MADISON EAST-WEST BRT PLANNING STUDY

Detailed Evaluation of Alternatives

Technical Memo 5: Operating and Maintenance Costs

FINAL

August 2019

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City of Madison

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REVISIONS

Revision No.	Date	Prepared By

Contents

List of Figures

List of Tables

Overview

The Madison East-West Bus Rapid Transit (BRT) Planning Study is a 12-month study led by the City of Madison in coordination with Metro Transit and the Madison Area Transportation Planning Board (MATPB).

The project will identify and evaluate a transit investment alternative for implementation within the study corridor (Figure 1), which runs from East Towne Mall to West Towne Mall, through the Isthmus. The corridor is approximately 15 miles long.

This study expands on previous planning work to identify a locally-preferred transit investment alternative that meets the needs set forth in the Purpose and Need Report. At a high level, these needs include providing safe, efficient, and expanded levels of mobility within the increasingly busy study corridor and to improve connectivity between the corridor and employment centers.

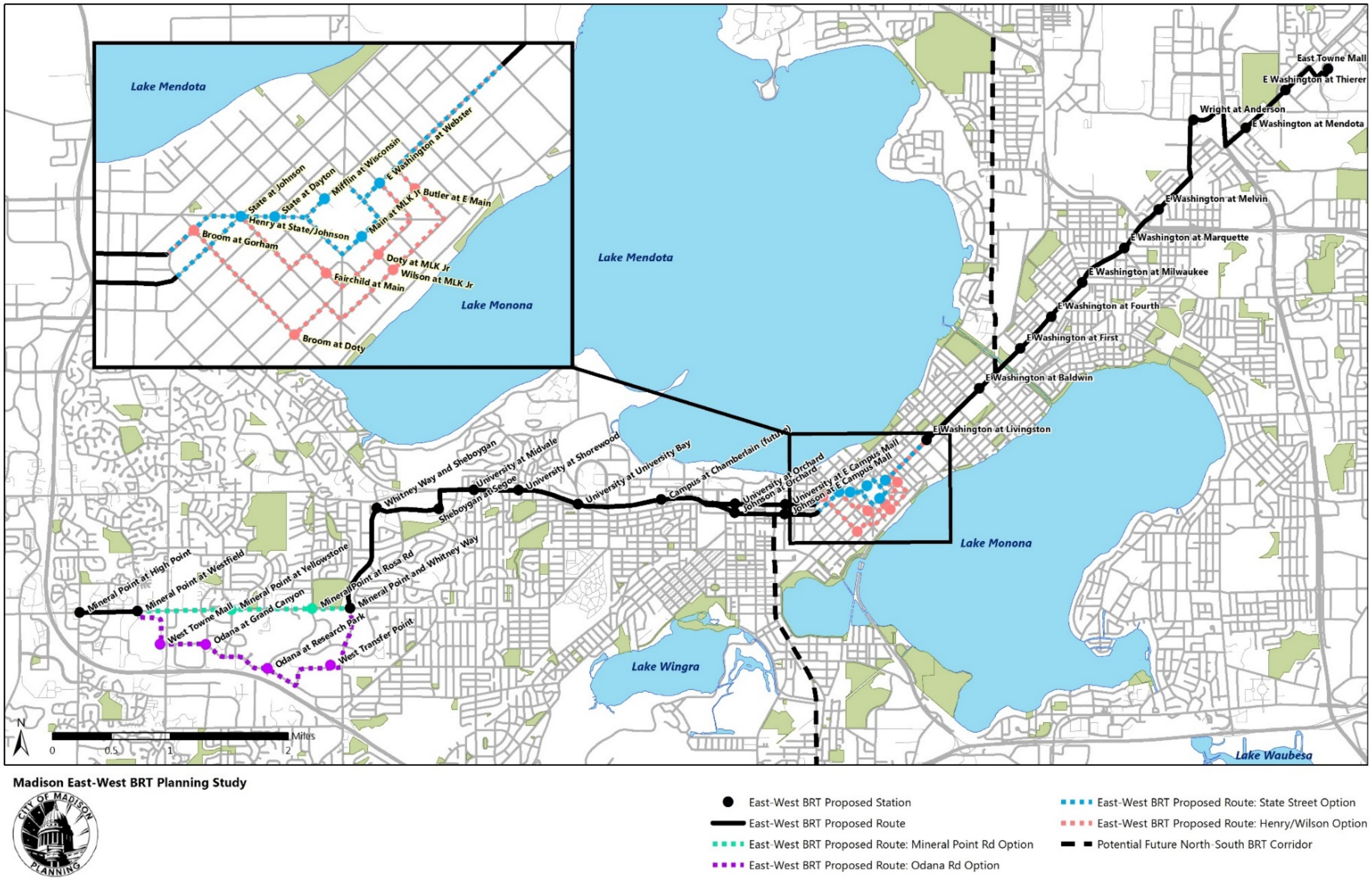
Following a multi-phase, iterative alternatives development and evaluation process that is supported by extensive public engagement activities, the City of Madison will recommend the locally preferred alternative (LPA) to the Common Council for adoption. The LPA will be the transit investment alternative that best meets the purpose of and need for the project (as defined in the Purpose and Need report) and is competitive for funding through the Federal Transit Administration (FTA) Small Starts capital funding program.

The study is scheduled for completion in fall 2019.

Corridor Context and Description

The proposed BRT corridor runs from approximately East Towne Mall on the east side of Madison, to West Towne Mall on the west side of Madison, running through the Isthmus and the University of Wisconsin (UW) campus (Figure 1). Two options on the west side will be analyzed as part of this study, as well as two options in downtown. One of each of these will be selected as part of the LPA.

Figure 1. Madison East-West BRT Corridor



Source: City of Madison

Overview of Project Evaluation Process

The East-West BRT Planning Study has two phases to identify and develop the LPA.

- Phase 1 includes the detailed evaluation of the potential alignment alternatives. The detailed evaluation will result in the identification of the preferred alternative, including the best-performing minimal operable segment[1] (MOS), which will include a preferred alignment on the west side and around the Capitol in downtown. The alternative resulting from this evaluation will become the preferred alternative, which will advance for further refinement in Phase 2.
- Phase 2 will refine the preferred alternative selected at the end of Phase 1 to become the LPA. The LPA will include an MOS, which will be the first investment in construction of the full 15-mile corridor.

The evaluation criteria associated with each phase are a combination of quantitative and qualitative performance measures. Phase 1 will apply metrics that are linked to the project goals and objectives (as defined in the study Purpose and Need Report, available under separate cover) and will identify the preferred alternative. Phase 2 will evaluate the preferred alternative against federal criteria to determine the LPA. This two-phase process will result in the identification of an LPA that not only meets locally-identified project purpose and needs, but is also competitive for federal funding.

Table 1 presents the evaluation criteria that are likely to be used during the two phases of alternative evaluation. Phase 2 will build upon the criteria from Phase 1, ensuring a consistent rating throughout. Details of these criteria, including the methodology and screening thresholds, will be defined as the study progresses.

Table 1. Evaluation Criteria

Project Goals	**Evaluation Phases**	
	Phase 1: Detailed Evaluation	**Phase 2: Refinement of the LPA**
Increase the efficiency, attractiveness, and utilization of transit for all users	• Ridership • Transit travel times	• Mobility improvements[a]
Efficiently manage the forecasted increase in corridor travel demand	• Traffic impacts • Parking impacts • Potential right-of-way impacts • Bicycle and pedestrian impacts	• Mobility improvements[a] • Congestion relief[a]

[1] An MOS is a segment of the LPA that provides the most cost-effective solution with the greatest benefits for the project. According to the FTA, the MOS must be able to function as a stand-alone project and not be dependent on any future segments being constructed.

Project Goals	Evaluation Phases	
	Phase 1: Detailed Evaluation	**Phase 2: Refinement of the LPA**
Contribute to a socially-, economically-, and environmentally-sustainable transportation network	• Station area population and employment densities • Station area equity characteristics • Station area land use and economic development opportunities • Environmental impacts/benefits	• Economic development[a] • Land use[a] • Environmental benefits[a]
Develop and select an implementable and community-supported project	• Capital and operating and maintenance costs • Cost effectiveness • Community support	• Financial capacity analysis[a] • Cost effectiveness[a]

[a] *Consistent with FTA New Starts criteria.*

Technical Memo #5 Overview

Six technical memoranda (tech memos) are being prepared to describe the results of the evaluation. The six tech memos include the following:

- Tech Memo 1: Station Areas
- Tech Memo 2: Transportation
- Tech Memo 3: Environmental Impacts
- Tech Memo 4: Capital Costs
- Tech Memo 5: Operating and Maintenance Costs
- Tech Memo 6: Ridership

Results contained in the six tech memos are summarized in the *Detailed Evaluation of Alternatives Report* (available under separate cover).

This tech memo includes the operating and maintenance (O&M) costs associated with a variety of build alternatives.

A summary of the O&M analysis can be found in the following sections.

Detailed Alternatives

As discussed in the *Detailed Definition and Downtown Routing Memo*, the corridor has been divided into segments to simplify the alternative definition and evaluation process, see Figure 2. This segmentation will facilitate the identification of the MOS through the modular organization of data. Consistent data collection and analyses will be applied along the full length of the corridor, but the results are reported in segments defined in the following subsections. This will enable a quick comparison of different combinations of segments as MOSs are developed and considered, and will facilitate internal and external decision making. These segments represent natural breakpoints in either corridor development character or right-of-way geometry.

Figure 2. Segments for the East-West BRT Corridor

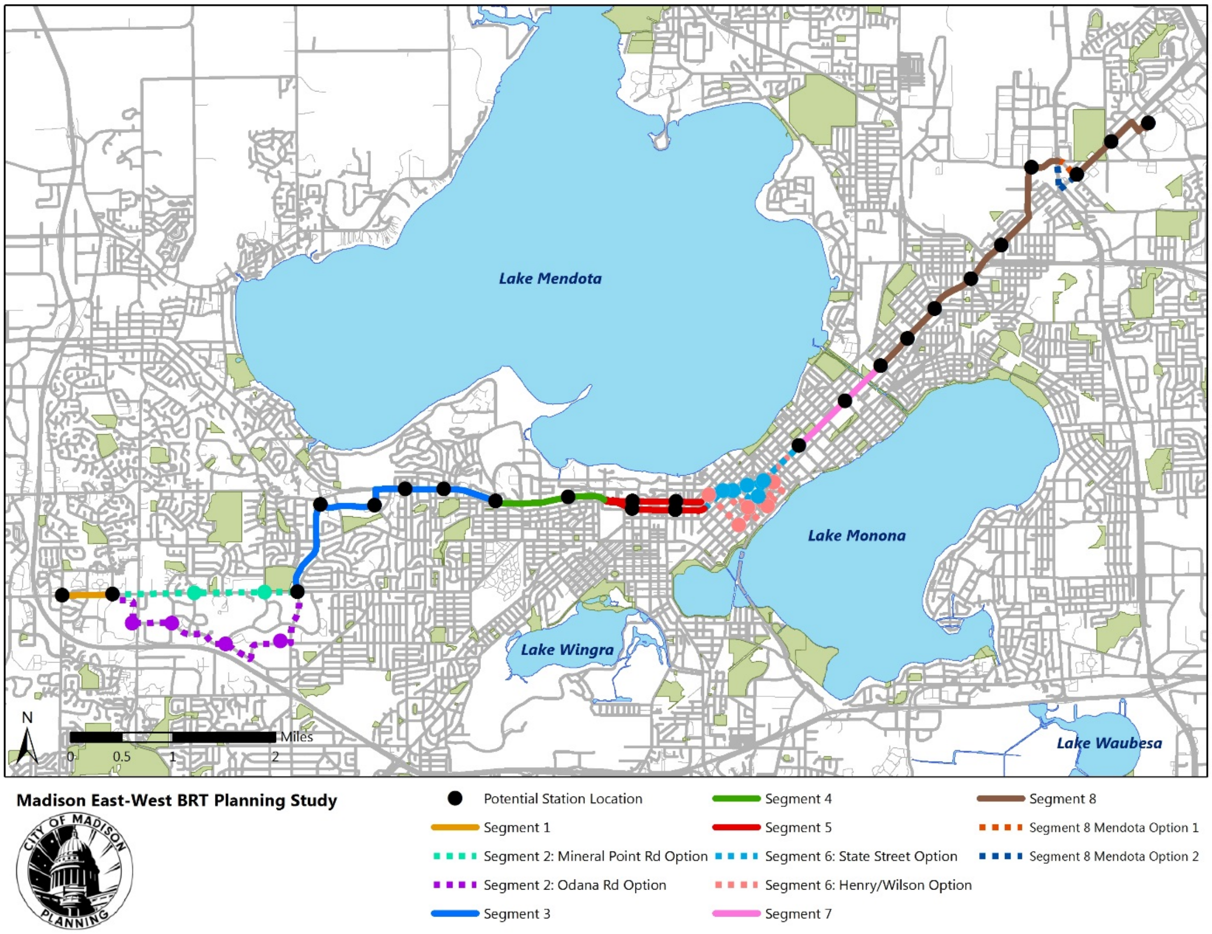


Figure 3 shows the two downtown options in greater detail. The first option runs on State Street and around the Capitol Square, then traveling east on East Washington Avenue. The second option uses paired one-way streets, Henry/Broom and Doty/Wilson to travel near the Capitol Square and is not affected by most detour events. One option will be chosen based on the results of the analysis in the next phase of this study.

Figure 3. Segment 6

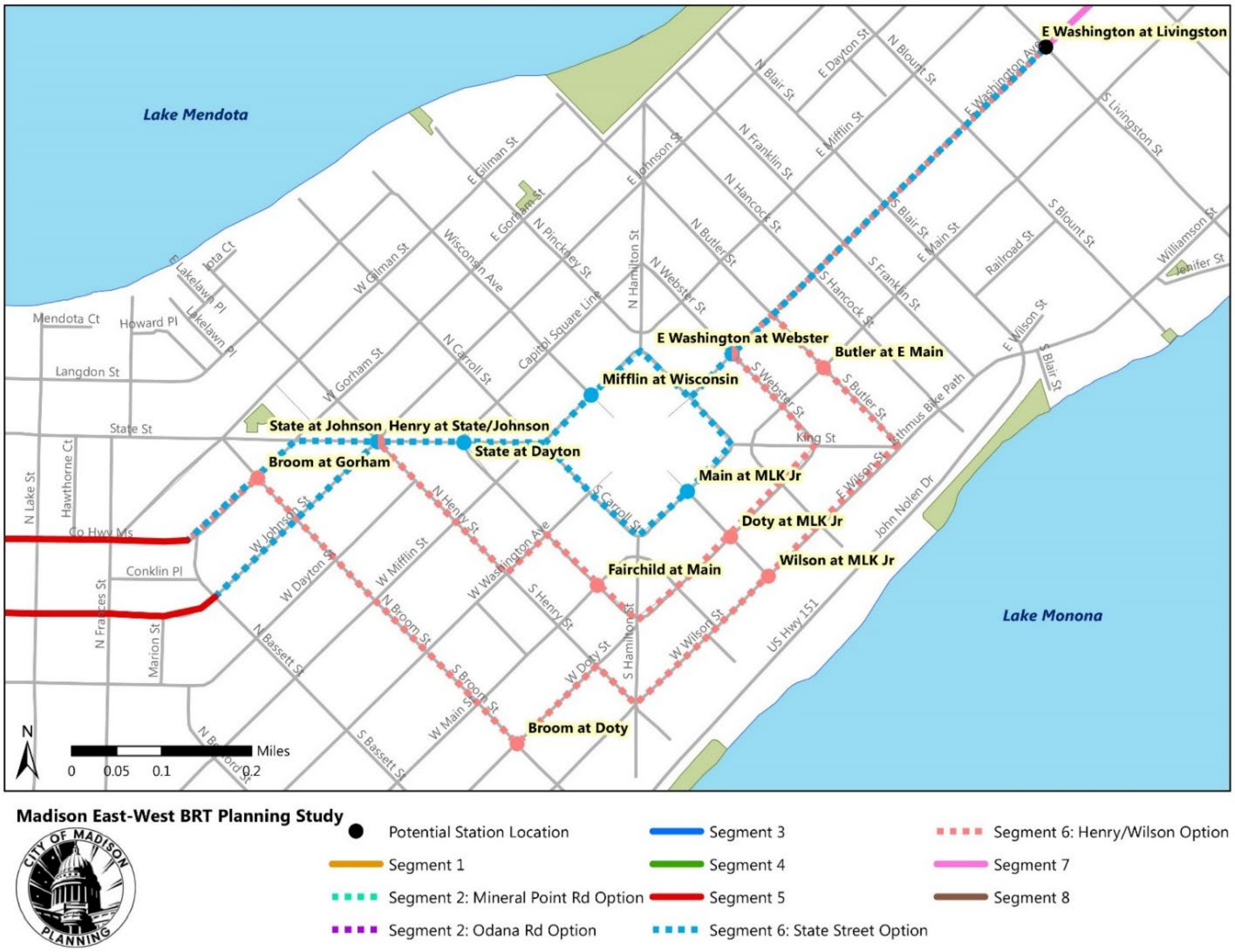


Table 2 lists the stations by segment. These are the stations included for the segment area analysis.

Table 2. Stations by Segment

Segment	Station Name
Segment 1	Mineral Point High Point
	Mineral Point at West Field
Segment 2: Odana	West Towne Mall
	Odana at Grand Canyon
	Odana at Research Park
	West Transfer Point

Segment	Station Name
Segment 2: MP	West Towne Mall
	Mineral Point at Yellowstone
	Mineral Point at Rosa
Segment 3	Mineral Point and Whitney Way
	Whitney Way and Sheboygan
	Sheboygan at Segoe
	University at Midvale
	University at Shorewood
Segment 4	University at University Bay / Farley
	Campus at Chamberlain (future)
Segment 5	University at Orchard
	Johnson at Orchard
	University at E Campus Mall
	Johnson at E Campus Mall
Segment 6: State St	State at Dayton
	Main at MLK Jr
	E Washington at Webster
	State at Johnson/Henry
	Mifflin at Wisconsin
Segment 6: Henry/Wilson	State at Johnson/Henry
	Fairchild at Main
	Doty at MLK Jr
	E Washington at Webster
	Butler at Main
	Wilson at MLK Jr
	Broom at Doty
	Broom at Gorham
Segment 7	E Washington at Livingston
	E Washington at Baldwin
	E Washington at S First
Segment 8	E Washington at 4th
	E Washington at Milwaukee
	E Washington at Marquette
	E Washington at Melvin
	Anderson at Madison College
	E Washington at Mendota
	E Washington at Thierer
	East Towne Mall

Station Siting

The BRT stations were initially laid out by MATPB staff in 2012 and have been adjusted and modified since. The goal was to space them out so that they are about a half mile apart. Several factors were considered:

1. **Physical site**
   There needs to be space for the BRT station; most of the time, BRT stations will end up where existing bus stops are.
2. **Ridership**
   BRT stations should minimize walk times and be close to ridership generators to the extent possible.
3. **Pedestrian infrastructure and crossings**
   Since BRT is mostly along arterial streets with higher traffic volumes and speeds, stations should be in places where people can cross, usually at traffic signals.
4. **Modal integration**
   Stations are placed where other bus routes intersect as well as where the street grid provides access to neighborhoods. Stations near the end of the line are in areas that could be served by park-and-ride lots.

The station locations identified resulted in about 50 station pairs for the full east-west, north-south system. In some locations, stations were closer together than ideal, but were placed to meet the criteria above. The current BRT study is looking closely at the station locations along the east-west corridor to continue to refine them.

Alternatives

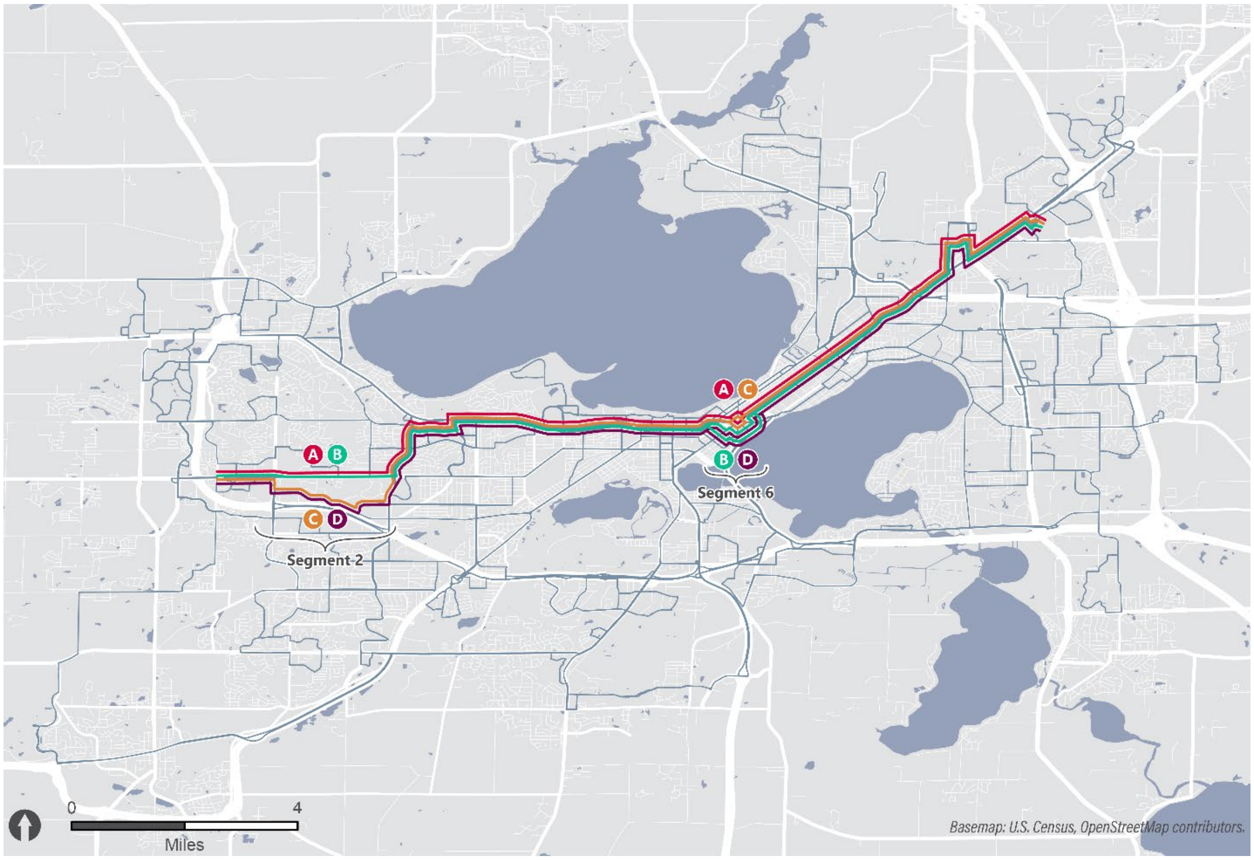
This analysis will look at four alternatives, varying based on alignment, as well as runningway type and intersection treatment.

Segments and Alignments

The proposed East-West BRT route has been split into eight segments, with two of the segments (Segments 2 and 6) having alternate variants, resulting in four potential end-to-end alignment alternatives (Figure 4):

- Alternative A, which uses Mineral Point and State Street/Capitol Square;
- Alternative B, which uses Mineral Point and Henry/Wilson;
- Alternative C, which uses Odana and State Street/Capitol Square; and
- Alternative D, which uses Odana and Henry/Wilson.

Figure 4. Overview of Proposed BRT Alternatives



Runningway Types

Alignments A, B, C, and D were each examined with three runningway types:

- "Mixed traffic" where the bus runs in existing mixed traffic lanes, except where there are existing bus priority measures (in Madison, these are bus and right-turn lanes, or Business Access and Transit [BAT] lanes).
- "Mixed traffic + TSP + QJ" where all signals are enhanced with transit signal priority (TSP), and where some intersections that are mixed traffic have new queue jumps (QJ[2]) (all segments with existing BAT already have queue jump benefits, so nothing beyond TSP is added to those).
- "BAT + TSP" where all signals are enhanced with transit signal priority, and where all segments that are mixed traffic are given BAT lanes.

[2] Queue jumps provide a pullout area for buses to bypass the cars that are backed up (or "queued") at the traffic signal and provide an advanced bus-only traffic signal phase to allow buses to leave the intersection ahead of other car and truck traffic.

Summary of Results

Running time — the time a bus spends in-service traveling between stops, excluding any operator breaks — determines a route's schedule and how long it will take a passenger to travel from "Point A" to "Point B" along a route. As a result, running times are a critical determinant of the quality and cost of transit services. A route's running time is also a key indicator of how many vehicles are required to provide transit service at a given frequency.

Proposed Bus Rapid Transit Scenario Results

The analysis used to estimate service characteristics for the Madison BRT Study builds upon methods typically used in the public transit sector. Additional detail has been added to these methods to account for the route's specific traffic conditions by time of day and direction, as well as the running time impacts of proposed infrastructure priority treatments.

Table 3 and Table 4 show that in all alternative alignments, *Mixed Traffic* is the slowest runningway type, followed by *Mixed Traffic + TSP*, and *BAT + TSP* as the fastest approach. Running times are fairly consistent across the alternative routings, with those running on 2OT having slightly higher speeds, but a longer route length.

Table 3. Summary of Running Times by Alternatives (Weekday)

Alternative	Runningway	Early AM Round-Trip Runtime (mins)	AM Peak Round-Trip Runtime (mins)	Midday Round-Trip Runtime (mins)	PM Peak Round-Trip Runtime (mins)	Evening Round-Trip Runtime (mins)
A (2MP 6S)	Mixed Traffic	115	125	131	135	116
	Mixed Traffic + TSP	108	118	123	127	109
	BAT + TSP	84	92	96	99	85
B (2MP 6HW)	Mixed Traffic	118	128	134	137	119
	Mixed Traffic + TSP	110	120	125	129	111
	BAT + TSP	85	93	97	100	86
C (2OT 6S)	Mixed Traffic	124	135	142	145	126
	Mixed Traffic + TSP	116	127	133	136	117
	BAT + TSP	86	94	98	101	87
D (2OT 6HW)	Mixed Traffic	127	138	144	148	128
	Mixed Traffic + TSP	118	129	134	138	119
	BAT + TSP	86	94	99	101	87

Table 4. Summary of Speeds by Alternatives (Weekday)

Alternative	Runningway	Early AM Speed (mph)	AM Peak Speed (mph)	Midday Speed (mph)	PM Peak Speed (mph)	Evening Speed (mph)
A (2MP 6S)	Mixed Traffic	14.6	13.4	12.8	12.5	14.5
	Mixed Traffic + TSP	15.5	14.3	13.6	13.3	15.4
	BAT + TSP	19.9	18.3	17.5	17.0	19.7
B (2MP 6HW)	Mixed Traffic	14.6	13.4	12.8	12.5	14.4
	Mixed Traffic + TSP	15.6	14.3	13.7	13.3	15.4
	BAT + TSP	20.2	18.5	17.7	17.2	20.0
C (2OT 6S)	Mixed Traffic	14.5	13.4	12.8	12.4	14.4
	Mixed Traffic + TSP	15.6	14.3	13.6	13.3	15.4
	BAT + TSP	21.0	19.3	18.4	17.9	20.8
D (2OT 6HW)	Mixed Traffic	14.5	13.3	12.7	12.4	14.4
	Mixed Traffic + TSP	15.6	14.3	13.7	13.3	15.4
	BAT + TSP	21.2	19.5	18.6	18.1	21.0

Table 5 shows that in all alternative alignments, *BAT + TSP* has substantially lower annual operating costs than other runningway types, with *Mixed Traffic + TSP* being somewhat less costly than *Mixed Traffic*. This is due to the faster speeds that are achieved under BAT + TSP, resulting in fewer buses required for service.

Table 5. Summary of Operating and Maintenance Costs by Alternative

Alternative	Runningway	Vehicles Operated in Maximum Service	Annual Revenue Hours	Annual Costs	Annual Revenue Miles
A (Mineral Point / Square)	Mixed Traffic	11	52,992	$5,864,000	559,678
	Mixed Traffic + TSP	10	49,648	$5,537,000	559,678
	BAT + TSP	8	39,668	$4,615,000	559,678
B (Mineral Point / Wilson - Henry)	Mixed Traffic	11	52,992	$5,863,000	569,858
	Mixed Traffic + TSP	10	49,648	$5,554,000	569,858
	BAT + TSP	8	39,668	$4,632,000	569,858
C (Odana/Square)	Mixed Traffic	12	54,756	$6,079,000	600,776
	Mixed Traffic + TSP	11	52,992	$5,916,000	600,776

Alternative	Runningway	Vehicles Operated in Maximum Service	Annual Revenue Hours	Annual Costs	Annual Revenue Miles
	BAT + TSP	9	40,928	$4,801,000	600,776
D (Odana/Henry/Wilson)	Mixed Traffic	12	54,756	$6,096,000	610,956
	Mixed Traffic + TSP	11	52,992	$5,933,000	610,956
	BAT + TSP	9	40,928	$4,819,000	610,956

Supporting Services Results

As described in the Madison Service Plan, modifications were proposed to eight routes to support the proposed BRT service, under the assumption that the West Transfer Point would not be moved. These routes are:

- Route 6, which would continue west of Capitol Square; would be subsumed into the proposed BRT service between East Towne Mall and Capitol Square; and which would be replaced by microtransit east of East Towne Mall.
- Route 17, which as it is currently laid out would not share a stop with the proposed BRT service, so has an alternate routing proposed.
- Routes 23, 26, and 36, which would be replaced by microtransit east of East Towne Mall.
- Routes 70, 71, and 72, which would serve as feeders to the proposed BRT line rather than extending to Capitol Square.

As with the proposed BRT service, Annual Revenue Miles and Annual Revenue Hours were the determining factor for total cost. For the existing service, these numbers were provided for 2018 by the City of Madison, with the exception of Route 23, which is planned to go into service in August 2019.

For the existing Route 23 service, as well as with all proposed supporting fixed-route service, a similar analysis to that completed for the proposed BRT was conducted, which allowed the derivation of Annual Revenue Miles, Annual Revenue Hours, and Vehicles Operated in Maximum Service.

Table 6 shows the total service characteristics and costs for the existing routes that are proposed to change to support BRT service.

Table 6. Existing Route Operating and Maintenance Costs

Route	Vehicles Operated in Maximum Service	Annual Revenue Hours	Annual Revenue Miles	Annual Costs
6	10	396,563.8	32,672.5	$3,930,000
17	1	70,858.0	5,567.3	$677,000
23	3	40,395.6	2,646.0	$337,000
26	1	92,818.0	5,587.3	$730,000

Route	Vehicles Operated in Maximum Service	Annual Revenue Hours	Annual Revenue Miles	Annual Costs
36	0.7[3]	21,454.1	2,753.7	$304,000
70	2[4]	100,797.7	6,747.5	$855,000
71	4	48,834.1	3,572.4	$442,000
72	4	71,335.9	5,092.9	$634,000
Total	24	64,639.6	843,057.2	$7,909,000

Table 7 shows the estimated costs for the proposed changes to supporting routes. For the area east of East Towne Mall a microtransit service is proposed, to which a cost per vehicle-hour has been applied. Microtransit is a form of on-demand transit service that mimics the interface of TNC service, but operates with a fixed fleet of transit vehicles. These transit vehicles are typically vans or cut-away-style buses, and can be operated by a transit agency or a third-party vendor.

Table 6 shows that supporting services would be in total about $2.2 million less costly than the existing routes, including the routes that would be eliminated. Route 17, with its longer running length, would require an additional bus to run the route to provide the same level of service, and would therefore have a higher number of revenue hours, revenue miles, and higher annual cost than in the existing condition, though the other routes would be less costly.

Table 7. Proposed Supporting Route Operating and Maintenance Costs

Route	Vehicles Operated in Maximum Service	Annual Revenue Hours	Annual Revenue Miles	Annual Costs
6	5	17,414.0	175,447.2	$2,012,000
17	2	11,184.0	91,708.8	$1,244,000
70	2[5]	7,056.0	71,971.2	$817,000
71	3	3,402.0	27,442.8	$377,000
72	3	3,780.0	44,856.0	$452,000
Total (Bus)	13	42,836.0	411,426.0	$4,903,000
Microtransit	2	12,400.0	-	$744,000.00
Total	-	55,236.0	411,426.0	$5,647,000

Combined Results

Table 8 shows the total proposed costs, including each BRT alternative/runningway combination, in addition to the proposed cost savings from changes to supporting routes. There is estimated that there would be a net increase in operating and maintenance cost of between $2.3 million and $3.9 million.

[3] Route 36 is a completely interlined route – at the beginning of each route, each bus has just come from another route, and at the end, is going to another route. This allows a fractional number of buses, which would not be possible on a non-interlined route.
[4] Route 70 is an off-peak service, so these vehicles do not add to the overall Vehicles Used In Maximum Service number.
[5] Route 70 is an off-peak service, so these vehicles do not add to the overall Vehicles Used In Maximum Service number.

Table 8: Total Proposed Operating and Maintenance Costs

Alternative	Runningway	Proposed BRT Annual Costs	Proposed Supporting Services Annual Cost	Total Proposed Annual Costs	Existing Annual Costs	Net Annual Costs
A (2MP 6S)	Mixed Traffic	$5,864,000	$5,647,000	$11,511,000	$7,909,000	+$3,602,000
	Mixed Traffic + TSP	$5,537,000	$5,647,000	$11,184,000	$7,909,000	+$3,274,000
	BAT + TSP	$4,615,000	$5,647,000	$10,262,000	$7,909,000	+$2,353,000
B (2MP 6HW)	Mixed Traffic	$5,863,000	$5,647,000	$11,510,000	$7,909,000	+$3,601,000
	Mixed Traffic + TSP	$5,554,000	$5,647,000	$11,201,000	$7,909,000	+$3,292,000
	BAT + TSP	$4,632,000	$5,647,000	$10,279,000	$7,909,000	+$2,370,000
C (2OT 6S)	Mixed Traffic	$6,079,000	$5,647,000	$11,725,000	$7,909,000	+$3,816,000
	Mixed Traffic + TSP	$5,916,000	$5,647,000	$11,562,000	$7,909,000	+$3,653,000
	BAT + TSP	$4,801,000	$5,647,000	$10,448,000	$7,909,000	+$2,539,000
D (2OT 6HW)	Mixed Traffic	$6,096,000	$5,647,000	$11,743,000	$7,909,000	+$3,833,000
	Mixed Traffic + TSP	$5,933,000	$5,647,000	$11,580,000	$7,909,000	+$3,670,000
	BAT + TSP	$4,819,000	$5,647,000	$10,465,000	$7,909,000	+$2,556,000

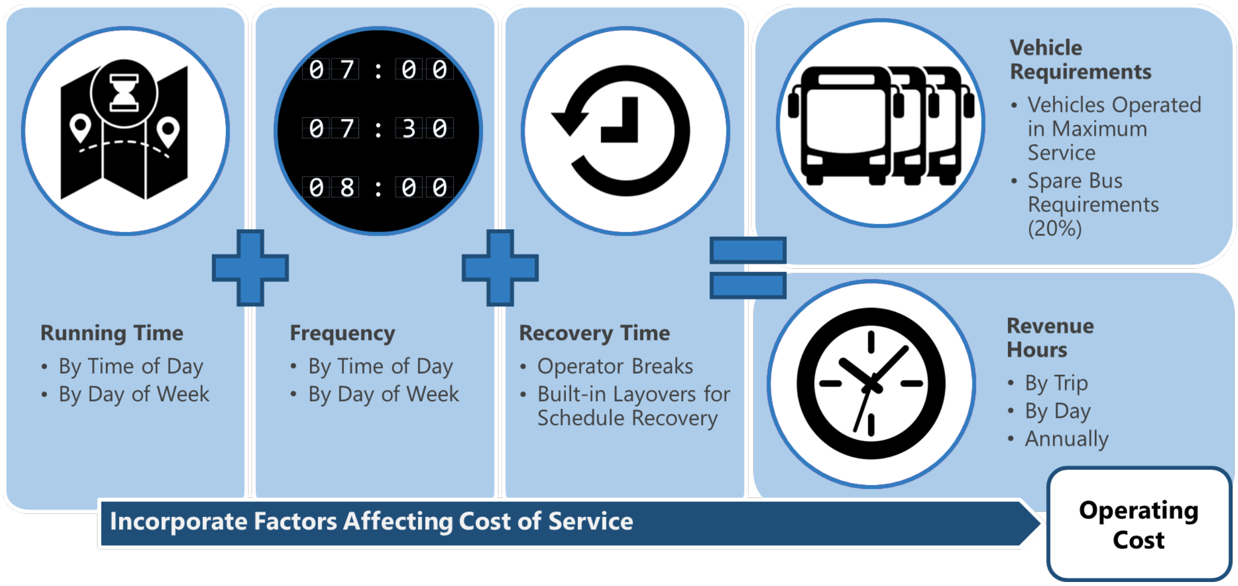
Operating and Maintenance Cost Development

Methodology

Service characteristics include many variables, which together allow for the calculation of operating and maintenance costs, as illustrated in Figure 5. These variables include:

- Running Time
- Frequency
- Recovery Time
- Revenue Hours

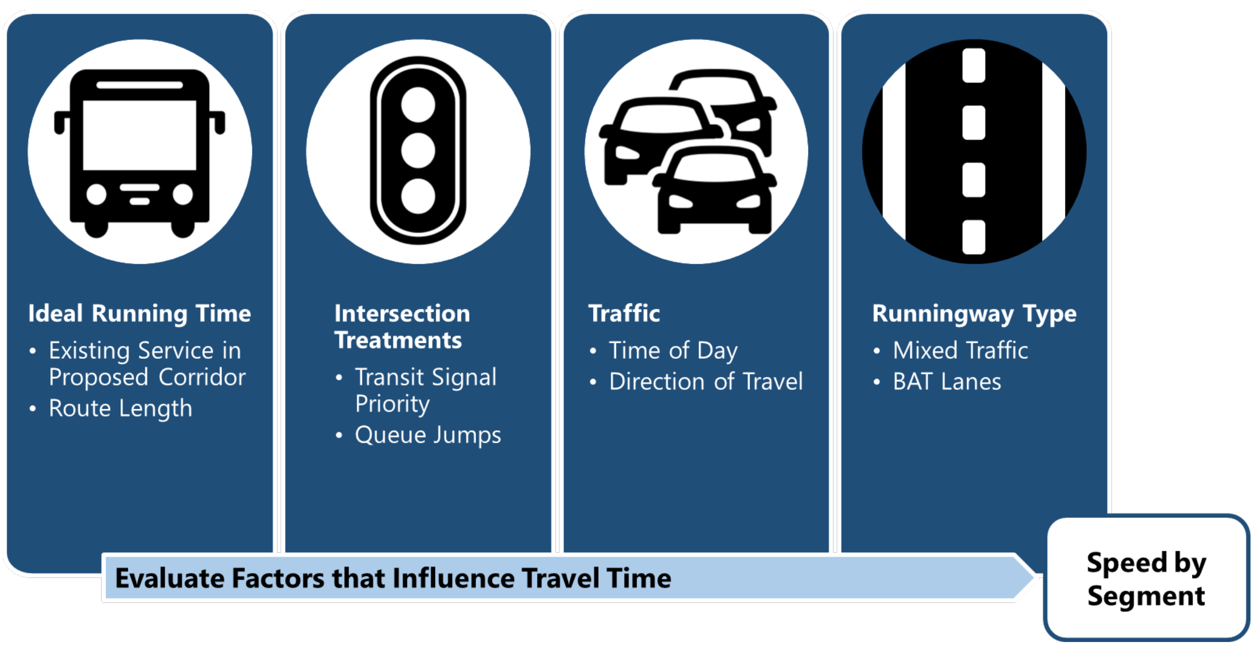
Figure 5. Overview of Service Characteristics Calculation



Running Times

BRT running times are determined by calculating running times at the alternative, segment, time-of-day, and direction levels, and then summing to determine the overall alignment running time (see Figure 6). The steps for this analysis are laid out below.

Figure 6. Overview of Running Time Calculation

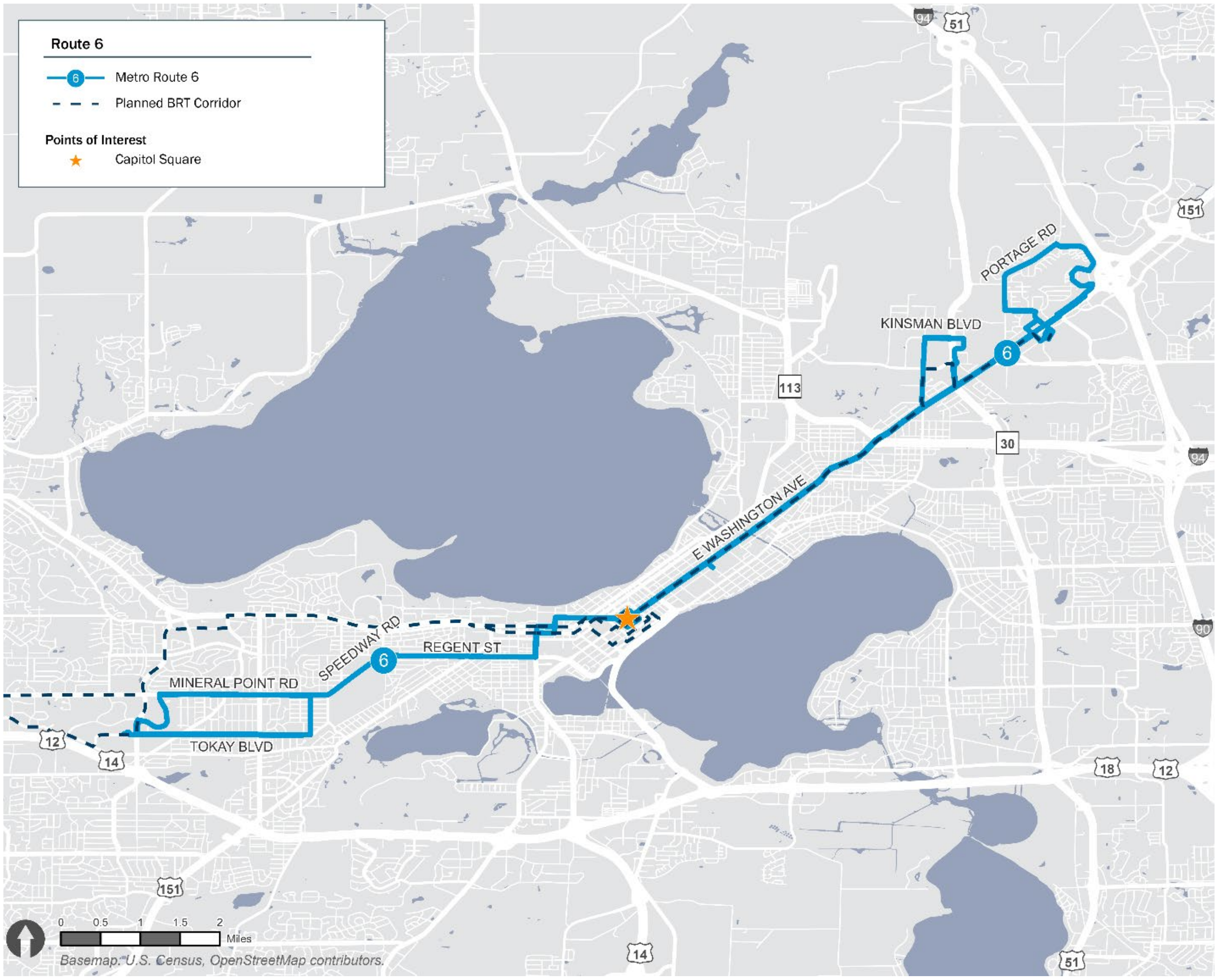


To build to **segment running time, raw segment running time** is, as appropriate, multiplied by a **runningway multiplier**, to which **transit signal priority and queue jump time savings** are then added when appropriate**.**

Raw segment running time is first calculated at the segment level based on **segment length** and speeds from existing on-time performance data. Segment lengths are estimated using an online tool. This data is parsed by time of day and direction. For segments west of the Capitol Square, existing Route 2 speeds were used (Figure 6), while for segments east of Capitol Square, existing Route 6 speeds were used (Figure 7). Because the existing routes include real-world traffic, bus stops, intersections, and signals, these speeds are used as the basis for "mixed traffic" speeds for segments that are now mixed traffic, and "BAT" speeds for those that already have BAT.

Figure 7. Overview of Route 2 and Proposed BRT Route

Figure 8. Overview of Route 6 and Proposed BRT Route



In the "BAT + TSP" scenario, the **raw segment running time** is multiplied by a **runningway multiplier** on segments with proposed new BAT. Segments that already have BAT do not benefit from this multiplier. This multiplier is based on a literature review [6].

Finally, **running time savings for transit signal priority and queue jumps** are added where relevant, using assumptions based in the literature[7][8][9][10]. The effect of transit signal priority and queue jumps could vary throughout the day (e.g., larger TSP savings during peak hours given longer intersection delays at peak periods), by treatment (e.g., little or no impact of queue jumps on segments where BAT lanes exist), or based on the level-of-service at the intersection (e.g., TSP likely to have small effect if the intersection

[6] Kittelson & Associates et. al. "Transit Capacity and Quality of Service Manual". 2013. P. 3-37.
[7] Zlatkovic, Milan et. Al. "Effects of Queue Jumpers and Transit Signal Priority on Bus Rapid Transit." November 14, 2012. P. 13.
[8] Rodriguez, Adriana and Alan R. Danaher. "Operational Comparison of Transit Signal Priority Strategies". November 15, 2013. P. 11.
[9] Danaher, Alan R. "Bus and Rail Transit Preferential Treatments in Mixed Traffic (TCRP 83)". 2010. Pp. 65, 67.
[10] Kittleson & Associates. "Bus Rapid Transit Practitioner's Guide (TCRP 118)". 2007. Pg. S-9.

level of service is "F" or failing). However, to avoid making additional assumptions in the model, a small time-benefit per intersection with TSP and/or QJ was applied at all times of day.

Frequency

For this analysis, a "peak" frequency of 15-minute headways was assumed for weekdays between 5:00 a.m. and 7:00 p.m., with 30-minute headways between 7:00 p.m. and 12:00 a.m. On Saturdays and Sundays, 30-minute headways were assumed from 7:00 a.m. to 11:00 p.m.

The proposed BRT frequency was developed by looking at existing bus frequency on the corridor. For each segment, a bus stop was selected that is representative of the number of routes along the segment. City stop data was then examined for each route which uses the stop, to determine the **effective frequency**, or the frequency of all routes which use the stop. For example, if an east-bound bus on one route departs a stop at 8:30 a.m., and an east-bound bus on a different route departs the same stop at 8:35 a.m., traveling in the same corridor, the effective frequency for passengers at the stop is five minutes. This effective frequency was analyzed for different times of day and days of the week.

While the effective frequency of current service is used to inform the frequency recommendations for BRT service, the BRT line will not completely replace all other service in the corridor, so the BRT service itself does not have to meet the full effective frequency of a segment. However, Federal Transit Authority (FTA) requirements for Bus Rapid Transit funding were a major factor in developing frequency recommendations for BRT service.

The *Service Plan* document lays out how the BRT and the supporting bus network will work together to provide high service frequency along the corridor.

Revenue Hours

Service characteristics were calculated for each alternative by time-of-day and direction using the following steps:

1. Running times were calculated using the methodology described in the *Running Times* section, above.
2. Frequencies were calculated using the methodology described in the *Frequency* section, above.
3. The minimum cycle time for each direction was calculated by adding the minimum recovery time or the battery charging time, whichever is greater, to the running time. "Minimum recovery time" is the time between trips that allows a driver to use the restroom or prepare for the next trip, estimated at 10 percent of running time. The time needed to charge an electric bus on a route of this length is estimated at 20 minutes. For example, 100 minutes of round-trip running time would require 10 minutes recovery time. The bus requires 20 minutes to charge, however, so 20 minutes are added, leading to a 120-minute minimum cycle time.
4. As minimum cycle times may be non-integers, a "clean" cycle time was calculated by rounding the minimum cycle time upward to a multiple of the route frequency (preferably a "clockface" frequency, that is, one that goes into 60 minutes evenly, or is a multiple of 60 minutes).
5. The expected number of trips per time-of-day period was generated by dividing the hours of service in a time period by the frequency.

6. The revenue hours for the time-of-day period were calculated by multiplying the number of trips by the clean cycle time for that period.

Revenue hours by time-of-day and direction were summed to determine the daily revenue hours for an alternative. Saturdays and Sundays were assumed to have constant frequency throughout the day, equivalent to weekday minimum frequency. These daily revenue hours by Weekday, Saturday and Sunday were multiplied by the respective number of days in the year to generate Annual Revenue Hours.

Service Costs

Operating Costs

The study team developed a forecast of BRT operating and maintenance (O&M) costs based on a two-variable cost model. The model took into account outputs of the above analysis, namely annual revenue hours and annual revenue miles.

The team prepared the cost model by taking data on operating costs from Metro Transit (or Metro Transit's most recent NTD submittal) and aggregating costs by one of two cost centers tied to a specific variable. The sum of each cost center was divided by its respective variable. These rates were then applied to the annual revenue hours or miles in the BRT service plan.

Madison is proposing to use electric vehicles for its new BRT service. Some of the inputs to this analysis were therefore different from a typical diesel bus service, such as electricity costs instead of diesel costs for running the main engines, diesel heating costs for winter months, and different projected maintenance costs. Nevertheless, these costs were then multiplied against the cost variables below, just as they would be for diesel buses.

Table 9. Costs by Variable Cost Center

Revenue Hours	Revenue Miles	Peak Vehicles	Fixed Infrastructure
• Driver labor and fringe benefits	• Maintenance expenditures • Fuel / energy and lubricants	• Administrative expenses	• Cost of BRT right-of-way upkeep.

The final O&M costs equal the sum of BRT costs related to each cost center.

Vehicle Requirements / Capital Costs

Additional vehicles are required to expand transit services. The total number of vehicles needed is the number of vehicles operated in maximum service (VOMS) plus additional spare vehicles. To calculate the VOMS, the "clean" service cycle time (defined above) was divided by the recommended frequency of service.

In addition to procuring vehicles to meet maximum service requirements, Metro will need to procure additional spare vehicles. Per Federal Transit Administration guidance[11], agency spare ratios should not exceed twenty percent of the active fleet.

Supporting Service Operating and Maintenance Costs Development

As with the proposed BRT service, those bus lines that are proposed to be changed in support of BRT were analyzed for existing and proposed operating and maintenance costs, following much the same process as in analyzing the proposed BRT.

Again, Revenue Miles and Revenue Hours were the variables needed to calculate costs. These were supplied by the City of Madison for most existing routes, along with peak and off-peak cycle times for all existing routes. These figures, when multiplied with fixed variables as described in Service Costs, allow the calculation of operating and maintenance costs for most existing routes.

Route 23 is starting in August 2019, so there was less data for this route. The existing Route 23 and all proposed services were calculated in a manner similar to the BRT analysis.

Route length was estimated using online mapping tools for each existing and proposed route. The supplied cycle time for each route, allowed the estimation an average speed for each existing route that the buses would have to run in order to support this cycle time. For the existing Route 23, this number, combined with hours of service, frequency, and route length, allowed the derivation of Annual Revenue Miles and Hours, which in turn allowed the derivation of "existing" annual operating and maintenance cost.

For the proposed service, hours of service and frequency were proposed to remain the same as in the existing service, and speed was estimated to remain the same. Route length was again estimated using online mapping tools. This again allowed the derivation of Annual Revenue Miles and Hours, which in turn allowed the derivation of annual operating and maintenance cost.

One section of the service area is proposed to be served by microtransit. This service, based on professional experience, can be costed at a rate per vehicle-hour. It is estimated that two vehicles would be required for this area.

[11] Federal Transit Administration. *Bus and Bus Facilities Program: Guidance and Application Instructions.* April 16, 2015, pg. IV-9.