bunching has risen due to unreliable traffic conditions (New York City Department of Transportation 2018).[2][3] During this two-year period alone, citywide bus ridership across both New York City Transit (NYCT) and MTA Bus fell 6.3% (Metropolitan Transportation Authority n.d.).[4]

2 Boroughwide average travel speed flattens a lot of variation by route, time of day, and day of the week. Not surprisingly routes, like the B41 and B35 have portions of their routes that average 5-8km/h during the peak period.

3 BusTime provides real-time positioning data on all buses operated by the MTA.

4 MTA Bus Company and New York City Transit both operate buses in New York City under the umbrella of the MTA. MTA Bus Company was created when seven private bus companies operating under franchises granted by the New York City Department of Transportation were taken over by the MTA in 2004.

For the most part, the decline in ridership has been concentrated in the innermost parts of the city. The worst declines have been in Manhattan, while bus ridership in Queens and Staten Island has fallen at a slower rate. Brooklyn, on the other hand, saw the second largest drop on a percentage basis in bus ridership, after Manhattan, but unlike in Manhattan, the subway network in Brooklyn is a poor substitute for intra-borough travel. Some of the sharpest declines have been along busy routes that run orthogonally to the Manhattan-centric subway network such as the B35 on Church Avenue, down 16.2% between 2011 and 2017, or are crucial subway feeders in farther out neighborhoods, like the B41 on Flatbush Avenue, the B44 on Nostrand Avenue, and the B46 on Utica Avenue, which are down 26.3%, 11.7%, and 12.7% respectively.

As bleak as these data points are, cities across the world have redesigned their bus networks and rebuilt ridership. The challenge of rebuilding bus ridership and designing better transit networks in the United States is all the more important as households without access to automobiles have seen their median incomes decline relative to households with access to automobiles. King et al. (2019, p.14) underscore this point when they write that "households without automobiles...have lost ground in both absolute terms and in comparison to households with automobiles." This conclusion highlights arguments from those concerned about equity and transportation justice (Martens 2017). Without access to good, reliable transit, carless households will have a harder time accessing affordable housing, jobs, and the benefits of living in a vibrant, dynamic city. Attoh (2019, p.42) summarizes the salience of these arguments when he writes, "fights for equity in public transportation have also been fights against alienation [and] isolation." Redesigning American bus networks is fundamental to ensuring that everyone has access to the promise of cities.

In this report, we examine bus network redesigns from around the world and studies about the determinants of transit ridership before introducing our own network redesign for Brooklyn. In particular, we focus on Barcelona's Nova Xarxa and use it as a productive model for Brooklyn. As we redesigned Brooklyn's bus network, we examined data sets that described land-use, demographics, Brooklyn bus schedules, and transit ridership. We also consulted spatialized datasets that identified the location of job centers, public housing, zoning, and wheelchair-accessible subway stations.

Next, we examine the bus-redesign and transit-ridership literatures. In section three, we introduce the data and methods we used to redesign the Brooklyn network. Before concluding, we describe the redesigned Brooklyn bus network and enumerate the benefits of our design, which we estimate will lead to a 40% gain in bus speeds.

2 Background

Despite the recent declines in bus ridership across the United States, we know how to get people on to the bus. Taylor et al. (2009) analyzed data from 265 urbanized areas in the United States using the National Transit Database (NTD) and found that when looking at the aggregate data, the determinants of transit ridership fall along two distinct axes: first, ridership responds to factors outside the control of a traditional transit agency, such as the proximity of the highway network or the overall trends in the economy. While there's nothing transit agencies can do to halt the construction of highways or alter the national economy, there are a second set of variables that affect ridership that are within the control of a traditional transit agency: fare, frequency of service, reliability, and route length. As these metrics are tuned to attract ridership, be it reductions in fares or a greater number of buses plying each route, transit agencies do have the ability to modify their offerings in order to attract passengers back onto the bus.

In considering the Brooklyn bus network, we made assumptions about the desirability of stops that provide greater connectivity, reduced waiting times, and improvements in bus travel speed. On the more practical side, we limited ourselves to the current bus service budget in Brooklyn so that our design reflected the existing economic constraints. While textbook planning may advocate for a systematic approach to network redesign, Goldwyn (2018, p.9) shows that bus planners at the MTA often follow a more "generative" approach — an approach that is "guided by relevant data…be it changing land-use restrictions that allow high-density residential development in a neighborhood or a crowded bus," rather than a systematic review of the network. Thus, we also looked to specific examples of network redesign from beyond New York to inform our process.

One of the core assumptions we wanted to understand was the difference between coverage and frequency (Mees 2010; Walker 2011). By studying Barcelona's bus network reboot, Nova Xarxa, we found a case that is a clear example of placing greater emphasis on service frequency than service area coverage (Badia et al, 2017). Nova Xarxa, or New Network, replaced Barcelona's radial system with a grid, veering from the perfect grid in order to serve major destinations such as metro stations. Nova Xarxa's grid simplified the network, reducing the number of routes in order to increase the frequency on each route. Service frequency rose from an average of one bus every 12 minutes to one bus every 6. Ridership rose sharply, and thanks to very high frequency service, the percentage of trips involving transfers rose as well, from 11% before Nova Xarxa to 26% in 2015 mid-implementation, with 44% projected at network completion.

When trading network coverage for frequency, networks need to encourage transfers so that riders can still access as much of the system as possible. Furthermore, higher-frequency service makes transferring more attractive because it reduces the time passengers spend waiting for connecting buses, also known as the transfer penalty. Currie and Loader (2010, p.14) found that in Melbourne, "an average headway of 15 min and at least one route with a headway of 10 min or better appear to be necessary to facilitate high transfer rates (at least well above the general trend in relation to service levels)."

The situation in Brooklyn is not quite the same as in Barcelona or Melbourne. The existing Brooklyn network already has the characteristics of a grid. However, there are significant variations that can be simplified, and some circuitous routes acquired gradually on the outer margins of the borough, especially around East New York. Nova Xarxa's success was the result of a combination of systemwide improvements in bus service levels (in particular, bus speedup) and network redesign; thus, it is a critical example of what Brooklyn's bus network should look like.

To this effect, we propose a sweeping restructuring of surface transportation in Brooklyn. We caution that what follows is not an easy proposition: a few streets require traffic redesign and not just changes to the bus network, and much of the benefit of our proposal comes from reallocating street space away from cars and toward buses.

Overall the new network is win-lose and not win-win, but the winners would greatly outnumber the losers. Moreover, there would not be an adverse impact on equity. The neighborhoods that would benefit the most include a range of poor and middle-income areas, while the most underutilized buses, which we propose to consolidate into fewer routes, are often in wealthier areas.

3 Key Interventions

For Speeding Up the Buses

The most important systemwide changes to New York's bus system concern bus speed. The average bus speed in the city has deteriorated due to increases in traffic. Brooklyn's average scheduled bus speed is 11 km/h, including limited-stop buses and Select Bus Service but not express buses; in Paris and its inner suburbs, which collectively are slightly less dense than Brooklyn but have higher job density and more through-traffic from outer suburbs, the average speed is 13.6 km/h (Bontinck and Plesse 2017).

We emphasize bus speeds because as buses travel slower over a fixed period of time, there will be fewer of them during that period, which degrades frequency and makes the remaining buses more crowded. At 15 km/h, a 10 kilometer route would take 40 minutes each way, so that (ignoring turnaround times) 10 vehicles would provide 8-minute frequency; at 10 km/h, the same route would take an hour each way and the same 10 vehicles would only provide 12-minute frequency. If people did not abandon the buses for their slowness, these less frequent buses would then be 50% more crowded.

This calculation relies on the fact that bus operating costs, for the most part, scale with service-hours rather than service-km, and thus an increase in speed allows a transit agency to provide more service-km for the same cost while a slowdown does the opposite. A large majority of the variable operating cost of a bus is the driver's wage: about 75% of New York City Transit bus workers are bus operators (MTA 2019, p. 273), as are about 80% of Chicago Transit Authority bus workers (CTA 2019). Moreover, nearly all of the remaining workers are in maintenance, but maintenance costs are based on engine acceleration cycles and not on total distance driven. The cost of fuel scales with time more than distance as well, since it's frequent acceleration that consumes the most fuel in an urban environment rather than cruising at the speed of city traffic.

The upshot is that if bus speeds increase, then it's possible to increase frequency for free. From the passengers' perspective this is a win-win, because they reach their destinations faster on top of having shorter waits and less crowded buses.

Reform-minded organizations have called for a variety of treatments that would increase bus speed. These include the following:

1. Off-board fare collection, allowing all-door boarding.
2. Stop consolidation, increasing the distance between stops.
3. Dedicated bus lanes, ideally physically separated from car traffic by means of small raised curbs.
4. Signal priority at intersections

Select Bus Service (SBS) in New York has included the first two treatments as well as the third, but without physical separation. However, it is important to treat these treatments not as special benefits available only to *select* bus routes but as systemwide improvements. We believe that with all of these treatments, the average Brooklyn bus speed would rise from 11 km/h to about 15 km/h, an increase of about 36%.

An average speed of 15 km/h is not especially rapid. The subway averages almost 30 km/h, and is among the slowest subway networks in the world, due to its old age and short stop spacing. Buses are not a substitute for grade-separated rail transit. However, they can be a powerful complement, serving areas beyond the subway's reach and providing trips that are perpendicular to the Manhattan-centric rail network. Faster, more frequent buses are likely to entice passengers to make more trips that they otherwise would not have made, or to choose the bus rather than to pay for a taxi or transportation network company (TNC) such as Uber or Lyft.

However, to fully realize the potential speed and frequency benefits of the redesigned network, it's critical to get every component right. On a traditional bus in New York City, passengers board from the front door and dip their MetroCard one by one. As more passengers board the bus, the bus must sit still and idle while each passenger finishes paying. Thus, each boarding passenger delays the the trip.

In contrast, off-board fare collection allows passengers to board from any door and reduces overall dwell times. The Select Bus Service regime in New York takes advantage of off-board fare collection by requiring passengers to pay at ticketing machines placed at every stop before boarding. The same regime is also used in Zurich, where every bus or tram stop has ticket vending machines where passengers can buy and validate tickets. A lower-cost alternative is found in Vancouver, where passengers can board the B-Line buses from any door and tap their smart cards on board.

Off-Board Fare Collection

There is no disaggregated data for the effect of the off-board SBS fare collection on bus speeds, since the implementations so far have also included stop consolidation, and NYCT reports the overall time buses spend at stops, conflating the two treatments. However, there is data from San Francisco, which changed its entire network to all-door boarding without any other treatments. Before the change, the average dwell time per boarding or alighting passenger was 3.9 ± 3.5 seconds; since the change, it has been 2.5 ± 2 (SFMTA 2014). The Transportation Research Board's (TRB 2017a) bus transit capacity manual claims a similar effect, though with smaller numbers: 2.6-3 seconds for boarding without prepayment and 1.7-2 seconds for alighting, 1.2 seconds for boarding with prepayment and two-door boarding and 1.0-1.2 seconds for alighting.

If the observed San Francisco numbers are also true for New York, then out of about 10,800 bus service-hours in Brooklyn every weekday, 1,290 are spent on station dwell times, and prepayment would reduce this to 830, cutting about 4.3% of the total time. Moreover, prepayment results in more stable travel time, which means that buses could also save some schedule padding (Sun et al. 2014). If the TRB's numbers are right, then the numbers are lower but prepayment would still cut about 350 hours from the current schedule, or 3.2% of total travel time.

While a reduction of 4% in total travel time may seem small, prepayment has another critical benefit: it reduces bus bunching. Bus timetables are inherently unstable. If a bus is slightly behind schedule, then passengers will have to wait slightly longer for it to come, which means more passengers will be waiting at each bus stop. The extra 3.9 seconds of dwell time per boarding or alighting passenger will slow the bus down further, creating a cascading delay. Eventually, a delayed bus will run so slowly the bus behind it will catch up to it, leading to bunching. Anything that reduces the average dwell time per passenger slows down this process in which buses tend to bunch, improving timetable reliability.

Prepayment with all-door boarding is also of special interest to the bus operators themselves. Our interviews and surveys reveal that operators are unhappy about needing to enforce the fare when passengers board without paying (Levy and Goldwyn 2018). New York City Transit's rules about what to do in case a passenger refuses to pay are confusing: drivers are supposed to announce the fare but not take further action. In practice, some passengers treat even that reminder as an act of hostility and retaliate against the operators. There were 75 assaults on bus drivers in Brooklyn in 2017, according to the Transport Workers Union (Levy and Goldwyn 2018).

In the survey of the operators, we asked what changes would make them more effective at their job. Operators could give multiple answers; the single biggest item was off-board fare collection, which 90% of drivers named. Under a regime of off-board fare collection, the responsibility for enforcement is no longer on the bus operators. Teams of inspectors board the bus and demand that people show proof of payment, and issue summonses for fines to passengers who cannot show such proof. In New York, these inspectors are called the Eagle Team and are separate from the New York Police Department's Transit Bureau.

Stop Consolidation

There is a tradeoff between travel time to a station and in-vehicle travel speed on every mass transit mode, from the local bus to the high-speed train. There are differing standards and models for how this tradeoff should be optimized. However, multiple unrelated methods show that the bus stop spacing on local buses in New York, and in North America in general, is too narrow, at 200 meters.

Models concerning the optimal stop spacing, or the impact of stop spacing on speed point to an optimal stop spacing of 400 meters or even more, up to 600-800 meters in some cases (Furth and Rahbee 2000; Mamun and Lownes 2014; Levinson 1983; Li and Bertini 2008; Murray 2001; and van Nes and Bovy 2000).

New York's practice is to keep bus stop spacing short, but have overlaid routes that make fewer stops, which are either conventional limited buses or SBS routes. This splits frequency between two routes, often with only a bus every 10 minutes off-peak even on some of the busiest, densest routes in the city. Moreover, SBS routes tend to have slightly wider stop spacing than the optimum, so wide that not only are walk distances long but also buses sometimes do not stop at intersections with other buses.

We propose the following model for the optimal bus stop spacing: if bus stops are spaced distance s apart, and passengers' origins and destinations are uniformly distributed along a line, then origins and destinations are an average of $s/4$ from stops, and thus passengers have an average walk length of $s/2$. However, if passengers have a fixed destination—say, a subway stop where everyone transfers—then the walk distance falls to $s/4$, since passengers only need to walk at the origin end, and thus the choice of s that minimizes total time is larger. On subway feeder routes, longer stop spacing is therefore appropriate, often stopping just at intersections with other bus routes or subway stops.

The minimum travel time occurs when

$$s = \sqrt{vp(2d + w\lambda)/w}$$

where we define d to be the length of the average unlinked bus trip, v to be the average walking speed, p to be the travel time added by each extra stop, w to be the penalty factor for waiting or walking relative to spending time on a moving bus, and λ is the distance between two successive buses on the same route.

This formula holds if origins and destinations are isotropic, that is if walk distance is on average $s/2$; if destinations are fixed at stop locations such as subway stations, in which case average walk distance is $s/4$, the formula is instead

$$s = \sqrt{2vp(2d + w\lambda)/w}$$

The interaction between the variables v, p, and d represents the tradeoff between longer walk times and shorter in-vehicle times if stations are spaced farther apart, and w is a correction factor for the fact that passengers exhibit a large penalty for walking, transferring, or waiting compared with in-vehicle time. Because higher in-vehicle speed permits running buses more often, passengers spend more time walking but less time waiting if stop spacing is wider, and this is controlled by the variable λ.

On New York City Transit buses, the average unlinked trip, d, is 3,360 meters (NTD). The average walking speed, v, depends on passenger age and disability and varies greatly in the literature. It is stated to be *1* m/s, with no penalty w, in Daganzo and Ouyang (2019 p. 33); 1.45 m/s in Forde and Daniel (2017); 1.4 m/s in TRB (2017b, p. 4-14); and 1.4 m/s for people under 60 and about 1.3 m/s for people over 60 in Bohannon (1997). We use v = 1.4.

Figure 2. A slice of Brooklyn's current bus network, centered on Church Avenue through Flatbush and East Flatbush

The value of the out-of-vehicle w has been studied in the literature, with references including (TOG 2017, p. 25) stating that w = 2 on buses and 3 on trains, and an internal literature review in (Lago et al. 1981) stating that w ranges from 2 to 3. The MTA's own model states
w = 1.75. We use w = 2.

An examination of the difference between local and limited travel time on the busier buses in New York suggests the value of p is in the range of 20-40 seconds, more likely near the lower end, about 25. This examination includes non-SBS routes such as the B41 but also SBS routes such as the B44 and B46, net of the impact of off-board fare collection.

Finally, the distance between successive buses on the same route, λ, depends on the shape of the transit network: if there are more buses in circulation relative to the total route-length of the network then λ will be lower, somewhat reducing the optimal stop spacing. On the network today the value of is 1,830 meters, but on our consolidated network it is 1,160 meters, representing higher frequency.

In total, we obtain an optimal value of s as 398 meters if destinations are isotropic, or 562 meters if they are at distinguished stop locations. Our network has an average interstation of 498 meters, falling to 490 if we exclude two nonstop freeway segments, right in the middle between the two values.

In practice, in a dense bus network, intersections with other routes can often force a rapid succession of stops. In Figure 2, from east to west, Church Avenue (B35) intersects New York Avenue (B44 northbound), Nostrand Avenue (B44 southbound), Rogers Avenue (B44 SBS northbound), Bedford Avenue (B49), and Flatbush Avenue (B41) within a kilometer, forcing a 250 meter interstation on this segment unless the north-south buses are rerouted. We propose such rerouting, making more streets two-way (such as Nostrand Avenue) to simplify the network. But even then, some locations where buses are forced to stop often are unavoidable.

The predicted effects of stop consolidation are large. The average midday speed of Brooklyn local buses (excluding limited and SBS routes, as well as the limited-only B100 and B103), weighted by service-hours, is 10.8 kilometers per hour, or 5.5 minutes per kilometer. The current stop spacing is about four and a half every kilometer. Consolidating stop spacing to two stops per kilometer means saving about a minute per kilometer, cutting nearly one fifth of the total travel time.

Outside North America, the stop spacing we propose is standard. Furth-Rahbee (2000) mention that in most of Europe, stop spacing is typically 400-500 meters, suggesting that different governance mechanisms have led agencies to place bus stops farther apart. A COST (2011) report about buses with high levels of service in Europe brings up widening of stop spacing from about every 200-250 meters to every 400-500. In personal conversation, Daganzo also added that Nova Xarxa widened stop spacing from less than 200 meters to every 330 meters. In none of these cases are there limited-stop buses.

Removing closely-spaced stops interacts especially well with prepayment. The reason is that if prepayment requires infrastructure at every bus stop, as it does in Zurich or along New York's SBS routes, then it's cheaper to provide infrastructure at fewer stops. If every transaction involves a smartcard then it's possible to put tapping stations at every bus door and avoid station-side infrastructure, and besides, such infrastructure is cheap (the readers used for congestion pricing in Singapore cost S$150). Nonetheless, for passengers who do not own the fare card, providing ticketing machines is valuable, which is why in Zurich there is a full ticket vending machine at every stop. These machines are expensive (they cost $75,000 per stop on average), and limiting their cost by reducing the number of required stops is valuable (RPA 2016).

In the other direction, the value of stop consolidation is slightly lower if there is no prepayment. Stop removal increases bus speed, and as the average stop spacing rises toward the modeled optimum, ridership should increase. Under on-board fare collection and front-door-only boarding, as buses attract more passengers the dwell times at stops rise, which limits the benefit of stop removal. Thus, in order to reap the benefits of optimal stop spacing, it is critical to implement off-board fare collection.

Finally, stop consolidation is useful for improving bus stop facilities to include shelter. High-quality bus shelters provide a place to sit and a measure of protection against rain, snow, wind, and the sun. Stover and McCormack (2012) found that the weather, specifically rain, snow, and wind had a negative effect on bus ridership in Pierce County, Washington. For passengers with disabilities who cannot stand for a long time waiting for a bus, bus shelters improve their journeys. Even though requiring passengers to travel longer to a bus stop imposes some physical hardship, this hardship trades off with higher-quality bus stops and shorter waits, since faster buses can run more frequently.

Dedicated Lanes

Giving the same priority to a bus with 40 passengers and a car with a single driver is inherently inequitable. In practice, this means giving buses dedicated lanes. However, there are questions concerning the quality of dedicated lanes. Bus lanes can be physically separated from car traffic, or they can be merely painted. They can also be placed on different sides of the street—on the curb side of a two-way street, or in the median. New York's current bus lanes, besides being incomplete, are painted and on the curb side, but the city should seriously consider physically separated median lanes.

The main benefit of physically separated lanes is that they are harder to violate (Aaron 2009). In our survey of bus operators, while the top concern for increased operator effectiveness was off-board fare collection, the second concern was traffic: 82% of bus operators said that reduced congestion would make them more effective at their jobs. Moreover, when we asked what causes them the most stress, 79% of drivers named double-parked vehicles and 63% named traffic, both far ahead of any other problem (Levy and Goldwyn 2018).

Physical separation does not have to be obtrusive. A small raised curb, a few centimeters wide, is enough in Paris. One perceived advantage of painted lanes is that they permit buses to move around obstacles, such as broken down buses, illegally parked vehicles, or slower buses running on the same route. While this is true, physically-separated bus lanes can be designed to allow for a similar level of maneuverability. By creating physical separation and consolidating stops, all buses along a route should run at approximately the same speed. Moreover, with better segregation between bus and car traffic, there would be no illegally parked cars or double-parked vehicles obstructing the bus. Only broken down buses would remain as an obstacle—but NYCT buses break down every 10,000 kilometers, corresponding to once every 1.5 days on the busiest routes, and on the rare occasion this happens the following buses can use shared lanes for a block (MTA 2017, p. 6).

In addition to or as an alternative to physical separation, it is possible to use bus cameras to enforce the bus lanes. However, using enforcement rather than physical separation is less reliable. Moreover, there have been political problems with any proposal for camera-based enforcement, including bus cameras and red light cameras. As we write this, it appears, the political support for these types of interventions is growing (Barone 2019).

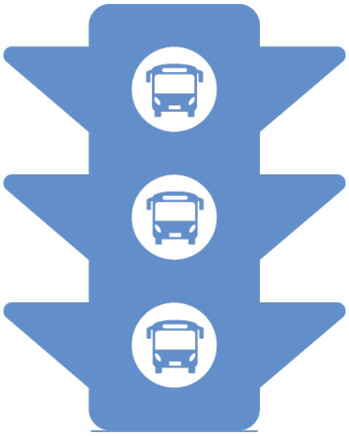
In general, the biggest obstacle to installing more bus lanes has been political. The tension between public and private transport are politically salient and inhibit local decision-makers from selecting solutions that favor public transport (Thomson 1977; Shoup 2011; Levinson and King 2019). In the case of bus lanes, the battle over parking spaces pits bus riders who would benefit from a bus lane that improves travel speeds and reduces bunching against drivers and shop owners who bemoan the loss of parking spaces for private automobiles. The recent controversy leading to the redesign of the B82 SBS proposal came about because of community opposition over, among other concerns, the proposed removal of 169 parking spots (Mena 2018).

Median lanes would not fully resolve this issue. They would still take away moving lanes from cars, which drivers may dislike. Moreover, median lanes still require curb space for bus stops. On a few arterial streets, including Odengatan in Stockholm and Boulevard Montparnasse in Paris, there are median lanes with lane-wide curbs at bus station locations to let passengers board. Odengatan is 30 meters wide, like Manhattan avenues and many major Brooklyn streets, but has no street parking, instead having wide sidewalks. Adapting this layout to New York would still remove parking at stop locations in order to let cars swerve around the bus boarding curb.

Because the quality of bus lanes varies so much, we cannot give precise estimates for the time savings coming from installing them, unlike with off-board fare collection or stop consolidation. SBS on the M15 on First and Second Avenues included new bus lanes, reducing total time spent in motion (not including red lights or stops) from 40 minutes over a 13 km route to 35.5 minutes (NYC DOT and MTA 2011). On the B44, where NYCT breaks down travel time differently, total time stopped in traffic (including red lights) fell from 20 to 12.5 minutes over a 15 km route, with incomplete bus lanes (NYC DOT and MTA 2016). On the M86, the total saving in motion and in traffic is 1.5 minutes over a 3 km route (NYC DOT and MTA 2017). On the Bx12, a 14 km route, time in motion including delays not coming from bus stops went down from 41 to 36 minutes (MTA 2009).

Mundy et al. (2017) examine examples from Western Europe, Canada, Australia, South East Asia, and the United States, including New York. In their study, they reference the Bx41 SBS, in which not only is the SBS route 19-23% faster than the pre-SBS limited, but also the local bus is 11-17% faster, using the bus lanes without stop consolidation or prepayment. While the four SBS routes for which we have data about the effect of bus lanes suggest the savings are 30 seconds per kilometer, on the Bx41 local the savings are higher, 50 seconds per kilometer.

Signal Priority



Bus lanes ensure that buses receive priority proportional to vehicle occupancy vis-a-vis cars. At intersections, transit signal priority (TSP) does the same, by making sure the light turns green for the bus. The M15 bus, which has no signal priority, spends 18 minutes out of its 68.5-minute trip stopped at red lights.

In no case do buses have absolute priority, the way railroads do at level crossings. TSP has many different flavors, typically extending a green light if the sensors detect a bus coming shortly after the light would have otherwise turned red, or perhaps turning a light from red to green early if the bus is coming shortly before it would have turned green anyway. One study in Minneapolis finds that the installation of TSP on one bus route reduced measured travel times by 4-6% (Liao-Davis 2011, table 5.2). In Jinan, signal priority on the bus rapid transit (BRT) network reduced travel times by about 7% (Zhou et al 2017).

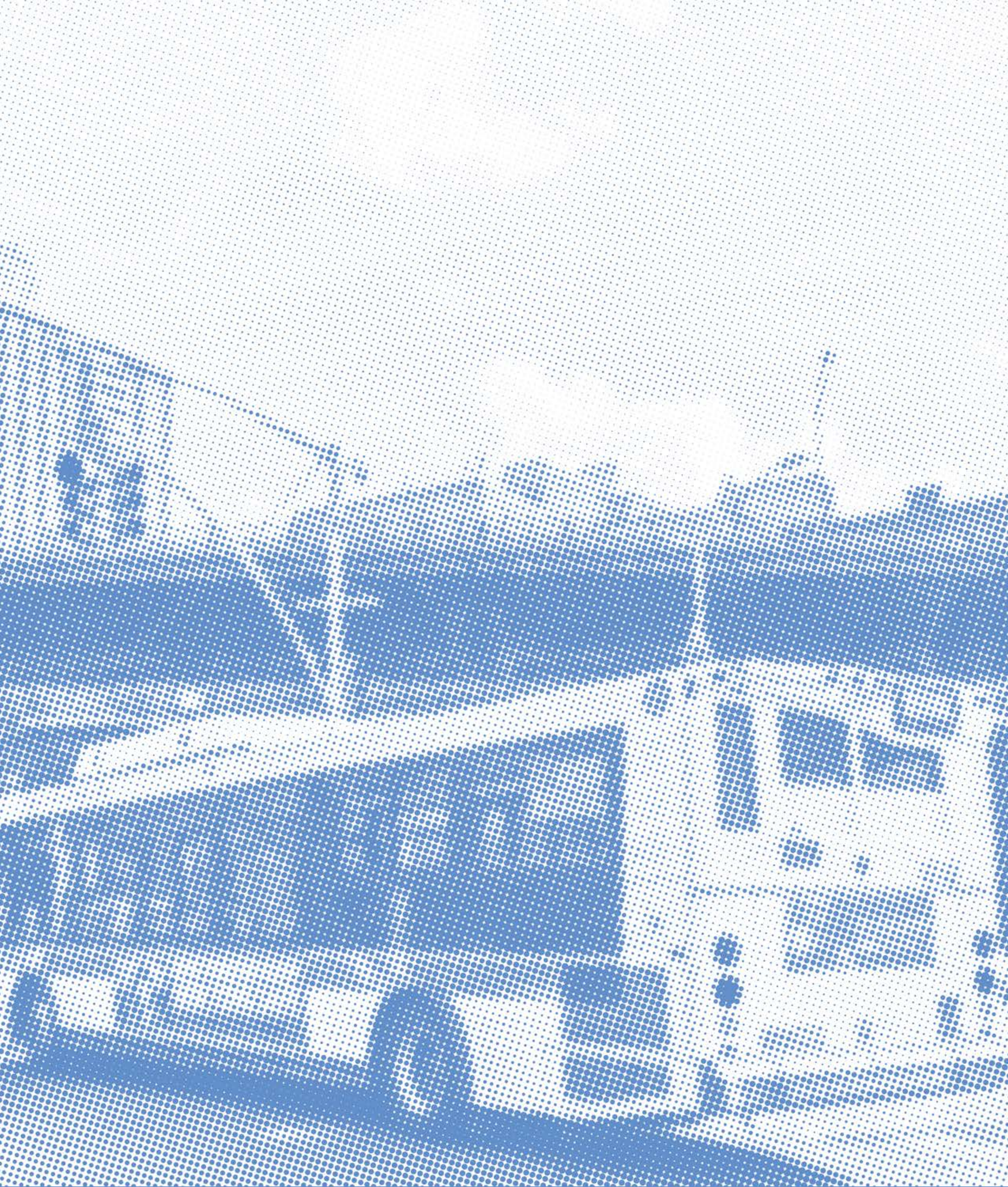
However, the situation in Brooklyn is more complex than in the above two examples. Minneapolis's TSP is installed on only one route. Jinan's is on a network with only one intersection between two different routes. In Brooklyn, the bus network is a mesh with many intersections between buses of equal importance. At major intersections involving key east-west corridors such as Church Avenue and Kings Highway with key north-south corridors such as Nostrand Avenue and Utica Avenue, it's not realistic to expect buses to always have a green light.

Moreover, the decision of which street stretches and which intersections to implement signal priority on must be taken based on technical rather than political criteria. Mundy et al. (2017) warn against bad implementations of TSP. In Vancouver, they warn, TSP was installed separately from other improvements, and the decision on which signals to equip with the technology was made by the city without input from the transit operator.

Nonetheless, in one respect Vancouver has successful signal priority: through-traffic on east-west arterials, including Broadway (the busiest bus corridor in North America) and 4th Avenue (Vancouver's third busiest), has priority over all intersecting traffic, so buses and cars don't stop at red lights often. The limited-stop buses on 4th Avenue, where there is little car traffic, average about 28 km/h with no BRT treatments, whereas the 99 B-Line on Broadway (which has prepayment) averages 20, both with about a stop every kilometer.

In Manhattan we see the peril of signals that aren't optimized for the entire network. The north-south avenues have green waves, effectively giving north-south traffic priority over east-west traffic, where cars as well as buses may encounter red lights at every block. As a result, east-west traffic is slower. The Straphangers Campaign highlights slow bus speeds in New York by giving annual pokey awards to the slowest buses, and every year the winner and runners-up are crosstown Manhattan buses, even though crosstown buses usually have wider stop spacing than north-south buses, especially if they go across Central Park (Straphangers 2018).

We recommend borough-wide and citywide TSP on the major bus corridors. But given the difficulty of finding data on the effect of TSP on bus speeds in two-dimensional mesh networks rather than one-dimensional lines, we cannot give estimates for the expected improvement in bus speed. Minneapolis's 5% improvement and Jinan's 7% are most likely upper bounds.



4 The Proposed Network and its Benefits

The current average speed of the buses in Brooklyn, weighted by service provision, is 11 km/h. Stop consolidation from a stop every 200 meters to one every 500 should reduce travel time by about 1 minute per kilometer; bus lanes should reduce travel time by a further 30 seconds per kilometer; and off-board fare collection and all-door boarding should reduce travel time by about 4%.

One countervailing factor is our proposed redesign of the network. In Barcelona, the replacement of a radial network with a grid increased bus speed independently of the increase in stop spacing, since the agency removed buses from the most congested part of the city. In Brooklyn, the existing bus network is already a grid, and its weakest links are faster than the average. Thus, the routes we propose would average 10.5 km/h if they ran at today's local stop frequency and had no prepayment or bus lanes.

Overall, we expect the combination of stop consolidation, prepayment, bus lanes, and the network redesign to boost the average speed from 11 km/h today to about 15 km/h. About 60% of the reduction in travel time comes from stop consolidation, another 30% comes from bus lanes, and 10% comes from prepayment. The main benefit of prepayment is that it reduces schedule variability and bunching, not that it increases average speed.

As a sanity check, the SBS routes have prepayment, widely spaced stops, and dedicated lanes. The average SBS speed on the B44 is 14.9 km/h and that on the B46 is 13.7 km/h. Both buses have somewhat wider stop spacing than every 500 meters, but even correcting for their wider stop spacing, at 500 meters they would together average about 14 km/h. However, while the B44 local has about the same average speed as the rest of the borough's local routes, the B46 local is one of the slowest routes, with a scheduled average speed of only 9.4 km/h. Thus an all-rapid borough bus network can be expected to average higher speed than the B46 SBS.

The direct effect on passenger usage is likely to be similar to that of existing SBS routes, which have enjoyed similar speed gains. But in addition we expect a positive effect coming from higher frequency (essentially plugging the efficiency gains from higher speed back into the system, rather than providing the same frequency NYCT runs today at a lower cost). In Barcelona, the implementation of Nova Xarxa raised annual TMB bus ridership by 16.6% between 2012 and 2018 while metro ridership only rose 9.1% (TMB).

Figure 3. MTA Brooklyn Bus Map, November 2018

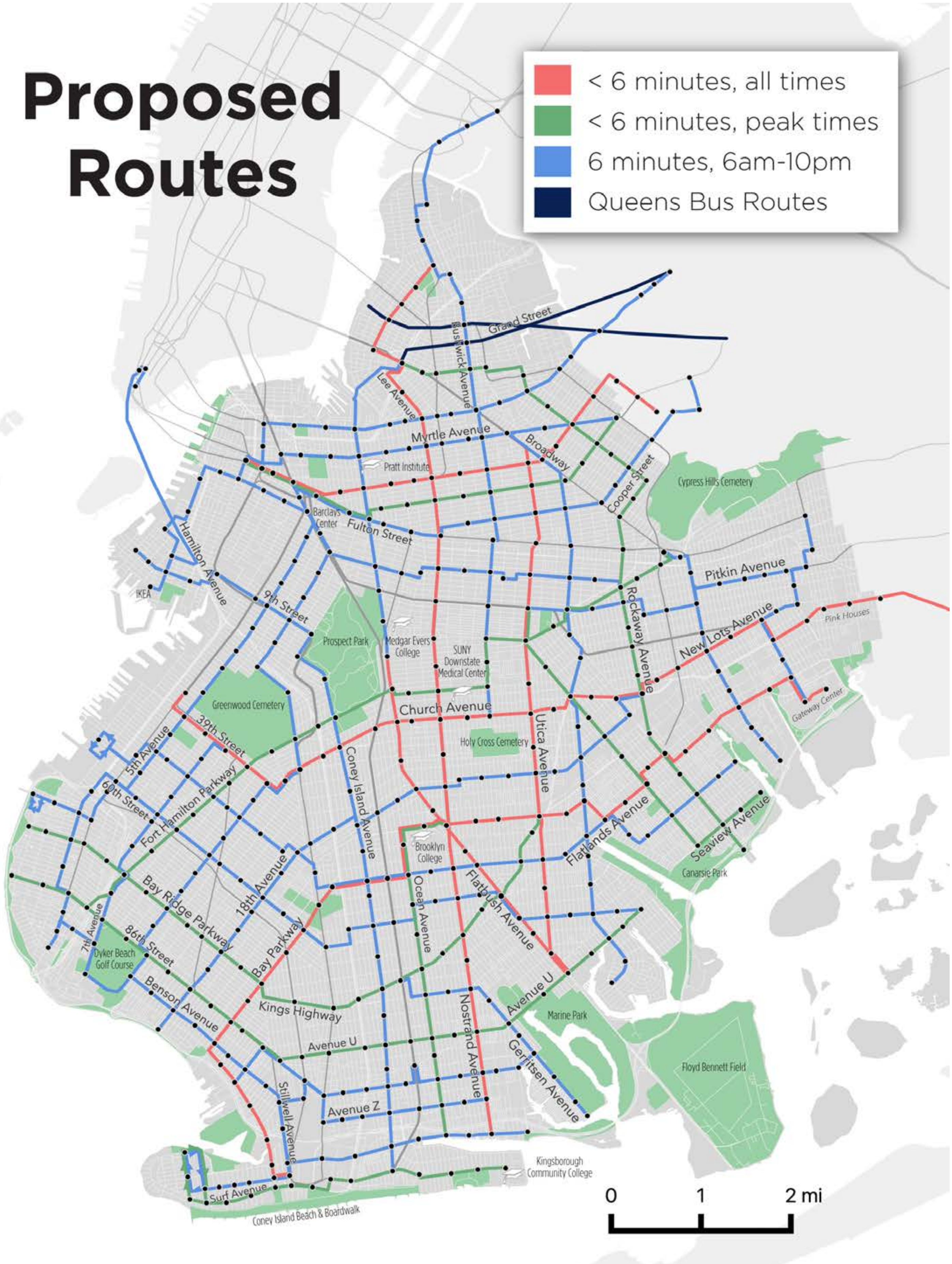


Figure 4. Proposed Brooklyn Bus Map

Proposed Routes and Headways

Headways By Line Weekday (minutes)	Color	7AM-9AM	9AM-5PM	5PM-7PM
8th Avenue	Blue	6	6	6
Washington	Blue	6	6	6
Avenue X	Blue	6	6	6
Avenue L/J/50th/55th	Blue	6	6	6
Avenue N/M/60th/Bay Ridge	Blue	6	6	6
Myrtle Avenue	Blue	6	6	6
Pitkin Avenue	Blue	6	6	6
St. Marks/Park Place/Atlantic Avenue	Blue	6	6	6
Fresh Pond/Halsey Avenue	Blue	6	6	6
Brooklyn Battery Tunnel	Blue	6	6	6
Coney Island Avenue/PPW/9th/Red Hook	Blue	6	6	6
Gerritsen Avenue	Blue	6	6	6
Mill/Ralph	Blue	6	6	6
Pennsylvania Avenue	Blue	6	6	6
Avenue Z/86th Street	Blue	6	6	6
Emmons/Mermaid Avenue	Blue	6	6	6
Bath Avenue/Poly Prep	Blue	6	6	6
3rd/5th Avenue	Blue	6	6	6
13th Avenue/McDonald/8th Avenue	Blue	6	6	6
Ditmas/18th Avenue	Blue	6	6	6
Flushing/Columbia	Blue	6	6	6
Albany/Garvey/Graham/McGuiness	Blue	6	6	6
Elton/New Lots/Fountain/Crescent	Blue	6	6	6
Avenue U/86th Street	Green	5	6	5
Kings Highway/75th	Green	3.33	6	3.33
Gates Avenue	Green	5	6	5
Ocean Avenue	Green	5	6	5
Rockaway Parkway Avenue/Wilson	Green	4	6	4
Seaview/Remsen	Green	5	6	5
Oriental/Surf	Green	3	6	3
East New York/Clarkson/Fort Hamilton	Green	4	6	4
Flatlands/Bay Parkway	Red	3	4.5	3
Seneca/Himrod/Lafayette	Red	2.5	5	2.5
Nostrand/Lee/Bedford	Red	2.5	4.5	2.5
Flatbush Avenue	Red	2.5	5	2.5
Linden/New Lots/Church/39th	Red	3	5	3
Utica/Malcolm X	Red	2	4	2

7PM-10PM	10PM-12AM	12AM-5AM	5AM-6AM	6AM-7AM
6	10	30	10	6
6	10	30	10	6
6	10	30	10	6
6	10	30	10	6
6	10	30	10	6
6	10	30	10	6
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6	10	30	10	6
6	10	30	10	6
6	10	30	10	6
6	10	30	10	6
6	10	30	10	6
4.5	10	30	10	4.5
5	10	30	10	5
4.5	10	30	10	4.5
5	10	30	10	5
5	10	30	10	5
4	10	30	10	4

How Speed Interacts with Network Design

In redesigning the network, we apply a first-order formula:

(Daily Service Hours) * (Average Speed)
=
(Daily Frequencies) * (Network Length)

The Brooklyn bus network, consisting of all buses with a B number, including the MTA Bus Company's B100 and B103 but not buses on Metropolitan and Grand Avenues that are part of the Queens network, has 10,800 revenue service-hours per weekday. If we take the future average bus speed as just under 15 km/h, then the left-hand side is about 160,000 km.

It may be possible to increase the amount of service-km from 160,000 by increasing the efficiency of bus turnarounds. In our interviews with the drivers we saw large variations in turnaround times, but at the same time, increasing efficiency is difficult as drivers often turn as fast as they can while still taking necessary bathroom breaks. There may be some potential savings coming from higher frequency on short routes, where running on headway management would allow shorter turnarounds, and there may also be potential for reducing schedule padding coming from better reliability thanks to prepayment and dedicated lanes.

However, the most important factor behind the proportion of bus-km that are in revenue service is the distance from the bus's two termini to the bus depots. A route with one end at a bus terminal, like the B25, can have 99% of its bus-km in revenue-service; among the busiest routes, the B6 (terminating near Ulmer Park Depot) and B41 and B46 (terminating near Flatbush Depot) all have an efficiency factor of about 95%. Routes far from depots are less efficient, and some, such as the B1 and B17, have a factor of not much more than 70%; the average for all Brooklyn routes except the B100 and B103 is 87%. We have made a few modifications to reduce non-revenue moves, but ultimately the bus depots are not located optimally for a bus grid, and on some routes, substantial pullout time is unavoidable. We believe an increase to 170,000 revenue-km through reduced deadheading to be at best aspirational.

On the right-hand side of the equation, the number of daily frequencies is an average across all routes. At the high end, the B46 has 161 local runs every weekday (including some that short-turn) and 232 SBS runs in each direction, for a total of 393 in each direction or 787 total. At the peak, frequency is about 43 buses per hour across the two service types, including many short runs only running south of the 3/4 subway station at Eastern Parkway.

For reference, offering 10-minute frequency all day and 30-minute frequency all night between midnight and 5 am involves 124 daily frequencies in each direction. Right now the total network length is 550 km and the average speed is 11 km/h, yielding just 108 bus runs in each direction, or perhaps a few more since the average speed is taken at midday, and night buses are faster because there is no traffic. Indeed, the average off-peak frequency today is about 15 minutes.

With today's 550 km network, even speeding up buses to 15 km/h can't truly transform off-peak frequencies. Replacing the average speed in the equation by 15, changing nothing else, gives 147 daily frequencies per route. With key routes like the B46 and B44 still requiring several times the service provision of the average route, there is little hope of providing even 10-minute service systemwide, let alone the higher frequencies that underlie Nova Xarxa.

Therefore, reducing the total length of Brooklyn's bus network is necessary to improve bus service on most routes. This should consist of pruning weak routes like the B39 (or else leaving them at today's low frequencies) but mostly of reorganizing the network to eliminate duplication of routes and rationalize the spacing between bus routes.

Providing a bus every 6 minutes between 6 am and 10 pm, every 10 minutes from 10pm to midnight and from 5 to 6 am, and every 30 minutes between midnight and 5 am requires 188 runs. As a first-order estimate, providing this exact frequency at 15 km/h and 10,800 daily revenue hours limits the network to 430 km; in practice the limit is lower, since many strong routes have much higher peak frequency than every 6 minutes, and a handful are more frequent even at the peak. The total number of service-hours required to match today's frequencies on routes that run more often than every 6 minutes is about 1,200, and this limits the network (including the highest-frequency routes) to about 380 km.

It's possible to trade off some of these limits. If we set the Brooklyn bus network at 350 km rather than 380 km, it would permit 5-minute frequencies between 6 am and 10 pm, a total of 220 daily runs. Alternatively, a 350 km network would permit 3.5-minute frequencies for two morning and two afternoon peak hours and 6-minute off-peak frequencies. As another alternative, the network could increase frequency on the busiest routes, anticipating future ridership increases from higher speeds and (for the crosstown routes) more convenient transfers.

Two-Way Streets

Many streets run one-way, forcing buses to run distinct routes in different directions. Usually they are arranged as consistent one-way pairs, or couplets: for example, in Manhattan the M15 runs northbound on First Avenue and southbound on Second Avenue, several buses run northbound on Third Avenue and southbound on Lexington Avenue, and several more run northbound on Madison Avenue and southbound on Fifth Avenue.

Within Brooklyn, most of the major streets are two-way, but some are not. A couplet separated only by a short block can work fine, but one separated by a long block is problematic for three distinct reasons:

1. The streets are often not of equal importance. For example, most of the B44 runs southbound on Nostrand Avenue (which hosts the subway) but northbound on New York Avenue or Rogers Avenue, both of which are far less important (Figure 5). This separation of of service introduces longer walks to passengers traveling northbound on the B44 and connecting to or from the subway on Nostrand Avenue.
2. Route legibility and identity suffer if buses don't run on consistent streets, especially if there is no consistent couplet as long as the Manhattan avenues. The BRT guidelines of the pro-BRT think tank Institute for Transportation and Development Policy recommend median lanes on the same street for this reason, reserving couplets only for very narrow streets without sufficient space for two bus lanes (ITDP 2016).
3. Finally, intersecting couplet routes require additional stops, one for each direction of the interchange, which reduces stop spacing. The closely-spaced stops on the B35 limited route as it connects to both directions of the B44 and then the B49 are a noticeable drag on its speed (Figure 6).

Figure 5. B44 and B44 Select Bus Service on Rogers, Nostrand, and New York Avenues

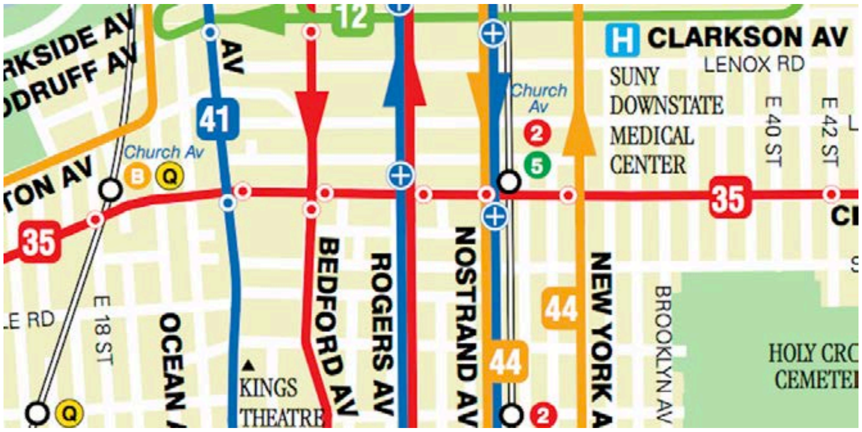

Figure 6. Interchange stops along the B35 route, intersecting with the B44, the B49, and B41 Routes.

The single most important street to be made two-way is Nostrand Avenue. With the B44 running on two separate streets northbound, the local up New York and the SBS up Rogers, the current layout is especially confusing, and the decision over which street to send the northbound route over when the two stopping patterns are consolidated is difficult. Nostrand is not a wide avenue, but it has enough space for median bus lanes if the parking lanes are removed and replaced with dedicated loading zones for delivery vehicles on cross-streets (Figure 7).

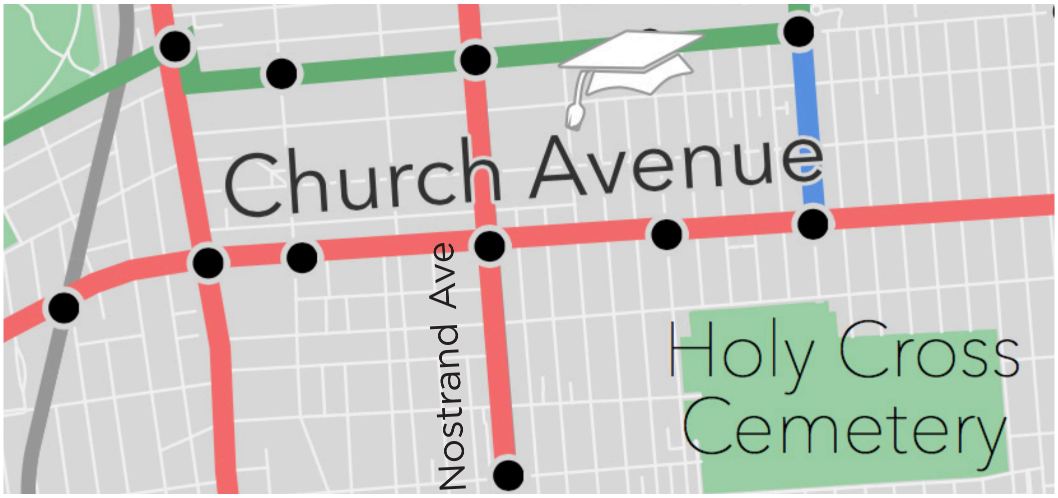

Figure 7. Section of Nostrand Avenue after proposed redesign

In addition to Nostrand Avenue, 13th Avenue in Borough Park is the main commercial artery, whereas the other street in the couplet, 14th Avenue, is residential. There is an argument for running buses on 14th and not 13th, as the subway connection to the N train is at 14th, but there is no argument for running in a couplet, forcing passengers to walk a long block to the subway in one direction and a long block to the main commercial node in the other.

Finally, the north-south avenues through Bedford-Stuyvesant between Nostrand Avenue and Malcolm X Boulevard all currently run one-way, but whatever buses run between the B44 and B46 should run two-way. The east-west routes through the neighborhood are slow and need to have stops spaced as widely as possible to compensate, which makes couplets onerous because the buses would need to stop twice rather than just once.

Network Redesign

With the tradeoffs between frequency and comprehensive coverage in mind, we propose a draft network of about 355 km. This network actually adds routes in some areas that are underserved relative to their density, such as Borough Park. In Central Brooklyn, some routes are cut if they run on top of the subway, including the B25 on Fulton Street and the inner segment of the B41 on Flatbush Avenue, and in South Brooklyn the bus network is greatly reduced as the area has good subway coverage in several directions. In East New York, the network is redesigned to have straighter routes (for example, buses reach Gateway Mall more directly from the north rather than from the east).

Outside South Brooklyn, which is replete with subway coverage, no neighborhood loses its bus service. However, some neighborhoods lose their one-seat rides. Southern Brooklyn's street network is amenable to a frequent bus grid like Nova Xarxa, with many east-west routes such as on Avenue U and Avenue X, and some north-south routes complementing the subway lines to Coney Island. Elsewhere in the borough, we sometimes consolidate closely parallel bus lines if they're weak, for example the north-south routes of Williamsburg or the east-west routes between the A/C trains on Fulton Street and the 3/4 trains on Eastern Parkway.

In choosing which corridors get buses, we looked at the current network but only as a secondary concern. The top concerns are serving the busiest nodes and running on busy commercial streets. The sites with the highest job density in Brooklyn outside Downtown Brooklyn (which has ample subway coverage) are all hospitals, of which the most important is the Kings County Hospital Center in Flatbush. In addition, many important nodes on the bus network are major subway connection points, such as Brooklyn College on the 2/5 and Utica on the 3/4, and retail centers including Kings Plaza and Gateway. Finally, we made sure to serve the housing projects in the borough, as they have high residential density.

In order to improve bus operator satisfaction, we avoid having routes that are too short or too long. Few are longer than an hour. Only two are much longer: we expect the B35 and B44 to average about 1:09, as both are lengthened, the B35 taking over the B15 to JFK and the B44 going beyond its current northern terminus at Broadway and Marcy Avenue. Moreover, the B44 can be shortened: its northernmost segment, beyond Broadway, can be given over to the B60 or the new B48 route on Washington Avenue through the Navy Yard.

At the same time, routes that are too short require considerable slack time in the schedule. On such routes, giving drivers breaks every roundtrip would lead to a lot of idle time. It's possible to give drivers break time per several roundtrips, for example 10 to 15 minutes per hour, but this means that there should be at a minimum four to six drivers per route, with one taking a break at a time. High frequency enables this rotation to take place on shorter routes, but there is still a minimum one-way trip time of about 12 to 15 minutes. For this reason, we have combined routes that might otherwise be split into short shuttle routes, such as the new B1 and B36, running east-west at the southern rim of Brooklyn, incorporating the existing B74 and the B1's shuttle runs from Brighton Beach to Kingsborough Community College.

Variations

There are many possible variations on the map within our framework. Borough Park today has one north-south bus running part of the way on 13th Avenue and 14th Avenue as a one-way pair, and part of the way on Fort Hamilton Parkway. We strongly believe two routes are needed, one on Fort Hamilton and one on either 13th or 14th; the one-way pair is bad practice, but it's an open question of whether to run in both directions on 13th, the more commercial avenue, or on 14th, which connects to the N train.
Moreover, the southernmost east-west routes form a grid with the subway in our plan, but it may be prudent to instead cross them as the B1 and B36 cross today, in order to serve Coney Island Hospital in more directions.

The biggest potential change is in Bedford-Stuyvesant. We have just one north-south route through the neighborhood between the B44 on Nostrand Avenue and the B46 on Malcolm X Boulevard, running on Marcus Garvey Boulevard, but there's a strong case for instead running on Throop Avenue for a better subway connection, or even for having two separate north-south routes as today. Having just one route would represent a service cut to the area, one of the few that would see fewer bus-km than today. Running two routes from Kings County Hospital north, one on Lewis Avenue and one on Throop Avenue, would provide better north-south service through the neighborhood.

Our choices of stops are open to debate. While the stop spacing of about half a kilometer is optimal, the individual stop locations aren't always. In parts of Brooklyn, such as Midwood, the best stop spacing is two out of every three avenues. Choosing which avenues get stops and which do not involve tradeoffs between local density, overall coverage, and system legibility.

The same tradeoffs happen at many other places in the borough. For example, where the B44 overlaps with the subway, should it aim to stop at the same locations as the subway for the best transfers, or should it stop on the major streets (which are not where the Nostrand Avenue Line stops) and rely on transfers only at Flatbush at the southern end and Eastern Parkway at the northern end? Our current draft chooses the latter option, but it is possible to instead realign stops with the subway.

More broadly, what we propose is a process and not just an immutable complete product. If the subway is extended in the future, the buses should be realigned appropriately. As more subway stops are made accessible, more bus routes that duplicate the subway should be removed and have their service-hours redeployed; for example, the B25 may be reasonable to keep until Broadway Junction is upgraded for step-free access on the A and C trains, while the B63 on 5th Avenue may be cut after more stations on the R are step-free.

Phasing

The MTA's process for bus redesign is projected to take years. It's fine to take time to deploy the entire network; Nova Xarxa began implementation in 2012 and concluded its roll out at the end of 2018. While the decision about which routes are optimal can be made quickly, some of the bus stop decisions can take longer, and the required street redesigns (especially making Nostrand Avenue two-way) are also likely to take some time.

Within this process, we can identify some higher priorities for phasing. In East New York, the current network is extremely circuitous, and it would be beneficial to straighten it as soon as possible. Moreover, as the L train undergoes significant service interruptions over the next two years, East New York buses that are designed to feed the L should instead be changed to feed alternative subways, the 3, the J/Z, and the A/C (MTA n.d.). The removal of the B82 from Starrett City and its replacement with a high-frequency north-south route on Pennsylvania Avenue feeding the 3 and Broadway Junction should happen right at the beginning of the L train service changes.

Very weak routes can be removed immediately, such as the B37. However, routes that duplicate inaccessible subway lines, such as the B39 across the Williamsburg Bridge, may be kept at their current low frequency until more accessible stations open.

Early route removals can be directed into higher off-peak frequencies on existing lines, or to splitting the B16 into two separate routes in Borough Park as we recommend. In the short run, a short route running up 13th Avenue between 39th Street and Bath Avenue would be both useful and (due to its northern end's proximity to Jackie Gleason Depot) efficient.

But given passenger complaints about high off-peak crowding levels, bunching, and low frequency, we prefer beefing up frequencies on existing routes. The best routes for increases in frequency are those with many passenger trips per service-hour (in which category the top two are the B74 and B36, both short subway feeders in Coney Island) and those with present-day off-peak frequency of about 10 minutes, which can be improved to 7.5 minutes with not too many new daily runs.

Among the speed treatments we recommend, we expect bus stop consolidation to be the most contentious. However, it is also the most critical, and the easiest to implement immediately. The best routes to start with are those with local and limited buses, including the B6, B35, B41, and B82; the process would consolidate each of these routes into a single variant with very high frequency, encouraging all-day ridership. But the MTA should be ready to consolidate stops on every route very quickly, on the scale of months after the B6 and other strong routes lose the local-limited distinction.

Median bus lanes would presumably require a pilot study before full deployment. Even after a number of years, we do not expect every bus route in the borough to have dedicated lanes; in the outer margins, such as in Coney Island and Gerritsen Beach, there is so little traffic that mixed traffic could work indefinitely. But key arteries should all have dedicated bus lanes. The first route to receive median bus lanes should ideally have a wide street, high ridership, and bus operator complaints about cars blocking bus traffic; we cannot make definite recommendations, but suspect that the B46 would be a top candidate, as would the central and southern portions of the B6.

While a phased approach is prudent, we caution against following a process similar to that of SBS, in which only one route at a time is upgraded, almost always with a slow local bus remaining on the same route. The redesign should aim to speed up all buses at the same time. Some compromises on stop spacing, the quality of bus lanes, and route consolidation are inevitable, and our current plan therefore has a contingency; we only use 10,100 out of 10,800 hours to guarantee every bus line on our map 6-minute all-day service, and if there are no big compromises slowing down the buses, the 700 hours' worth of difference can be redistributed to adding more routes (such as another north-south route in Bed-Stuy). However, compromises involving a local and a limited route on the same street should be out of the question, as they would only reduce frequency on both stopping patterns.

Expected Ridership

Bus ridership in New York has been falling rapidly for a decade. We use models for the effect of speed and frequency on ridership relative to the current state of the network. These models include the benefits of higher travel speeds and shorter wait times and the countervailing force of longer walk times to bus stops.

As a note of caution, the estimates in this section are necessarily rough. We use estimates for the elasticity of ridership with respect to frequency in the reviews of Lago et al. (1981) and Totten and Levinson (2016), both of which find large variations in the literature depending on the city, the study, and the preexisting frequency: in particular, they both find that the elasticity is smaller when the frequency is already high, as an increase in frequency then only cuts a few minutes from travel time, rather than (say) cutting headways from one hour to half an hour. As we propose a large increase in frequency, the frequency regime we must use is the highest one, which may well involve extrapolation from the regimes studied so far. In Totten and Levinson (2016) the lowest elasticity is 0.3, removing a single outlier, and in Lago et al. (1981) it is 0.22, for bus routes more frequent than every 10 minutes.

Lago et al. (1981) reports an additional elasticity of 0.64 for bus-miles, averaged over agencies with a variety of frequencies (averaged over all agencies, the elasticity of frequency alone is 0.44), which covers increases in coverage and frequency but not speed. It reports an elasticity of 0.3 with respect to bus speed for specific treatments giving buses dedicated lanes on freeways, and a range between 0.12 and 0.6 with respect to bus speed on city streets in three cities, in addition to an elasticity of about -0.2 for wait time and (for Minneapolis only) -0.14 to -0.26 for walk time.

The current unlinked bus trip averages 18 minutes in-vehicle, with a frequency of about 10 minutes averaged over the peak, off-peak, and evening. We assume average walk distance today is 300 meters at the origin end and 100 at the destination end, taking 5 minutes.

Under our proposal, in-vehicle time falls to 13.5 minutes, average frequency increases to every 5 minutes, and walk distance increases by about 100 meters, lengthening the walk to 6.5 minutes. The extra walk distance is based on stop consolidation and not route consolidation, since we mostly consolidate weak routes, and are creating new ones in areas with big gaps in service in Southern Brooklyn. Using ridership elasticities of -0.3 with respect to in-vehicle time, -0.22 with respect to frequency, and -0.26 with respect to walk time gives us a 20% increase in ridership.

We caution about this estimate for three separate reasons. First, it involves extrapolation, since we propose very large increases in frequency and speed. Second, even in the existing data there is a wide variation in the elasticity figures, and while we try to use the most conservative ones (that is, the most inelastic figures for frequency and speed and the most elastic one for walk time), they are still averages and worse results are possible as well as better ones. And third, the new network will change people's behavior in the short as well as long terms, as seen in the large change in the share of trips involving a transfer in Barcelona under Nova Xarxa, and this introduces additional complications into any attempt at a model, which could change ridership in either direction depending on the specifics of the transfer penalty.

5 Conclusion

For too long the bus has been a mode of last resort in the United States. This doesn't have to be the case. Cities like Barcelona, Seoul, and Bogotá, have demonstrated that by redesigning their bus networks, increasing service frequency, consolidating stops, separating out traffic, and introducing improvements, such as all-door boarding and transit signal priority, buses can become a reliable and desirable option for accessing the promise of cities.

In this report we combined the experience from bus network redesigns from around the world with a plan of action for Brooklyn that calls on different actors, such as the MTA and the New York City Department of Transportation. We believe that this kind of work is central to the discipline of planning. Rather than waiting for the MTA to release a plan, we have proposed our own. Friedmann and Hudson (1974, p.2) describe the purpose of planning plainly when they write, "A useful way to look at planning is to consider it as an activity centrally concerned with *the linkage between knowledge and organized action* (emphasis in the original)." In this study, we have actively sought to connect knowledge with action while improving commuting time for the slowest mode. This normative frame, in our view, is also critical to planning (Bertaud 2018, p.31).

By proposing a new bus network for Brooklyn, we have staked out a vision for American cities. One that argues that the bus is a powerful tool that allows all people to participate in the life of cities by providing access to jobs, schools, shopping, and other modes of transport at an affordable price (Attoh 2017). By proposing a radically specific plan that identifies stops, headways, street redesigns, and routes, we are translating abstract ideas of transport justice and best practices into a concrete plan that can be debated, assailed, and improved.

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