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Introduction and Methodology

Transit agencies across the country are redesigning their bus networks to provide more frequent service, at headways of every 15 minutes or less. Yet the adoption of new standards and practices to provide those services with reliability has lagged. This white paper, developed by Sam Schwartz Engineering, D.P.C. in cooperation with TransitCenter, documents existing practices and offers recommendations for scheduling and dispatching of frequent bus service. It proposes elevated standards and best practices for bus operations (i.e. what transit agencies should strive to achieve) and guides agencies in their pursuit of these reliability goals. Recommendations include the following:

- Agencies should use data to further their frequent service reliability goals, including customizing run times, recovery/layover times, and time bands.
- Headway management is an alternative strategy to timepoint-based scheduling that may increase reliability on frequent routes. Headway management can give operators the latitude to adjust service in real-time, and it does not necessarily require more on-street supervision.
- Drop-back dispatching is another reliability strategy that is underutilized for frequent bus service.
- Agencies may need to create different on-time performance metrics for frequent services or make their frequent service on-time performance metrics more stringent.
- Headway management, terminal dispatching techniques, and performance measurement cannot increase reliability if agencies do not also address underlying traffic and congestion issues.

This white paper begins with a literature review of scheduling, dispatching, and how transit agencies define and measure reliability. It then draws on eight transit agency case studies across the US. Phone interviews with the agencies were conducted in March and April 2019 to understand how they currently schedule and dispatch frequent service and the challenges they face with maintaining reliability. The information throughout the paper reflects the research team's understanding and interpretation of the information discussed during the interviews. A matrix comparing each agency's frequent services and operations is included as an appendix. The team also developed a companion white paper on operator engagement drawing on the same research and interviews.

- **Capital Metropolitan Transportation Authority (Cap Metro), Austin, Texas.** Cap Metro first launched its MetroRapid services (801 and 803) in 2014 with limited stops, enhanced stations, and mobile ticketing. This followed with a high frequency service (every 10 minutes) in 2017 and a full system redesign (Cap Remap) in 2018. Cap Metro now has 14 routes operating at 15 minutes or less on weekdays from 7am to 7pm.

- **King County Metro, Seattle, Washington.** King County Metro operates six RapidRide routes with service at least every 10 minutes during peak hours (~6am to 9am and 2pm to 7pm). Introduced between 2010 and 2014, these corridors have Bus Rapid Transit (BRT)-like features, including off-board fare payment, Transit Signal Priority (TSP), and branded stations and vehicles.

- **Maryland Transit Administration (MTA), Baltimore, Maryland.** In June 2017, the MTA launched a system redesign that designated frequent routes ("CityLinks") with at least 15 minute headways. Of its 65 local bus routes, 18 operate at 15 minutes or less on weekdays from 6am to 7pm.

- **Massachusetts Bay Transportation Authority (MBTA), Boston, Massachusetts.** In 2012, the MBTA designated 15 "Key Bus Routes" for improvements like better stop spacing and stop amenities. This was followed by the "Better Bus Project," which was a budget-neutral analysis to improve and streamline all routes in the system. The MBTA now has 19 frequent routes that operate at 15 minutes or less from 7am to 8pm.

- **Metropolitan Transit Authority - New York City Transit (NYCT), New York, New York.** MTA NYCT operates 300+ routes, many of which have headways of 10 minutes or less during peak periods. This includes its 17 BRT-branded routes, called Select Bus Service (SBS).

- **Rhode Island Public Transit Authority (RIPTA), Providence, Rhode Island.** RIPTA operates 55 bus routes throughout Rhode Island. The agency created the "RLine" in 2014, which operates with 10 minute headways on weekdays from 8am to 7pm and 15 minute headways during those hours on weekends. The RLine effort included new shelters, wayfinding, wrapped vehicles, stop consolidation, and TSP on the corridor.

- **VIA Metropolitan Transit, San Antonio, Texas**. VIA's two "Primo" routes have peak headways of every 10-12 minutes on weekdays from 6am to 6pm and are distinguished by enhanced stations, CNG articulated buses, and TSP. The agency also classifies additional routes in the system as frequent services, defined as running every 20 minutes or less during the peak.

- **Washington Metropolitan Area Transit Authority (WMATA), Washington, DC.** WMATA has many frequent routes in its bus network (less than 15 minute headways), and seven routes that, since June 2018, are operated using headway management. These routes (70, 79, X2, 16Y, 90, 92, and Metroway) are communicated to the public as "no-schedule-needed routes" and do not use timepoints during the peak.

Overall, reliability is achieved through a toolbox of strategies such as adjusting and customizing schedules with robust datasets, implementing headway management and/or drop-back dispatching, creating appropriate on-time performance metrics, and investing in capital improvements and infrastructure like dedicated bus lanes and TSP. Transit agencies must ensure that their policies and procedures support the tools and technology at their disposal, and commit to making upfront investments and structural changes in order to see results. Critically, agencies cannot provide reliable frequent service on their own – city transportation departments must be partners in the effort and help address the fundamental issues of traffic and congestion.

Literature Review

Background – Reliability

Bus service reliability is an essential factor impacting customer satisfaction, operating costs, and overall system performance, explaining why it is one of the most important performance indicators measured by transit agencies and service providers. However, the practices and measures employed to achieve high levels of service reliability differ among transit operators, and even between bus routes with frequent service of 15 minute headway or less and those with longer headways within the same agency.

Reliability is a function of multiple external factors including traffic congestion, construction, incidents, weather, dedicated bus treatments, passenger demand and distribution along a route, boarding/alighting rates, etc. (Schmocker). Gittens and Shalaby found that time of day, spacing between stops, route length and the location of routes within a metropolitan area all impact route performance. Network design can also affect reliability. Where multiple routes serve the same set of stops along a corridor, passengers can experience higher reliability if overtaking is allowed (Schmocker). Bus bunching (and its corollary, gapping) is an indicator of poor reliability. When several buses arrive or depart close together, this results in a longer headway for passengers waiting for this or the next bus. Service deteriorates for passengers, and buses can be either overcrowded or underutilized (Cevallos). Other factors that may affect reliability that are not part of the reviewed literature include the availability, accuracy, and application of real-time data, bus operator behavior, irregular and unpredictable demand spikes, and the amount and assertiveness of road supervision.

Reliability encompasses both punctuality and regularity. Punctuality, or on-time performance, refers to bus adherence to an arrival and departure schedule and how much each trip deviates from pre-determined timepoints. Arrivals up to five minutes past (or another specific window) of the scheduled time are considered on-time, while those beyond the chosen window are late. Buses arriving generally no more than one minute early may also be consider on-time. Fixed measures of on-time performance may not be meaningful on high frequency routes, where bunched buses could technically be counted as on-time, per the measure. Thus, some agencies have adopted separate measures for frequent and infrequent routes, and/or proportional measures

By contrast, regularity refers to how consistently headways are maintained between two consecutive buses on a route. The variation in headways of a route is measured by the Coefficient of Variation (CoV). This regularity measure is increasingly being adopted by transit agencies either as a supplemental measure or a full replacement of timepoint punctuality (Van der Werff).

Scheduling

Transit schedules are the building blocks of bus system operations. They define the service to the public, establish operators' work days, and shape the efficiency and effectiveness of the system (TCRP 135). For both frequent and non-frequent service, transit agencies use scheduling to help ensure service reliability.

Both static and dynamic strategies can be employed to improve bus reliability and reduce bus bunching. First, schedulers must determine appropriate trip times, often from a wide range of historical data. Trip times may vary by time of day, day of the week, season, and can be influenced by load factor, traffic conditions, weather, and other unpredictable variables. This can result in highly variable historical running times that cannot be translated into a reliable running time. Using worst-case running times will yield scheduled running times that are excessive, incur higher operating costs, and are unattractive to customers. Rather than using the worst-case scenario, van Oort found that using as low as the 35^{th} percentile of the historical total trip time value minimized passenger wait time and travel time. Although this could lead to more late vehicles, preventing early vehicles "will on average decrease the average additional travel time per passenger" (van Oort). The optimal value for routes with control/holding points was between the 30^{th} and 50^{th} percentile of the total trip time, depending on the route's standard deviation.

Schedulers must also determine the number and location of time points (potential holding points). Set too soon after the start of a route, control points may have little impact, while those farther along may benefit fewer passengers (van Oort).

Building recovery time between trips into the schedule is another key strategy to increase reliability. Recovery is a buffer that allows buses to begin their next trip back on schedule if they arrived late from the prior trip. This may mean an operator gets no or minimal break time between trips when running late. Layover is paid break time at the terminal for operators, often stipulated in a labor agreement (TCRP 135). It is time the bus operator "owns," which they may elect not to use to help get the route back on schedule, or to claim pay for if they do. Recovery time is a buffer to help ensure that delays along the line do not cascade, disrupting subsequent trips; layover or stand time may or may not offer that opportunity. Providing ten percent of the trip running time as layover/recovery is common practice, but it could be as high as 15 or 20 percent for particularly unreliable routes, e.g. those with congestion or frequent wheelchair boardings and alightings (TCRP 135). For shorter routes, percentage may not be the most meaningful measure.

Holding buses along a route can also improve reliability. A static holding strategy uses pre-determined timepoints, while a dynamic holding strategy determines the holding time based on real-time Automatic Vehicle Location (AVL) data of buses ahead and behind (Van der Werff). Holding may benefit downstream passengers by equalizing intervals of buses that come after the bus being held, but it worsens service for passengers already on, or who will be picked up by the bus being held.

Other dynamic strategies to recover from disruptions or irregular headways include skipping stops, expressing, deadheading, short-turning, limiting boarding, or inserting standby buses into a line and retiring the replaced bus (Cevallos). Using a simulation model, Petit and Ouyang found that standby bus insertion outperformed schedule-based recovery strategies. An advantage of standby bus insertion is its minimal impact to passengers - no extra dwell time or transferring (Petit and Ouyang). Periodic insertions have the advantage of minimal impact to passengers, as they do not require transferring or extra dwell time. However, this strategy can generate unbudgeted labor and fleet costs. If this strategy is employed at peak times, the cost may be disproportionately greater; operators may only be available on overtime, and the peak fleet may already be on the road. If extra operators and service-ready spare buses are available, the customer benefits may be more favorable. It is understandable that Petit and Ouyang's modeling found that this strategy outperformed others. Requiring passengers to disembark from a bus that is short-turned or will no longer serve their intended stop is disruptive under the best circumstances In addition to generating ill-will, management must gauge the true benefits; if customers resist disembarking, or the process takes too long, the hoped-for time savings to help normalize service may be reduced. The number of passengers harmed versus helped should be a factor in management's decisions. Short-turning is a standard agency practice, but it is unclear if and how agencies measure and track its effectiveness and impacts.

Agencies are also using data to refine schedules and improve reliability. Automatic Passenger Counter (APC) and AVL data can find causal variables of delays, such as passenger boarding and alighting information per stop. Ji found that real-time information improved service reliability for timepoint-based schedules. Another strategy is to partition schedules into more fine-grained time-of-day (ToD) intervals (Bie). ToD intervals may be based on a mix of professional judgement and ridership data, and attempt to account for variable traffic conditions and dwell times. However, increasing the number of intervals must be balanced with operational complexity and possibly increased costs.

Real-time understanding of buses through AVL technology has led to a shift at some agencies away from timepoint-based reliability strategies to dynamic headway management for specific routes (e.g. WMATA, Cap Transit). Headway management's focus on regularity is appealing for high-frequency bus routes, as keeping to fixed timepoints becomes increasing challenging as headways decrease.

Dynamic control strategies have been assessed in both simulations and real-world experiments. Berrebi (2018) conducted several experiments testing a dynamic headway dispatching strategy on the Atlanta, Georgia streetcar system, the Georgia Tech shuttle service, and VIA Metropolitan Transit's Primo 100 route in San Antonio, Texas. The model used AVL data and a discrete probability distribution to alert drivers of their dynamic, modified departure time using countdown displays at control points.

In Atlanta, dispatchers provided radio instructions to the operators. In San Antonio and at Georgia Tech, dispatchers had tablets with real time information at the terminals.
This real-time strategy decreased headway variability, but adherence to the strategy was affected by AVL data lag time, loss of data connection, judgment calls by operators, and the design of control points (Berrebi). These shortcomings may be less of an issue for agencies with very advanced AVL systems. However, the pilots led Berrebi to conclude that operators will perform better, in terms of headway reliability, when they have more information to make informed decisions on the road. He argues that operators know their routes better than any algorithm or anyone else in the agency, and they are best positioned to make judgement calls in real-time. The question is whether many well-intentioned individual decisions combine to improve overall performance, and whether operators will use judgment to benefit customers or to further their personal interest (such as completing their shift on-time).

Van der Werff generated simulations of a high-frequency bus line in the Netherlands (Line 400, Leiden – Zoetermeer), with the goal of lowering headway CoV. Van der Werff found that headway and schedule-based strategies "performed more or less equally well" when "excessive buffer times" were included in timetables. When these buffers were reduced and vehicles were less likely to arrive to control points early, the headway-based dynamic strategies performed better and were able to recover from or prevent the negative effects disruptions, such as detours. The added cost of excessive buffers makes dynamic strategies all the more attractive.

Terminal Dispatching and Operations

Terminal dispatching involves providing each trip with a departure time (either by schedule or dynamically), insuring it is adhered to, and then allowing the bus to complete its trip with no, or perhaps one intermediate time point. The ability of terminal dispatching and overall terminal operations to improve service reliability depends in part on contextual factors that may be internal or external to the transit agency. Planning stage decisions affect operations, including network design, traffic signal prioritization, queue jumps, and infrastructure design, such as the location of terminals, stops, and short-turn facilities (Cevallos). Internal day-to-day factors that can affect the regularity of operations include driver behavior and availability and vehicle availability. External factors such as weather, irregular passenger loads, and traffic can also generate irregular service that may require real-time interventions.

Terminal conditions and operational strategies can have ripple effects for an entire route. A terminal may experience the most passenger boardings along a line, or it may not include any passenger activity. Recovery time can be incorporated to account for delays, and excess buses may be kept at terminals and inserted when bus bunching occurs (Van der Werff). However, this buffer is generally determined at the planning stage and can therefore be inadequate or excessive, depending on real-time conditions (Berrebi 2015).

One technique to increase reliability and contain delay at terminals is the use of drop-back (or fall-back) dispatching (TCRP 135). Operators still take their layover when they arrive at the terminal, but their vehicle is unlinked from the operator, making it immediately available for service, possibly used for the next scheduled departure, driven by the operator of a preceding run who is now coming off their layover. On routes with frequent service, this may offer opportunity to reduce peak bus requirements, and with that, fleet size. The approach depends on there being another operator available to place the bus in service. Drop-back dispatching is common on rail lines where frequent headways do not allow sufficient layover time. For buses, a mitigating factor may be whether regulation and/or labor contracts require the operator to inspect any “new” bus they are assigned. Inspection should not be a deterrent to drop-back dispatching, but it is a factor that must be built into schedules if it is required. Inspection generally takes no more than 10 minutes at maximum.

Terminal dispatching can also be dynamic, based on real-time location data of buses ahead and behind (Van der Werff). Cats (2014) tested a headway-based model on high-frequency transit lines in Stockholm, Sweden. It could be adjusted by time of day and time of year and customized at the level of each line or stop. The model achieved several benefits for passengers, including decreases in excessive waiting times, in-vehicle time, and total travel time. The transit agency also experienced benefits, including an annual cost savings of 3.87M euros. Cats noted that it was necessary “to introduce supporting measures including scheduling drivers and vehicles such that interlining is minimized.” Cats also recommended an on-time performance measure of headways that deviate by less than 50 percent from schedule, at the terminal and along the route. It is important to stress that the suitability of 50 percent depends on the headways – in Stockholm the headways were every four to six minutes.

Scheduling and Dispatching Frequent Service – the Building Blocks

Agencies generally approach scheduling for both frequent and non-frequent routes with the basics - building a schedule with timepoints. This typically involves a route-by-route analysis to determine appropriate run and layover times. For run time, the agency may consider if a route's run time normally varies by time of day, day of week, and/or route segment. The agency must determine if intermediate route timepoints could help or hinder the route and if they will be advisory or mandatory/enforced. Depending on the history of the route and its function, customers may or may not expect to consult a schedule as to arriving at a stop, which is another scheduling consideration. With the proliferation of real-time apps, it may be worth rethinking whether adherence to a schedule is more important that simply knowing accurately when the next few buses will be arriving.

For layover time, the agency must balance the benefit of enough of a buffer to handle incidents and traffic issues/variability versus excessive cost in dollars, equipment, and curbside or terminal space. Financial constraints may limit the agency's ability to schedule effectively; a trip with a two minute recovery may really need six minutes, but change could mean an additional vehicle or operator, or extended headways. Layover requirements are shaped by layover facilities (e.g. access to restrooms), as well as contracts and longstanding practices that define recovery versus layover. Of the case study agencies, King County Metro and VIA reported having guaranteed operator time even if a trip arrived to the terminal late.

Many agencies rely on paper paddles with timepoints (MBTA, King County Metro, MTA), and some, like the MBTA, have no intermediate timepoints, listing terminal timepoints only (see Figure 1). Regardless of the number of timepoints, schedules can be refined using recent historical data, as a supplement to the agency's anecdotal understanding of how routes function. This can be further customized by creating multiple time bands and day-of-week schedules, both for run time and layover.

Report Time	**Start Place**	**Start Time**	**End Time**	**End Place**	**Clear Time**
401a	charl	411a	947a	charl	947a
1031a	charl	1036a	1216p	charl	1216p

-	**malden ctr station - fells charls.........935a** **C charlestown....................................947a**	
	Split break	947a 1031a
	Block	89 - 13
-	**C charlestown..................................1036a** **sullivan sta - charl fells somvl.........1041a**	
89	**sullivan sta - charl fells somvl.........1041a** **davis square - charl fells somvl.......1102a**	
89	**davis square - charl fells somvl.......1110a** **sullivan sta - charl fells somvl.........1135a**	
89	**sullivan sta - charl fells somvl.........1141a** **davis square - charl fells somvl.......1202p**	
-	**davis square - charl fells somvl.......1202p** **C charlestown..................................1216p**	

Figure 1: Example Paddle, MBTA, March 2019

A key theme from the agency case studies was the need for agencies to use data to make better decisions, specifically tailored schedules. Applicable to frequent and non-frequent routes, “historical” data can be from the last month, week, day, or even the last hour. To achieve this, agencies are increasingly turning to technology platforms. User-friendly interfaces can allow schedulers to easily input and update running times, time points, and system requirements/preferences. These platforms allow for very flexible timepoint-based schedules; in theory every trip could have a different running time.

The MTA, for example, is using data to modify run times and create custom time bands for each route. At the launch of its redesign, MTA did not have a strategy on how to specifically manage frequent services. Its CAD AVL system was inadequate, updating locations only every 1 to 3 minutes. The agency engaged a new technology platform to install transponders on its vehicles for more accurate location data. It is now using the data to modify run times, making schedules more realistic and increasing operators’ “chance of success.” The agency currently allocates 10-12 percent of run time for layover on its frequent routes. It is in the process of a trip-level analysis of on-time departures, analyzing layover performance and customizing layover times. It hopes to report on-time departure statistics in real-time from gate readers, further emphasizing the importance of starting off right.

NYCT also uses data to guide its operations. Each of its route has a route manager who receives a daily Operations Research Computational Analysis (ORCA) report. These reports both help identify issues and highlight when on the ground efforts are working. The ongoing review of routes and route segments help managers and supervisors understand the problematic segments and create action plans to address them (e.g. changing a supervisor position, requesting additional police presence). Though of great value, it does not offer a real-time solution.

Once the schedule is determined, agencies have other strategies to maintain reliability mid-route. This can include short-turns, holding at timepoints, deadheading vehicles to an injection point, using standby vehicles, dropping trips, bypassing stops or segments, or detouring to bypass traffic. Of the case study agencies, deadheading to an injection point and bypassing stops or segments were the most commonly employed. Holding at timepoints was viewed as somewhat problematic, as without clear and consistent on-board announcements, customers question why a bus is idling. All the agencies reported using real-time data for on-street staff, to inform when and where to execute the mid-route strategies.

Communication among control center dispatchers, on-street staff, and operators is a challenge for agencies as they try to maintain reliability. MTA for example, is constrained by a dispatch communication system between the control center and operators that only has three channels, one of which is reserved for emergencies. Multiple case study agencies (MTA, MBTA, NYCT) also stressed their preference for in-person communication both at terminals and on the street. They conveyed that even the best technology cannot substitute for staff presence, and that operators take performance more seriously when they have in-person supervision. Justifications for in-person supervision include ability to check on operator fitness, uniform, and appearance, but that depends on the supervisor making actual contact. Contact may not occur when operations are normal, in inclement weather, or when supervisors are allowed to perform from within cars or sheltered areas not at actual stops. In the absence of in-person staff (a reality given resource constraints), control centers are paying closer attention to frequent routes with more proactive monitoring, generally using traditional methods like radio communications.

Terminal operations also help or hinder reliability for frequent routes. Terminal performance is key – it is very difficult to catch up if a trip starts late. Agencies may have an in-person supervisor/dispatcher to coordinate departures at the terminal, a remote supervisor/dispatcher, or rely solely on the operator to adhere to the paddle departure time. The case study agencies reported having either remote instruction or in-person staff, though this was location dependent and limited by staff resource constraints. Dispatchers are often juggling multiple routes; the MBTA reported having as few as six dispatchers for the system's almost 180 bus routes, and only one dedicated dispatcher for its 19 frequent routes. None of the case study agencies reported having audio/visual signals for the operator to signal departure.

Only WMATA and RIPTA reported using drop-back dispatching, with NYCT using this technique during overnights only. King County Metro recognized the potential of drop-back dispatching to increase reliability and decrease fleet and layover space requirements, but noted the strategy would require a more flexible approach to scheduling and operator assignments as well as updates to its scheduling software.

Other terminal operations strategies can also help increase reliability; WMATA reported using technology at its garages to help ensure on-time departures, specifically a "division yard management system" that helps operators know which vehicle to use and exactly where it is on the lot.

Scheduling and Dispatching Frequent Service – Experiments with Headway Management

Both the literature review and the agency case studies highlight the challenge of providing service that the customer perceives as reliable when operations are tied to schedule adherence and timepoints. A lag exists between implementing frequent routes and making changes to scheduling, dispatching, and performance measures. Only two of the eight case study agencies have different scheduling/dispatching techniques for frequent versus non-frequent routes, with non-frequent routes maintaining timepoint schedules (Cap Metro, WMATA). The lag may in part be a result of agencies' lack of recognition that different techniques or measures are necessary or could be beneficial to their system. Operations personnel and planners may work in silos, and not communicate the how changes in one area affect the other and vice-versa.

Despite the lag, agencies are taking steps to accommodate frequent service. Changing how route information is presented to the public is one example. VIA builds all their schedules based on timepoints but does not publish timepoint schedules for the Primo 100 route, instead advertising service as every ten minutes. MTA's public-facing schedules for its CityLink routes are also as advertised as every 10 minutes during peak times; operations are based on schedules.

Updating performance measures is another example of a change that agencies make after implementing frequent routes. Four of the eight case study agencies have different frequent and non-frequent performance measures, basing the frequent measure on the scheduled headway interval rather than a timepoint window. Other agencies are adopting new reliability evaluation measures that are more passenger oriented, as opposed to the traditional vehicle-centric measure of on-time performance.

NYCT, for example, has transitioned to Customer Journey Time Performance (CJTP) for all of its bus routes. CJTP is made up of additional travel time and additional bus stop wait time and measures the percentage of customers who complete their journey within 5 minutes of the scheduled time.[1] The measure has the potential to guide NYCT's operational improvements in a more targeted and effective way, as it reflects "how many passengers are affected and how significantly" (Graves 2019). However, its actual impact on operations to date is unknown.

NYCT is using customer fare swipes combined with AVL data to calculate the metric, combining elements of regularity and punctuality. CJTP was developed using MTA's origin–destination (OD) ridership model, which connects fare swipes on buses and off-board fare kiosks to specific bus stops, and infers destinations by riders' next boarding swipe (Graves 2019). The OD pairs are assigned a weight based on ridership from a previous month, and an algorithm assigns riders arrival times at their bus stops based on route headway length. The algorithm assumes that passengers arrive randomly when headways are under 11 minutes and arrive based on schedules when headways are longer.

Despite CJTP's potential, Transport for London (TfL) is the only other known agency besides NYCT using a similar metric for buses. Additionally, TfL, MBTA, and WMATA use similar metrics for their rail networks. This is likely because of data availability, specifically rider destinations, and data processing requirements.

Agencies may decide to maintain timepoint scheduling for frequent routes, customizing schedules as much as possible using recent, robust data sets, as described above. Another tactic is to break with traditional schedules and use headway management for frequent routes. Headway management can take place at the terminal initiated by dispatchers, or mid-route by both dispatchers and operators. The following case studies describe the experiences to date for those four agencies that have tested pilot headway management projects or have adopted/plan to adopt headway management on a sub-set of their routes.

- **Cap Metro's** MetroRapid operators (and dispatchers) use an onboard Headway Monitoring tool that displays real-time spacing. According to the MetroRapid operating procedures, it is the operator's responsibility to continually adjust to stay equally spaced between their leader and follower (see Figure 2). MetroRapid routes do not have public timepoint schedules, and internal schedules have terminal timepoints only during peak service. This is in contrast with less frequent routes that have timepoint schedules and timepoints displayed to operators via their mobile data terminals (MDTs).

  Cap Metro also conducted a10-day headway pilot project on MetroRapid Route 801 in September 2018. To test whether more proactive terminal management could improve bunching and gapping, staff were located at the terminals to dispatch buses at 10-minute intervals (as opposed to the standard procedure of dispatchers monitoring terminals from the control center). The pilot found that despite the in-person dispatching effort, headways did not improve throughout the rest of the route. Variability due to congestion and other on-route factors negated much of the dispatching effort. Route 801 has dedicated lanes, but only in certain segments in downtown Austin.

[1] Per the MTA Bus Performance Dashboard: http://busdashboard.mta.info/

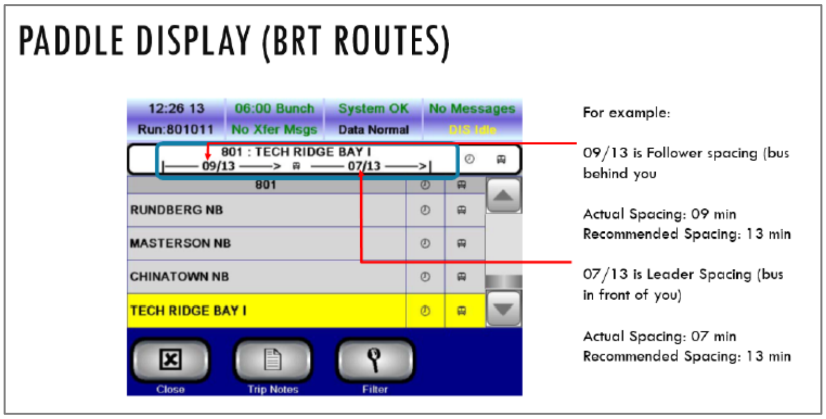

Figure 2: Image from "MetroRapid Operating Procedures," August 2017

- **WMATA** piloted a "Headway Management by Operator" program on its Route 79 beginning in June 2018. The route runs on Georgia Avenue and 7th Street between Silver Spring, Maryland and downtown DC. Georgia Avenue-7th Street is one of the top ridership corridors system, with the Route 70 and 79 moving over 16,000 passengers on an average weekday. Short segments on the Georgia Avenue corridor have dedicated bus lanes, and three intersections have queue jumps. The corridor has TSP and all Route 70 and 79 vehicles communicate with the TSP system.

  During the pilot, all Route 79 operators received a mountable smart phone that displayed their distance from the vehicle ahead and behind. The display (a third party app called MetroHero) is color coded, allowing operators to monitor if the bus is well spaced (blue smiley face), should slow down (yellow arrows), or advance running time if traffic conditions permit (green arrows) (see Figure 3). WMATA made adjustments in its transition to headway management pilot. The relief location for the Route 79 was moved to the terminal (previously mid-route). The agency revised its on-time performance metric for headway-based routes, using intervals rather than timepoints. WMATA is still in the process of analyzing the results of pilot, but initial operator feedback has been positive.

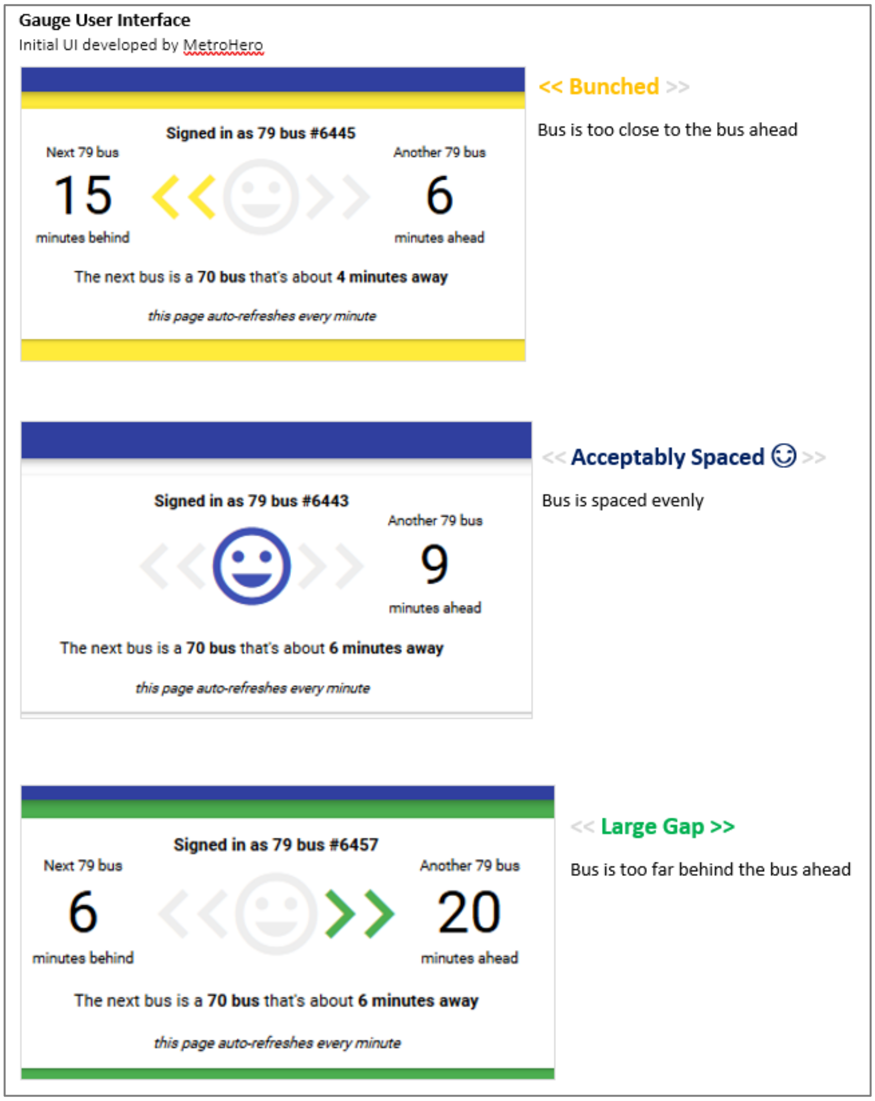

Figure 3: WMATA Headway Management by Operator Process document

- In the spring of 2017, **VIA** worked with transit researcher Simon Berrebi of the Georgia Institute of Technology on a pilot project using headway management at terminals to address bunching. The pilot subject was Primo 100, a 22-mile roundtrip route between downtown San Antonio and the South Texas Medical Center. During the pilot, operators were instructed to disregard the timepoint information they saw on their MDT. When they reached the terminal, they were directed by a dispatcher using real-time information. Adjustment occurred at the terminals only, based on data fed to a countdown screen.

  Via and Berrebi found that terminal holding reduced headway variability for Primo 100, as compared to historical data. From VIA's perspective, the pilot worked well but highlighted two challenges. First, the agency found it difficult to transition back to the non-headway based terminal dispatching when service levels decreased in the evenings. Second was the issue of layover and relief. Dispatchers had to sort out issues when operations did not align with the established relief schedule. Operators (and the union) were used to the traditional system and not always eager to adjust. The agency felt they would need in-person dispatchers in order to explain and enforce the terminal dispatching, which would be untenable in the long-term. VIA also voiced concern that, as currently configured, TSP on the Primo 100 corridor could conflict with headway management.

- **NYCT** has not yet implemented headway management but plans to implement a pilot on select routes in Staten Island in late 2019. "Transit Control Heads" will be added on-board to show operators their real-time location relative to the preceding and following vehicles (see Figure 4). The new technology will also reinforce terminal dispatching by featuring a countdown departure notification. Currently, NYCT operators receive feedback via dispatcher calls, and/or instruction from a field supervisor using a tablet with real-time information.

Figure 4: Transit Control Head – Image via Streetsblog NYC.

Four of the eight case study agencies do not currently have plans to implement headway management. The following describes some of their considerations.

- **King County Metro** recognizes the unique challenges of frequent service but as of now does not have different scheduling or dispatching practices for RapidRide versus other routes. Operators have run cards for service but do not have MDTs. Control center-based staff contact operators as necessary and are proactive in monitoring the RapidRide routes in particular. Staff may tell operators to switch to drop-off only/express service, authorize followers to pass, or have vehicles operate express to a certain stop before starting service. Standby buses are strategically placed in the case of incidents or to inject into service gaps.

  King County Metro considered headway management as a tool to improve frequent route reliability, either through a quasi-timepoint system with real-time terminal dispatching or a complete headway management option. However, Metro foresees obstacles to this transition, including how to apply it to a sub-set of routes and how to transition between headway management and standard scheduled operations at different times of day. The agency felt that headway management would require more flexible terminal operations, including creating or dedicating indoor space for operators and terminal managers.

- **MTA** speculated on some of the issues that would make headway management difficult to implement in practice. This included:
  - Dealing with interlined routes and the impacts that go beyond individual vehicles.
  - Eliminating mid-route relief to only having relief at terminals, which could be more resource intensive.
  - Ensuring breaks and relief that meet contractual obligations – schedules are the framework within which operators currently understand their responsibilities.
  - Enhancing communication systems within the context of limited resources - on-board systems would be needed for operator awareness, as well as enhanced communications between dispatchers and operators.
  - Increasing on-street staff, as headway management is viewed as needing more supervision to ensure that operators are accountable.

Overall, headway management is an appealing strategy for frequent bus routes because it can directly address bunching and gapping. It eliminates timepoints that become increasing challenging to meet as headways decrease. However, the case study agencies show that perceived and actual challenges prevent its adoption. Agencies may need to adjust the labor contracts that define the relationship between operators and management, specifically regarding procedures and locations for relief. They must deal with the ramifications of interlined routes, and plan for the transition from peak to non-peak times. Agencies may be reluctant to have operators making service adjustments or feel that they would be distracted by onboard headway management.

The primary challenge of headway management is its demands on resources compared to traditional timepoint scheduling – staff, communication systems, technology, etc. As one agency put it, headway management is “a resource hog.” This is in part due to the need for flexibility in staff and vehicles, as well as costs associated with technology training and hardware/software.

More experimentation and data analysis are needed to determine the impact of headway management on route performance and reliability, as well as ridership. As of this writing, WMATA had not yet fully analyzed its data to show if and how the Route 79 pilot has increased reliability. However, operator feedback has generally been positive, and WMATA plans to incorporate this tool into its on-board equipment for all headway routes. For Cap Metro, the terminal dispatching pilot highlighted that even with headway management along the route and proactive, in-person terminal dispatching, bunching and gapping is still an issue. In addition, agencies have experienced ridership growth on their frequent routes even without adopting headway management. King County Metro, for example, reports that its six RapidRide routes provide 70 percent more rides per weekday than their replacement routes, and operate as much as 20 percent faster during peak hours.

Headway management at the terminal and/or by operators during service cannot alone ensure reliability. Agencies must also consider conditions operators face along the route, specifically variable traffic. The case study agencies emphasized the interplay of operations with capital investments like dedicated and enforced bus priority lanes, TSP, and queue jumps. RIPTA is an example of an agency focusing on other improvements, independent of scheduling and dispatching, to improve their service: TSP, new shelters, enhanced wayfinding, wrapped buses, and stop consolidation.

Recommendations and Conclusions

This white paper describes how eight transit agencies across the US are attempting to maintain and increase the reliability of their frequent bus services. The recommendations below draw on their experiences and suggest steps all agencies can take and standards they can adopt related to scheduling and dispatching.

Agencies should use data to further their frequent service reliability goals. Good data can help operators do their jobs, address the variables under the agency's control, and fine tune their allocation of resources. This can mean customizing run times and recover/layover times to reflect travel variabilities. Agencies should determine on a route-by-route basis how many time bands are most effective and how frequently schedules should be reviewed and updated.

While timepoint-based scheduling is the common practice, headway management is an alternative strategy to increase reliability. Some agencies are experimenting with shifting away from timepoint schedules, while others consider its costs to outweigh its benefits. This perception is important. It is based in the reality that headway management requires a commitment to rethink every part of the scheduling and dispatching process. Furthermore, agencies may need to make upfront investments and structural changes to see results that only pay off over time. Agencies must address existing practices for layover and relief, and dedicate resources to communication systems and onboard technology.

Experimenting with headway management while retaining traditional elements of operation may hamper its execution. For example, **the idea that headway management requires more street supervision should be reexamined.** Adding on-street staff is an expense that is not realistic for budget-constrained agencies. However, operators should comply with remote instruction in the same manner as they would in-person. Agencies should assess the effectiveness of their existing pool of on-street staff to prioritize key locations and potentially reassign some staff to a command center. Unlike on-street staff that may be focused on one location only, command center staff can assess routes comprehensively, and they may be better positioned to consistently implement mitigation strategies.

In addition to allowing supervisors and dispatchers to address reliability, headway management can also **give operators the latitude to adjust service in real-time** and address reliability along the route. WMATA stands out as an example of an agency that has had success empowering and engaging operators to increase reliability. How each agency implements operator-initiated headway adjustments is, of course, influenced by labor contract provisions and relationships. Agencies should determine the best path forward to implementation, evaluate how this strategy impacts service through a pilot or test phase, and then adjust their procedures and operator training accordingly.

Drop-back dispatching is another reliability strategy that is underutilized for frequent bus service. Agencies may be reluctant to adopt drop-back dispatching, as it adds complexity to relief and may require more flexibility in labor contracts. However, concrete steps like moving relief from the midpoint of a route to the terminal can help address these issues. Agencies should test the extent to which drop-back dispatching increases labor costs and/or their fleet requirements; it is possible that labor costs could be offset by reducing overtime that currently occurs when buses are late.

How agencies measure their frequent service performance is another component of reliability. Agencies may need to **create different on-time performance metrics for frequent services or make their frequent service on-time performance metrics more stringent.** Frequent service on-time performance metrics may be harder to explain to the public and may require more resources devoted to data processing. However, these characteristics may be necessary to raise agency expectations and strive for the best customer experience possible.
Finally, headway management, terminal dispatching techniques, and performance measurement cannot increase reliability if agencies do not also address underlying traffic and congestion issues. Cap Metro's experience with terminal management highlights this reality. Transit treatments such us dedicated bus lanes, TSP, and queue jumps, as well as traffic engineering solutions like signal phasing and geometric adjustments may be necessary to minimize bus bunching and gaps. This means allocating resources for capital improvements and collaborating with local partners such city and state transportation departments.

Further research is necessary to assess the impact of implementing the frequent service scheduling and dispatching strategies suggested in this paper. Launching frequent services, adopting new standards and practices to provide those services with reliability, and evaluating the results and impacts are all relatively new for most transit agencies. Evaluation via frequent service performance measures will be critical as agencies collect data and develop a record of performance over time.

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