SACRAMENTO REGIONAL TRANSIT DISTRICT

BATTERY-ELECTRIC BUS FEASIBILITY STUDY (2023)

FINAL
MAY 2023

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TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

Acronym	Description
AC	alternating current
ACF	Advanced Clean Fleets
BEB	battery-electric bus
CARB	California Air Resources Board
CNG	compressed natural gas
DC	direct current
EV	electric vehicle
FCEB	hydrogen fuel cell electric bus
GVWR	gross vehicle weight rating
HVAC	heating, ventilation, and air conditioning
ICT	Innovative Clean Transit
kW	kilowatts
kWh	kilowatt-hour
NZEV	near-zero emission vehicle
OEM	original equipment manufacturer
SacRT	The Sacramento Regional Transit District
SOC	state-of-charge
WSP	WSP USA Inc.
ZE	zero-emission
ZEB	zero-emission bus

EXECUTIVE SUMMARY

ES.1 PROJECT BACKGROUND

SacRT is committed to transitioning its entire fleet to zero-emission buses (ZEBs) by 2040, in compliance with California's Innovative Clean Transit (ICT) regulation. Pursuant to the CARB ICT regulation, SacRT has taken many steps to achieve a 100% ZEB fleet. To date, SacRT has developed and submitted its CARB-compliant ICT Rollout Plan, developed a series of studies to analyze the viability of deploying battery-electric buses (BEB) and constructing BEB and fuel cell electric bus (FCEB)-supporting infrastructure, and has also deployed several BEBs for its fixed-route and paratransit services.

However, despite these deployments and initiatives, the ZEB market continues to evolve, making it increasingly challenging for SacRT – and all transit fleets – to successfully align components of their respective transitions so that the latest and most advanced technologies are deployed at the lowest cost. To mitigate the risk of planning for technologies that are notorious for rapid obsolescence (such as battery efficiency), it is essential that SacRT frequently updates its inputs, especially as it relates to service schedule and BEB technology assumptions.

This report provides an updated evaluation of the BEB feasibility study, utilizing the latest 2023 BEB technology specifications, and the most recent service schedule. The findings will help inform strategic decisions regarding the transition to ZEBs, including potential solutions for enhancing range, such as opportunity charging, service changes, and/or the integration of FCEBs. While this study focuses exclusively on BEB performance, SacRT is concurrently conducting a separate FCEB feasibility analysis to further inform its transition strategies.

ES.2 FINDINGS

The fixed-route modeling analysis indicates that the majority of SacRT's service blocks can be adequately served using current BEB technology, with all blocks completing at least half of their required service. Notably, blocks from Hazel garage demonstrate the highest level of completion, followed by blocks from Elk Grove, Downtown, and McClellan garages. Should the vehicle replacement schedule align with the projected 3% annual range growth in battery efficiency/performance, full electrification of all garages could be achieved by either 2033 or 2040 (dependent on battery performance).

For demand response services, most of SacRT Go's blocks (as of March 2023) present challenges with existing BEB technology, suggesting the need for adjustments to block assignments and/or a potential increase in fleet size. As a potential solution, SacRT may consider deploying smaller vehicles, such as electric passenger vans, which are predicted to have better range capabilities. However, the current availability of these vehicles is limited but expected to improve in the coming years.

Per the CARB ICT regulation, starting in 2023, 25% of SacRT's standard bus procurements must be ZE, increasing to 50% for both standard buses and cutaways in 2026, and 100% for all buses in 2039. The ICT regulation enables a gradual transition, allowing SacRT to phase in ZE vehicles while taking advantage of technological advancements. However, for a successful transition, comprehensive analyses and strategic planning are essential.

Table ES- 1. Summary of Findings

Garage	Service Type	No. of Blocks	Vehicle Type	Blocks Completed*
Downtown	Fixed-Route	190	40’	59% - 82%
	Demand Response (SacRT Go)	10-23	Cutaway	6% - 20%
McClellan	Fixed-Route	7	Cutaway	0% - 71%
	Demand Response (SacRT Go)	11-27	Cutaway	8% - 29%
Hazel	Fixed-Route	2	Cutaway	100%
Florin	Demand Response (SacRT Go)	24-33	Cutaway	4% - 19%
Elk Grove	Fixed-Route	53	40’	91% - 96%
	Demand Response (eVan)	2-7	Cutaway	81% - 100%

Source: WSP
Note: *Block completion rate varies depending on battery performance and operating conditions

ES.3 CONSIDERATIONS AND NEXT STEPS

To improve service completion, SacRT can consider a range of mitigation strategies. For routes that fall just short of full completion with existing BEBs, less capital-intensive strategies such as aligning block transition schedules with BEB technology advancements and utilizing more efficient buses are recommended. For service with more demanding range requirements, more capital-intensive strategies like service adjustments, opportunity charging, or FCEB integration may be explored.

To advance SacRT’s zero-emission goals, it is recommended that future garage locations be identified and confirmed, enabling more detailed planning for the future ZEB fleet. Once confirmed, SacRT should develop a comprehensive ZEB Master Plan, encompassing a garage construction and phasing schedule informed by Sacramento Municipal Utility District (SMUD) design and construction durations, procurement requirements, and other processes. The plan will also provide the framework for securing competitive grants for design and implementation.

Further, periodic refinement of the BEB feasibility analysis is crucial, aligning results with facility construction timelines, vehicle replacement plans, regulations, and projected technology growth. This analysis will facilitate evaluation of viable solutions to address range shortfalls.

1 INTRODUCTION

1.1 PROJECT BACKGROUND

The Sacramento Regional Transit District (SacRT) provides a comprehensive range of transportation services, including fixed-route, on-demand transit, paratransit, and light rail options that span a 400 square-mile area. As part of its commitment to sustainability and in compliance with California Air Resources Board's (CARB) Innovative Clean Transit (ICT) regulation, SacRT plans to transition its fleet to zero-emission buses (ZEBs) by 2040.

Pursuant to the CARB ICT regulation, SacRT has taken many steps to achieve a 100% ZEB fleet. To date, SacRT has developed and submitted its CARB-compliant ICT Rollout Plan, developed a series of studies to analyze the viability of deploying battery-electric buses (BEB) and constructing BEB and fuel cell electric bus (FCEB)-supporting infrastructure, and has also deployed several BEBs for its fixed-route and paratransit services.

However, despite these deployments and initiatives, the ZEB market continues to evolve, making it increasingly challenging for SacRT – and all transit fleets – to successfully align components of their respective transitions so that the latest and most advanced technologies are deployed at the lowest cost. To mitigate the risk of planning for technologies that are notorious for rapid obsolescence (such as battery efficiency), it is essential that SacRT frequently updates its inputs, especially as it relates to service schedule and BEB technology assumptions.

In 2020, SacRT's *Battery-Electric Bus (BEB) Feasibility Study* (Feasibility Study), assessed the viability of operating its fixed-route services with a fully electrified bus fleet. The analysis found that between 56% and 99% of the Downtown Garage's weekday blocks, 38% to 86% of McClellan Garage's weekday blocks, and 100% of Hazel Garage's weekday blocks could be supported by BEB technology. However, since the Feasibility Study's completion, BEB technology has advanced, and SacRT's services have undergone notable developments, including the incorporation of the City of Elk Grove's transit services, the introduction of the Airport Express Bus, and the integration of BEBs into regular operations.

For the reasons stated above, the following report reassesses SacRT's service under existing conditions with existing BEB technology (2023) to identify the current state of electrification viability. Using this information, SacRT can better assess the specific solutions and technologies needed to support a full fleet transition to ZEBs.

1.2 PURPOSE AND STRUCTURE

This study serves as the foundation for subsequent decision-making related to ZEB transition strategies. It aims to provide SacRT with a high-level understanding of the viable options that can be considered to fully complete service using BEBs. The extent of block completion influences the future fleet size, which ultimately informs the amount of charging and utility infrastructure required. For blocks that cannot be supported, the study also informs potential range-enhancing solutions, such as opportunity charging, service changes, and integration of FCEBs.

It should be noted that this study only evaluates BEB performance. SacRT (at the time of this writing) is currently evaluating the feasibility of adopting FCEBs under a separate study.

This report is organized into five primary sections:

1 **Introduction –** Overview of the project, and the purpose and structure of the report.
2 **Methodology –** Overview of the service modeling analysis, inputs, and assumptions.
3 **Existing Conditions –** Overview of SacRT's service and transit systems.
4 **Service Modeling Results –** Overview of the modeling results for SacRT's services, by garage.
5 **Conclusion and Next Steps –** Summary of the modeling results, considerations, and next steps.

2 METHODOLOGY

The following sections provide an overview of the methodology, inputs, and assumptions used in the service modeling analysis.

2.1 OVERVIEW

The service modeling analysis provides a high-level assessment of the feasibility of operating BEBs with SacRT's current service schedule, for both fixed-route and demand response services. The analysis focuses on service blocks[1], which are groups of sequential trips assigned to a single bus. A service block begins when the bus leaves the garage and concludes when it returns. A bus (or operator) may support multiple blocks in a single day, such as separate AM and PM blocks, or a singular (presumably long duration or distance) block for the day.

The analysis estimates the energy required (expressed in kilowatt hours [kWh]) to fully complete each service block. This energy demand determines the number of service blocks that can be completed with a single BEB on a single charge, depending on the modeled battery capacity. The range (mileage) of a battery-electric vehicle varies based on several operating and environmental factors. These factors were considered in the analysis, including service blocks' length and duration, heating, ventilation, and air conditioning (HVAC) usage, and prospective BEB specifications such as battery capacity (accounting for a safety buffer), stated range, and weight (Figure 2-1).

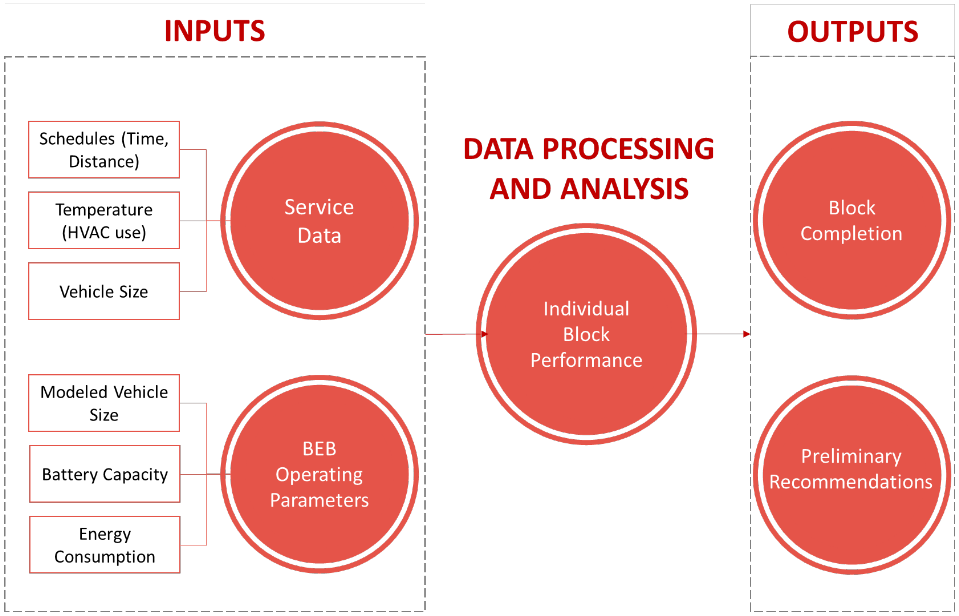
For failing/incomplete blocks where the modeled BEB cannot complete the block due to insufficient energy storage capacity, the analysis records the extent of the shortfall (the amount of energy [kWh] required to complete the service block) and suggests preliminary solutions. Solutions to complete service blocks may involve modifying the prospective BEBs' specifications (in the model), adjusting current service for additional vehicle pullouts and/or less energy-demanding blocks (shortening in duration and/or distance), installing opportunity chargers, and integrating fuel cell electric bus technology. Each strategy will affect individual garages' energy needs and transition costs, which will have to be further analyzed.

The results of two modeled scenarios, "Typical" and "Intensive", are presented by garage. The typical scenario represents preferable operating conditions such as moderate weather, while the intensive scenario accounts for increased HVAC usage due to more extreme weather conditions. The following sections discuss the data inputs and assumptions used in the service modeling analysis.

It is important to note that various factors, such as the number of stops, speed, passenger load, slope, driver behavior, and battery health, can also impact energy consumption rate and, hence, BEB performance. These factors were not included in this high-level feasibility study. As SacRT gains experience operating BEBs on different routes, a more comprehensive model can be developed. By leveraging real-world performance data, the improved model can account for these additional factors and capture the nuances of the various routes.

[1] The demand response data refer to blocks as "runs" For simplicity, this report uses the term "blocks" for both fixed-route and demand response services.

Figure 2-1. Methodology Overview



Source: WSP

2.2 INPUTS AND ASSUMPTIONS

The inputs used for the model fall into two categories: service data and operating parameters. Service data includes bus schedules, vehicle inventories, and temperature, whereas operating parameters refer to specific BEB assumptions and adjustments, including vehicle size, battery capacity, and energy consumption. The following section details the service data and operating parameters established in the model.

2.2.1 SERVICE DATA

A number of data were provided by SacRT to provide a comprehensive understanding of the existing fleet and service conditions. Table 2-1 summarizes the service data used in the analysis.

Table 2-1. Service Data Summary

Data	Description	Source
Fixed-Route Service Schedule	Trip IDs, block IDs, garages, routes, revenue and non-revenue miles, and duration	SacRT Trapeze data; March 2023
Demand Response Service Example	One month data of Run IDs, vehicle IDs, total mileage, duration	SacRT; March 2023
Fleet Inventory	Vehicle IDs, vehicle types, garages, status, uses, useful life	SacRT; December 2022
Ambient Temperature	Five-year data of average daily temperature for the Sacramento area	2018-2022 data from the National Weather Service[2]

Source: WSP

[2] National Weather Service. 2023. *https://www.weather.gov/wrh/Climate?wfo=sto*

SCHEDULES

The fixed-route analysis utilized data from March 2023, focusing on weekday blocks to capture peak service demand. Meanwhile, for the demand response analysis, given the variable nature of the service, example data from March 2023 were examined to capture the service's overall characteristics and establish baseline for the analysis. Two demand response services were analyzed: the SacRT Go and eVan.

SacRT operates five different garages: Downtown, McClellan, Hazel Station, Florin, and Elk Grove garages. Downtown, McClellan, and Elk Grove garages operate both fixed-route and demand response services. Hazel Station garage only operates fixed-route service, while Florin garage only operates demand response service.

TEMPERATURE

The region's ambient temperature was derived from five years of daily average temperatures data obtained from the National Weather Service. Ambient temperature directly correlates to HVAC consumption. Studies and real-world applications demonstrate that low or high ambient temperatures, and the resulting energy required to heat or cool the bus interior, have a significant impact on total BEB energy use and vehicle range. Research indicates that total BEB energy use is higher during extreme low temperature conditions than during extreme high temperature conditions if using electric heating.

The typical scenario uses an average daily temperature of 78°F, which represents the level of HVAC consumption on most days of the year. For the intensive scenario, the *highest* HVAC energy consumption observed between the minimum and maximum average daily temperatures was applied. For Sacramento, HVAC energy consumption during the lowest average daily temperature (37°F) was found to be greater than the consumption during the highest average daily temperature (94°F). This ambient temperature is assumed to remain constant for each modeled block's duration.

VEHICLE SIZE

The current vehicle type assigned to each block determines the BEB operating parameters modeled for the block. Fixed-route services from the Downtown and Elk Grove garages are assumed to utilize 40-foot standard buses, while McClellan and Hazel Station garages utilize cutaway buses. An additional analysis was conducted for the Airport Express and Causeway Connection to assess the feasibility of operating these routes using 45-foot over-the-road coaches. All demand response services are assumed to use cutaway buses.

2.2.2 BEB OPERATING PARAMETERS

BEB operating parameters include the size (length) of the modeled BEB, battery capacity (advertised and usable), and the advertised energy consumptions. Generally, the analysis utilizes average values of currently available BEB models to capture current market conditions.

A BEB's performance is typically measured by its range (miles), directly influenced by its energy consumption, as expressed in kWh per mile (kWh/mi.), and battery capacity, expressed in kWh. A vehicle with a higher numerical energy consumption per mile has a shorter range, while one with a lower numerical energy consumption has a longer range. Energy consumption can vary based on various factors such as battery health, operator driving behavior, temperature (HVAC usage), stops, speed, passenger load, and route topography.

Battery capacities *advertised* by original equipment manufacturers (OEMs) may differ from the actual *operating* (or usable) capacity that a battery provides. Determining the operating capacity of a battery is crucial for accurately assessing range and performance. Generally, OEMs consider 10% or more of a battery's advertised capacity as unusable to maintain battery health. SacRT may deem an additional portion of the battery unusable to provide a safety buffer, reducing range anxiety for operators and mitigating service impacts. Other benefits of a safety buffer are that the battery (while charging) can maximize charger use, reduce charging times (batteries typically receive peak power between 20% and 80% state-of-charge), and minimize battery degradation. This analysis assumes a 20% safety buffer from the total advertised battery capacity.

Table 2-2 summarizes the modeled BEB operating parameters used in the analysis.

Table 2-2. Summary of Modeled BEBs

Vehicle Length	Modeled BEB (Make: Model)	Advertised Range (miles)	Advertised Capacity (kWh)	Average Advertised Efficiency (kWh/mi)	Average Advertised Battery Capacity (kWh)	Average Usable Battery Capacity (kWh)**
Cutaways	Greenpower: EV Star	153	118	0.87	135	108
	Forest River LLC: E-450	140/170*	130/157*			
	Lightning Electric: ZEV4	130	120			
40’ Standard Bus	BYD: K9MD	231	496	2.07	543	434
	Gillig: Battery Electric	216/257/295*	490/588/686*			
	Proterra: ZX5+ and ZX5 MAX	262/374*	452/675*			
	New Flyer: Xcelsior Charge NG	221/258*	435/520*			
45’ Over the Road Coach	BYD: C10M	196	496	2.29	520	416
	MCI: J4500 Charge	240	544			
	MCI: D45 CRT Charge	250	520			

Source: WSP, various OEMs
*Model has several battery configurations
** Usable battery capacity is 80% of the advertised total battery capacity (20% safety buffer)

Batteries are expected to continue to improve in parallel with SacRT’s transition – expected improvements include more energy capacity, density, and efficiency. These advancements will improve the overall range of BEBs. Considering these anticipated improvements, this analysis also projects when each block can be completed, assuming a 3% annual range improvement[3]. When considering technological advancements, it is likely that fewer capital-intensive mitigation strategies will be needed to support blocks that are failing under existing conditions.

[3] Bloomberg New Energy Finance (2021) estimated a 7% annual battery density improvement. For the analysis, a 3% annual range improvement rate was chosen to provide more conservative values of future BEB ranges.

3 EXISTING CONDITIONS

The following sections describe SacRT's service area, existing fixed-route and demand response services, and existing fleet inventory.

3.1 SERVICE AREA AND OPERATING CONDITIONS

SacRT provides service throughout Sacramento County, which includes service in the cities of Sacramento, Citrus Heights, Elk Grove, Folsom, and Rancho Cordova. Located in California's Climate Zone 12, the county experiences cooler winters and hotter summers as compared to the Bay Area.

Daily average temperature data from 2018-2022 reveals that Sacramento has an average daily temperature of about 63°F. The highest daily averages, reaching up to 94°F, occur between July and September, while the lowest daily averages, dropping to 37°F, occur between December and February.

Previous analysis of elevations within 0.75 miles of SacRT's fixed-route service indicates an average elevation of 102 feet, a low of -0.5 feet, and a high of 1,164 feet. The service area's higher elevations are found in the east, in Folsom, with most of the area being just under 100 feet in elevation.

Electrical service in the County is provided by the Sacramento Municipal Utility District (SMUD).

3.2 SERVICE

SacRT's transit service includes 82 bus routes (fixed-route, microtransit, and dial-a-ride), 43 miles of light rail serving 53 light rail stations, and the Americans with Disabilities Act (ADA) paratransit services within a 440-square-mile service area throughout Sacramento County[4]. Following the integration of Elk Grove Transit Service, SacRT now operates both fixed-route and demand response services on behalf of Elk Grove within its area.

SacRT currently operates five garages: Downtown, McClellan, Hazel, Florin, and Elk Grove. However, there are plans in place for SacRT to relocate the Florin garage to a new site. Figure 3-1 presents SacRT and Elk Grove routes, existing garage locations, and the vicinity of a future south garage (in place of Florin).

Operating 365 days a year, buses run daily from 5 AM to 11 PM, every 12 to 60 minutes, depending on the route. Annual systemwide ridership in Fiscal Year 2022 reached approximately 11 million passengers, with 55% from fixed-route bus service and 4% from demand response service.

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[4] SacRT system-wide map (August 2021) can be accessed here.

Figure 3-1. System-wide Service Map and Garage Locations

Source: SacRT and Elk Grove GTFS, 2023

3.2.1 FIXED-ROUTE

Fixed-route services operate a total of 252 weekday blocks out of four garages: Downtown, McClellan, Hazel Station, and Elk Grove garage, with the majority of service originating from the Downtown Garage. Blocks from this facility have longer average durations and distances compared to blocks from other garages. The average duration and distance for the 190 Downtown Garage blocks are 10.5 hours and 134 miles. SacRT also operates two BEB express lines out of the Downtown Garage: the Airport Express, connecting downtown Sacramento with the Sacramento International Airport, and the Causeway Connection, linking Sacramento to Davis. Additionally, all of SacRT's Saturday and Sunday fixed-route services run from the Downtown Garage. For the modeling purpose, this analysis will focus on weekday blocks to capture peak service demand.

Fifty-three (53) weekday blocks operate out of the Elk Grove garage, with an average duration of 4.5 hours and an average block length of 64 miles. Seven blocks operate out of the McClellan Garage with an average duration of 6.6 hours and an average block length of 101 miles. Lastly, two fixed-route blocks operate out of the Hazel Station Garage. Hazel's blocks are relatively shorter blocks with an average duration of three hours and average distance of 52 miles. Table 3-1 summarizes the key statistics for the block duration and length.

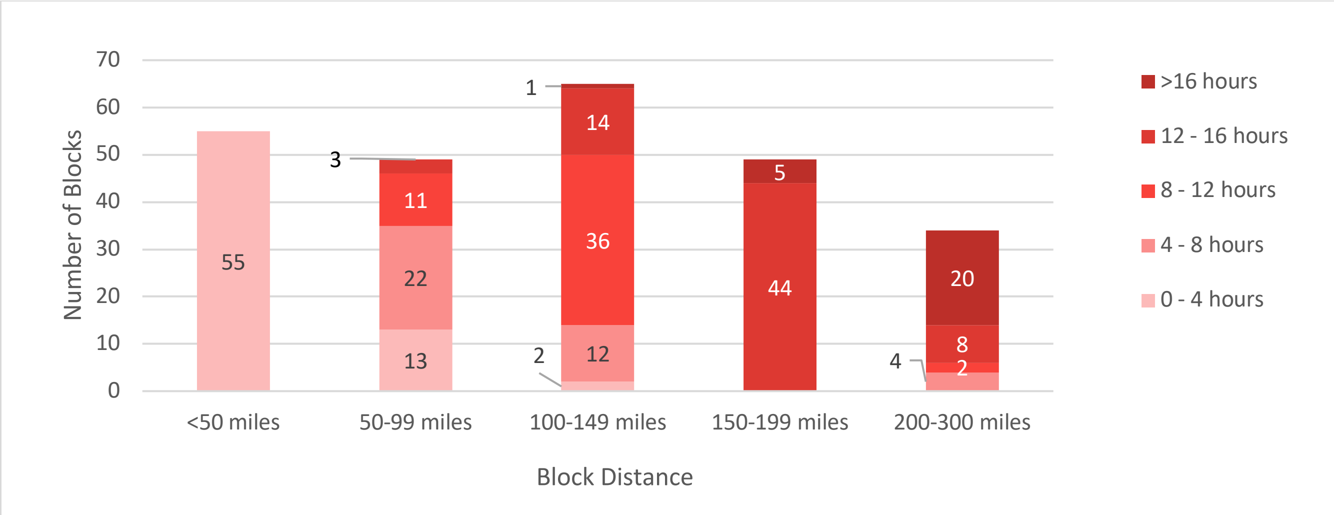
Table 3-1. Fixed-Route Block Statistics by Garage

Garage	Number of Weekday Blocks	Vehicle Type	Block Duration (hh:mm)			Block Length (miles)		
			Min	Average	Max	Min	Average	Max
Downtown	190	40'	1:22	10:34	18:33	12	134	258
McClellan	7	Cutaway	4:17	6:36	12:16	90	101	118
Hazel Station	2	Cutaway	2:54	2:59	3:04	51	52	53
Elk Grove	53	40'	1:34	4:33	15:35	21	64	217

Source: SacRT Service Schedule, March 2023

Figure 3-2 provides a breakdown of the block distances and durations. The majority of SacRT's blocks (67%) have a length of less than 150 miles. Meanwhile, 13% of the blocks have a total length exceeding 200 miles. The longer blocks predominantly originate from the Downtown Garage. As a general rule of thumb, blocks with a total distance of 150 miles or less are often considered suitable for BEBs. However, the following analysis will provide more tailored results that account for SacRT's specific schedule and operating conditions.

Figure 3-2. Fixed-Route Weekday Service Block Summary



Source: SacRT Service Schedule, March 2023

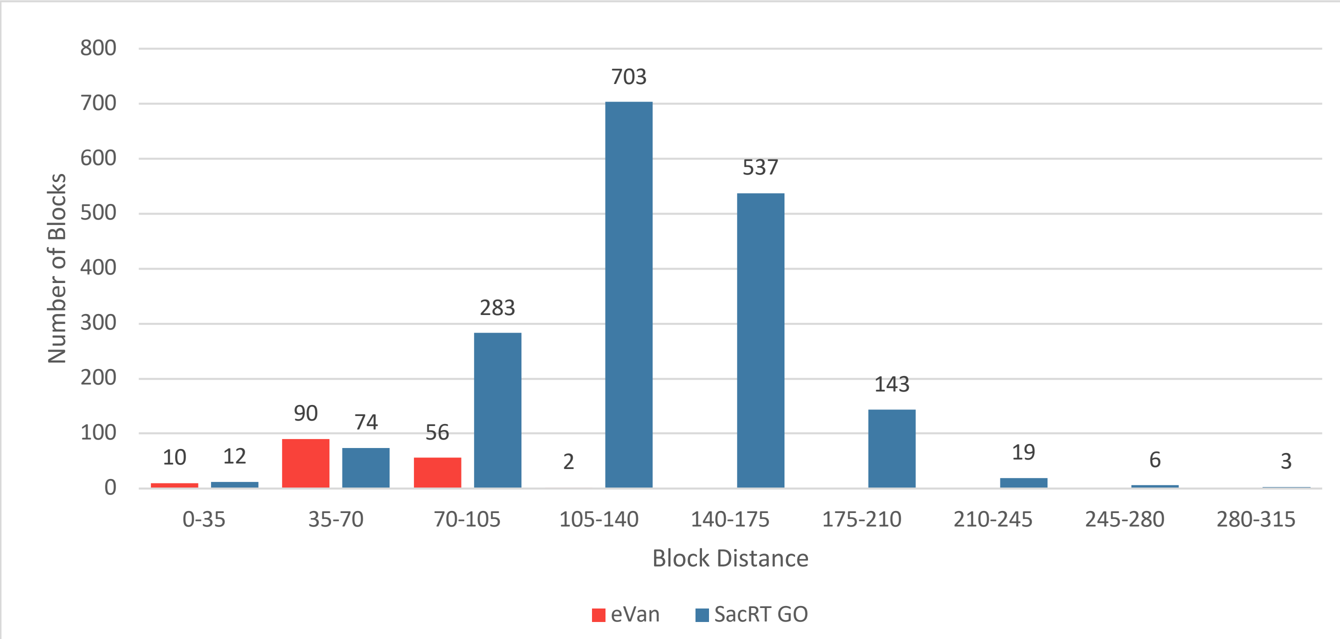
3.2.2 DEMAND RESPONSE

SacRT operates SacRT Go Paratransit and eVan demand response services. SacRT Go is a door-to-door, shared-ride transportation for those unable to use the fixed-route services. The eVan service operates within the City of Elk Grove and provides service to medical facilities in South Sacramento. The service areas and hours of the demand response services are designed to be comparable to the fixed routes, providing paratransit service to origins and destinations within a 3/4 mile radius of the fixed-route service.

Riders must book rides at least one day in advance, with service demand varying daily. SacRT's schedulers then create runs/blocks to assign to vehicles. Due to the variability of the service, example block data was used to provide a better understanding of service characteristics.

In March 2023, there were a total of 158 eVan blocks and 1,780 SacRT Go blocks. eVan blocks were significantly shorter than SacRT Go blocks. The majority of eVan blocks (99% or 156 blocks) were under 105 miles, while the majority of SacRT Go blocks (79% or 1,411 blocks) exceeded 105 miles, mostly between 105-175 miles. Figure 3-3 shows the block length distribution for eVan and SacRT Go services in March 2023.

Figure 3-3. Demand Response Block Summary (March 2023)



Source: SacRT Go and eVan Vehicle Mileage Data, March 2023

The eVan service operates out of the Elk Grove garage, while SacRT Go operates from Downtown, McClellan, and Florin garages. Florin garage only operates on weekdays. The average block distance for eVan (63 miles) was significantly shorter than SacRT Go's blocks (127-138 miles).

Generally, two to seven blocks were dispatched daily for eVan service, averaging five blocks per day. The number of daily blocks dispatched for SacRT Go varied by garage. Florin garage had the most blocks, ranging from 24 to 33 daily blocks, with an average of 28 blocks dispatched. The Downtown garage dispatched between 10-23 blocks daily, with an average of 17 blocks. Meanwhile, the McClellan garage dispatched 11 to 27 blocks daily, with an average of 19 blocks. Both services had more blocks on weekdays than weekends. Table 3-2 synthesizes the minimum, average, and maximum number of blocks per day and distances for both services by garages.

Table 3-2. Demand Response Block Statistics (March 2022)

Service	Garages	Number of Blocks per Day			Block Distance (miles)		
		Min	Average	Max	Min	Average	Max
eVan	Elk Grove	2	5	7	15	64	108
SacRT Go	Downtown	10	17	23	22	138	304
	McClellan	11	19	27	0.2	127	307
	Florin	24	28	33	33	131	253

Source: SacRT Go and eVan Vehicle Mileage Data, March 2023

3.3 FLEET

3.3.1 FIXED-ROUTE

Table 3-3 summarized the number of active vehicles for the fixed-route service at each garage. In December 2022, there are 226 vehicles assigned to the fixed-route service. Most of the active vehicles are parked at the Downtown Garage. The majority of the vehicles are fueled by compressed natural gas (CNG). SacRT currently have a total of nine 40-foot standard BEBs that are deployed on the Airport Express and Causeway Connection routes.

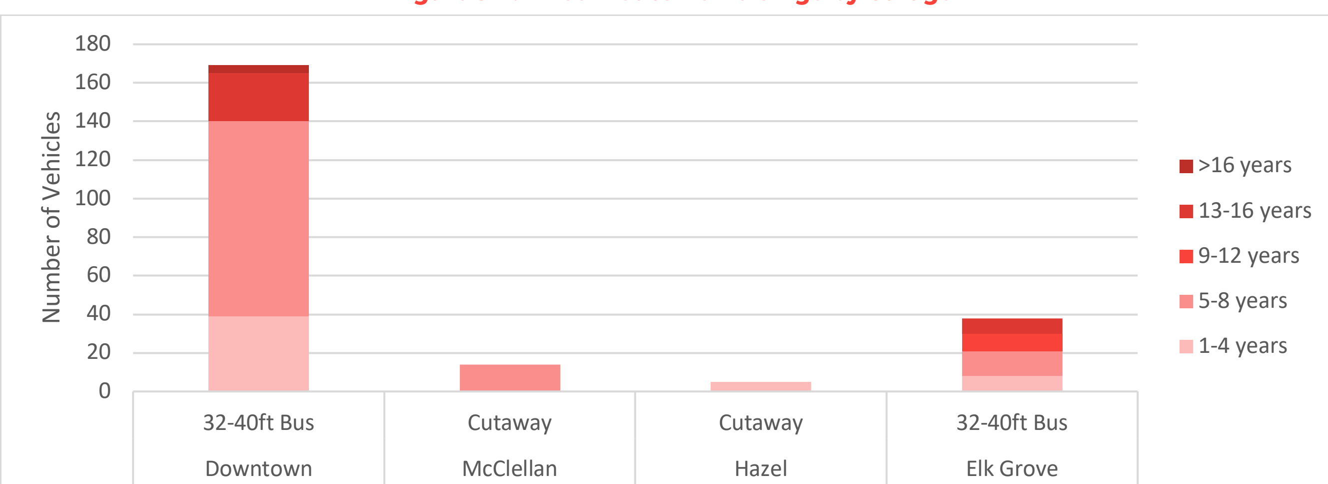
Table 3-3. Fixed-Route Vehicles

Garage	Fuel Type	Bus Length	Number of Vehicles
Downtown	CNG	40’	155
	Diesel	32’	5
	Electric	40’	9
McClellan	CNG	Cutaway	6
	Gasoline	Cutaway	8
Hazel Station	Gasoline	Cutaway	5
Elk Grove	CNG	40’	38
		Total	**226**

Source: SacRT Vehicle Inventory December 2022

The majority of the fixed-route fleet (187 vehicles/83%) have not yet reached their designated useful life: 12 years for standard buses and 5 to 7 years for cutaways. Those that have reached the useful life (39 vehicles/17%) are predominantly standard buses assigned to blocks from the Downtown Garage, as shown in Figure 3-4. Most of these vehicles have been identified as eligible for re-tanking.

Figure 3-4. Fixed-Route Vehicle Age by Garage



Source: SacRT Vehicle Inventory December 2022

3.3.2 DEMAND RESPONSE

Table 3-4 summarized the number of active vehicles for the eVan and SacRT Go services at each garage. As of December 2022, there are 128 active vehicles assigned to eVan and SacRT Go. Most vehicles are parked at the Florin and McClellan Garages. The majority of demand response vehicles are fueled by gasoline.

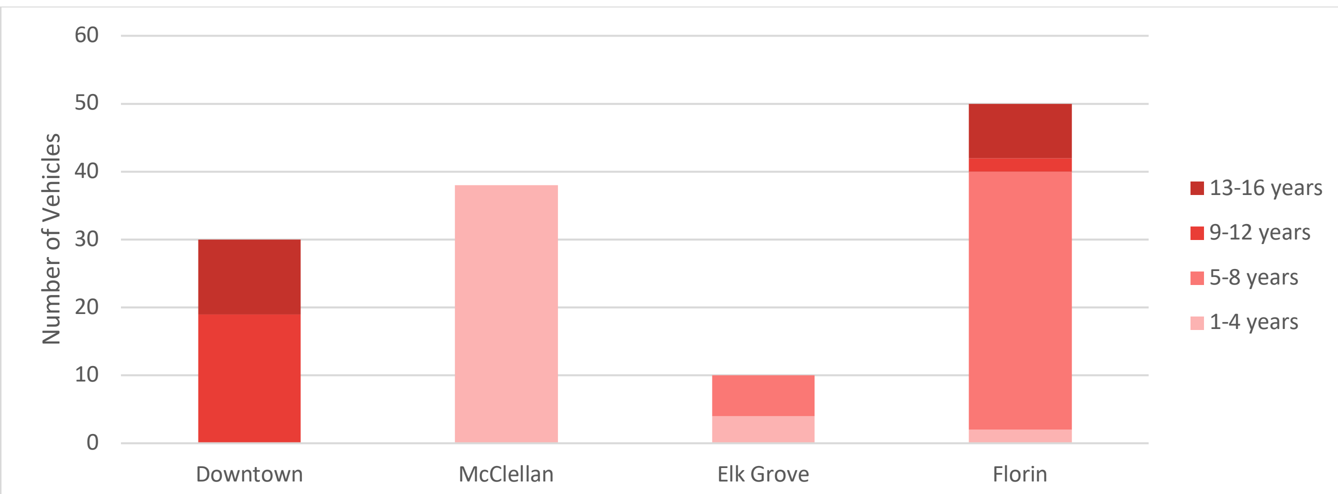
Table 3-4. Demand Response Vehicles

Garage	Fuel Type	Bus Length	Number of Vehicles
Downtown	Gasoline	Cutaway	30
McClellan	Gasoline	Cutaway	38
Florin	Gasoline	Cutaway	50
Elk Grove	CNG	Cutaway	10
		Total	**128**

Source: SacRT Vehicle Inventory December 2022

The majority of the demand response fleet (88 vehicles/69%) have not yet reached their designated useful life of 5 to 7 years. Of those that have reached the useful life, 30 are parked at the Downtown Garage and ten at the Florin garage. Figure 3-5 shows the age distribution by garage.

Figure 3-5. Demand Response Vehicle Age by Garage



Source: SacRT Vehicle Inventory December 2022

Besides the vehicles that are assigned to eVan and SacRT Go, SacRT also manage 42 cutaways for its micro transit SmaRT Ride service. The service runs out of Downtown, McClellan, and Hazel Station garages. Most of the vehicles are fueled by gasoline and CNG, but nine of the 42 vehicles are electric cutaways.

4 SERVICE MODELING RESULTS

The following sections discuss the service modeling results by garage (Downtown, McClellan, Elk Grove, Hazel, and Florin) and service type.

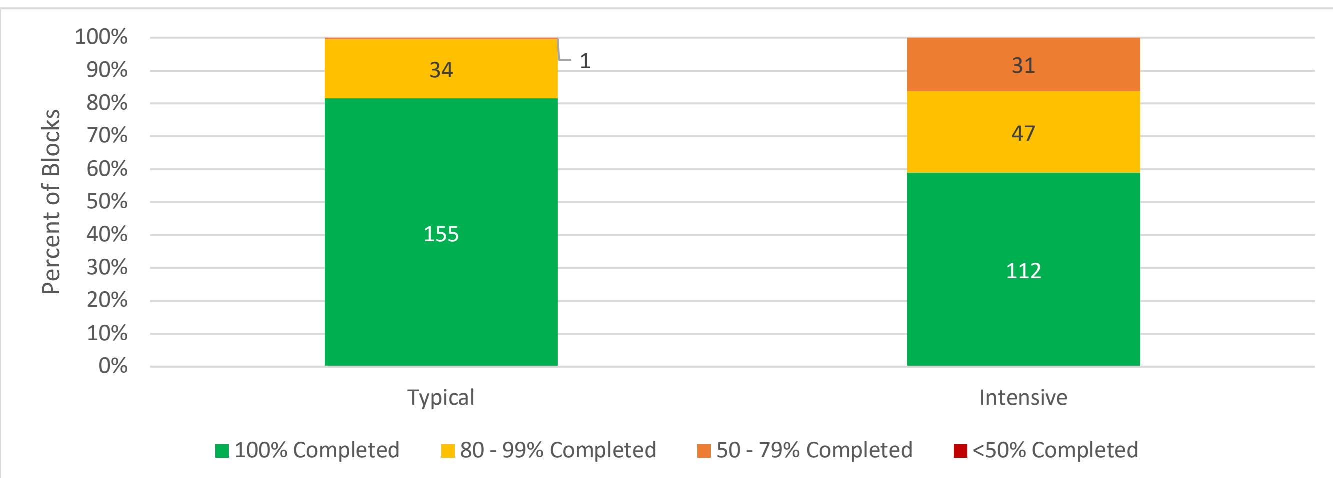
4.1 DOWNTOWN GARAGE

4.1.1 FIXED-ROUTE

The fixed-route service schedule operated from the Downtown Garage includes weekday, Saturday, and Sunday blocks. The analysis focuses on the 190 weekday blocks to reflect peak service demand. All blocks are modeled using the specifications of 40-foot BEB.

In the typical scenario, 155 of the 190 weekday blocks (82%) can be completed by BEBs, as shown in Figure 4-1. Among the failing blocks, 34 blocks (18%) can complete over 80% of their scheduled distances, with only one block completing less than 80% of its designated distance. The block completion rate decreases in the intensive scenario due to higher HVAC energy consumption. Out of 190 blocks, 112 (59%) can be fully completed by BEBs, 47 blocks (25%) fail after completing at least 80% of their service, and the remaining 31 blocks (16%) achieve 50-79% completion.

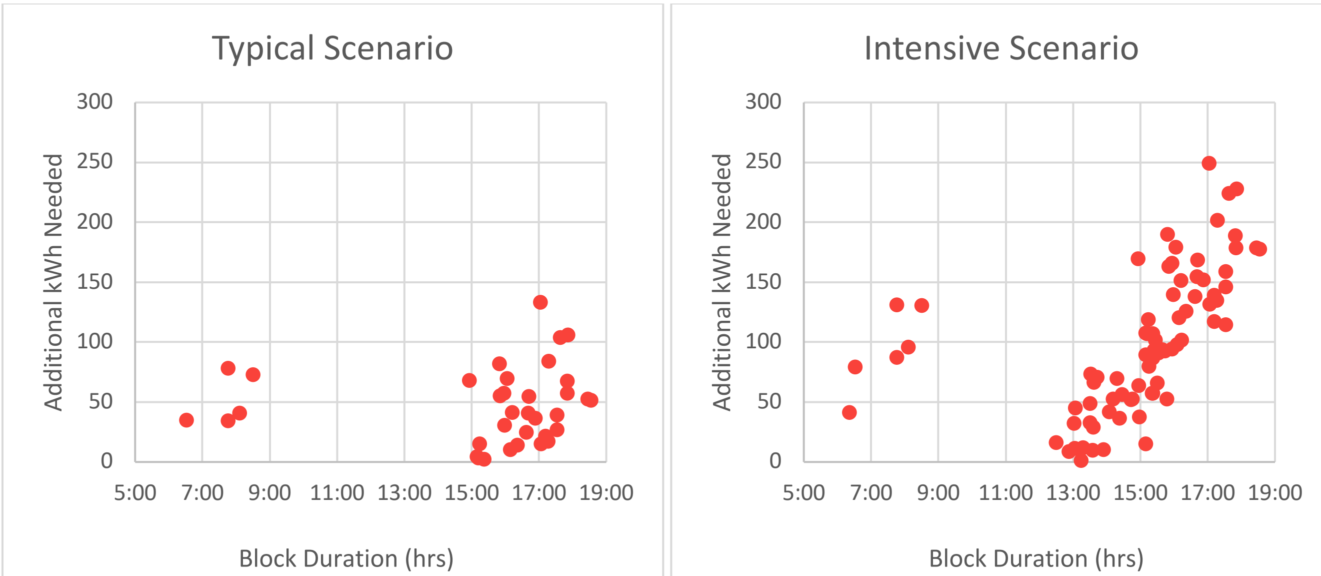
Figure 4-1. Downtown Garage - Block Completion Rate



Source: WSP

Figure 4-2 illustrates the additional energy needed to complete the failing blocks. In the typical scenario, the 35 failing blocks require between 2-133 additional kWh to complete service (0%-31% additional battery capacity for each block). Meanwhile, in the intensive scenario, the 78 failing blocks require between 1-249 additional kWh to complete service (0%-57% additional battery capacity for each block). See Appendix A for detailed results for each block.

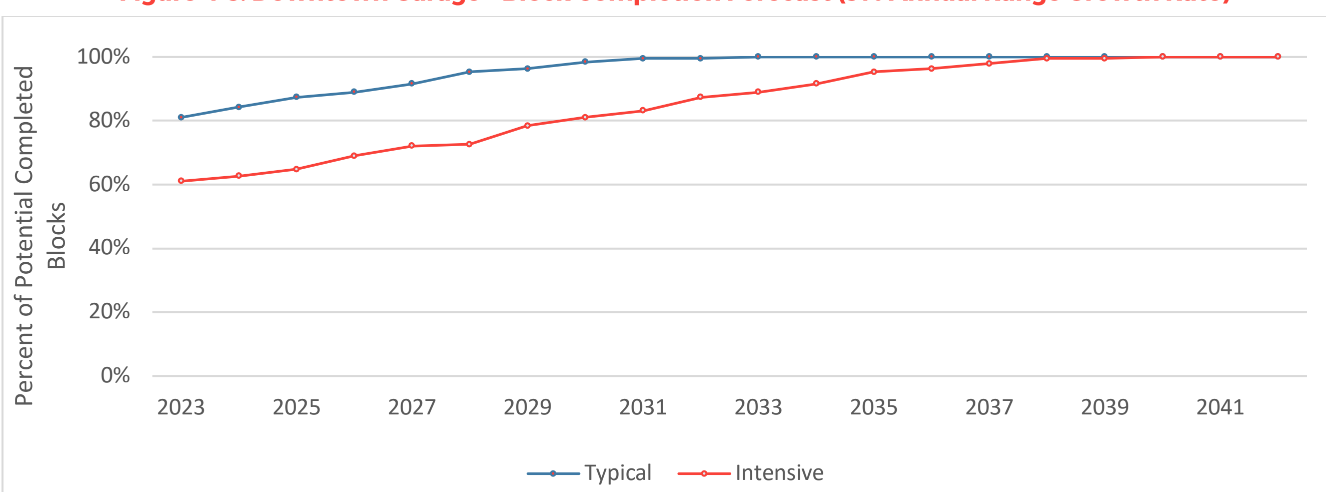
Figure 4-2. Downtown Garage - Additional Energy Needed (kWh) to Complete the Failing Blocks



Source: WSP

Figure 4-3 illustrates the projected future block completion, taking into account the anticipated annual technology growth (3%). Under these conditions, all blocks are expected to be able to be electrified by 2033 in the typical scenario and 2040 in the intensive scenario, assuming the vehicle replacement schedule aligns with technology growth. The actual electrification timeline may deviate from the service forecast if vehicles need to be replaced by BEBs before the necessary technology is available, or if vehicles have not yet reached the end of their useful life.

Figure 4-3. Downtown Garage – Block Completion Forecast (3% Annual Range Growth Rate)



Source: WSP

AIRPORT EXPRESS AND CAUSEWAY CONNECTION

SacRT are considering to deploy 45-foot BEB coaches on two of its routes, the Airport Express and Causeway Connection, due to the additional luggage and bike space. This analysis explores the feasibility of completing both routes using 45-foot BEB coaches.

Currently, both routes operate 40-foot standard BEBs. The Airport Express route has an average block length of 147 miles, while the Causeway Connection has an average block length of 118 miles. Table 4-1 summarizes the key statistics for the service blocks of both routes.

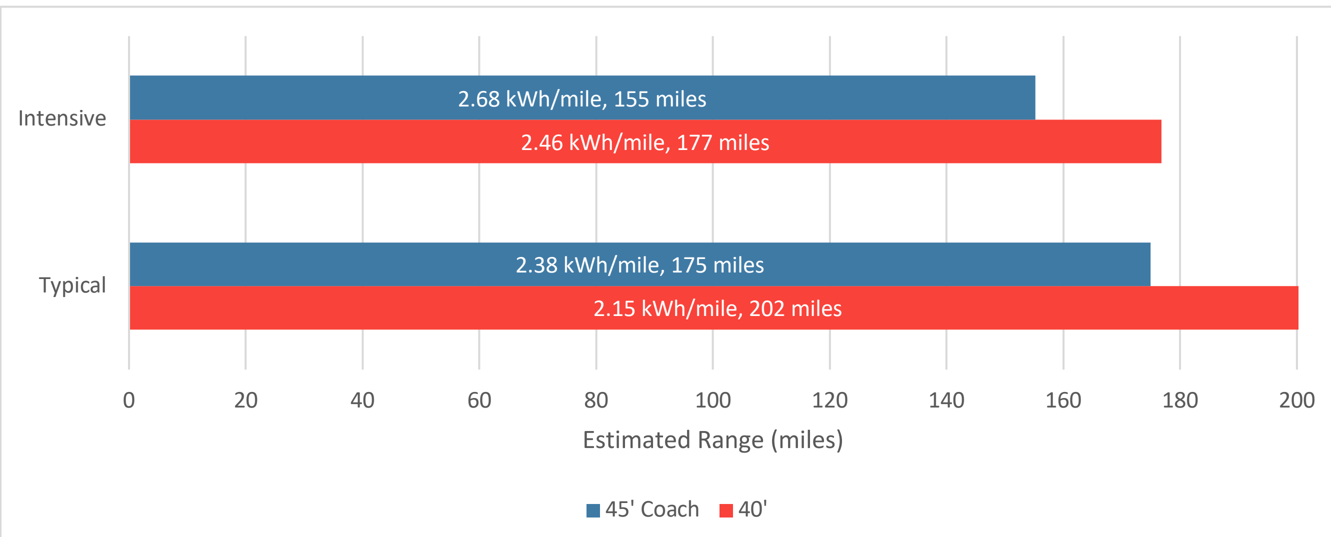
Table 4-1. Downtown Garage – Airport Express and Causeway Connection Blocks Statistics

Routes	Number of Weekday Blocks	Min. Block Length (mi.)	Avg Block Length (mi.)	Max. Block Length (mi.)
Airport Express	3	147	147	147
Causeway Connection	3	90	118	133

Source: WSP

Figure 4-4 contrasts the modeled performance of a 40-foot standard BEB with that of a 45-foot BEB coach. When deployed on the Airport Express and Causeway Connection routes, a 45-foot BEB coach has a slightly lower expected range than a 40-foot standard BEB. However, with an anticipated range of 155-175 miles, it remains capable of completing the service blocks for both routes, which have block distances ranging between 90-147 miles. As a result, deploying a 45-foot BEB coaches on these routes appears to be feasible.

Figure 4-4. Downtown Garage – 40-foot BEB and 45-foot BEB Coach Performance Comparison for the Airport Express and Causeway Connection

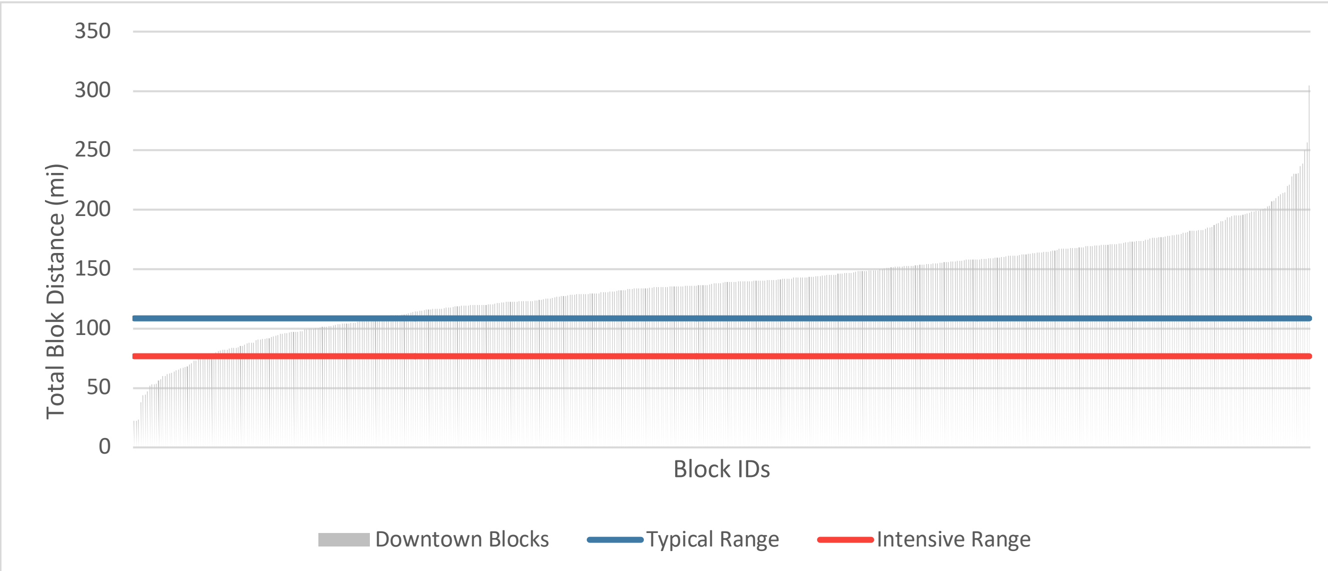


Source: WSP

4.1.2 DEMAND RESPONSE

In March 2023, there were 532 blocks dispatched from the Downtown Garage, with most of them exceeding the modeled electric cutaway range. Approximately 79% of total blocks were longer than the expected typical range of 109 miles, and 94% of the blocks exceeded the expected intensive range of 77 miles. On average, the Downtown Garage's block distance is 138 miles. Figure 4-5 illustrates the comparison between the blocks' lengths and the BEB expected ranges.

Figure 4-5. Downtown Garage – Block Lengths Compared to Modeled BEB Range



Source: WSP

There were about ten to 23 blocks dispatched daily from the Downtown Garage in March 2023. Daily block completion ranged from 5% to 56% in the typical scenario and 0% to 28% in the intensive scenario, depending on the varying daily block length assignments.

In March 2023, the maximum total service miles completed by all vehicles in a single day was 3,567 miles. Assuming the estimated cutaway range, SacRT would need 33-47 electric cutaways to complete the same amount of miles, which means an additional three to 17 vehicles would be required compared to the current fleet, not including spares. Table 4-2 summarizes the daily completion rate for the Downtown Garage.

Table 4-2. Downtown Garage – Demand Response Daily Completion Rate

Number of Blocks (Daily)	Total Number of Vehicles	Typical Scenario Daily Completed Blocks (%)			Intensive Scenario Daily Completed Blocks (%)			Max Total Daily Service Miles	Additional Vehicles Needed	
		Min	Avg	Max	Min	Avg	Max		Typical	Intensive
10-23	30	5%	20%	56%	0%	6%	28%	3,567	3	17

Source: WSP

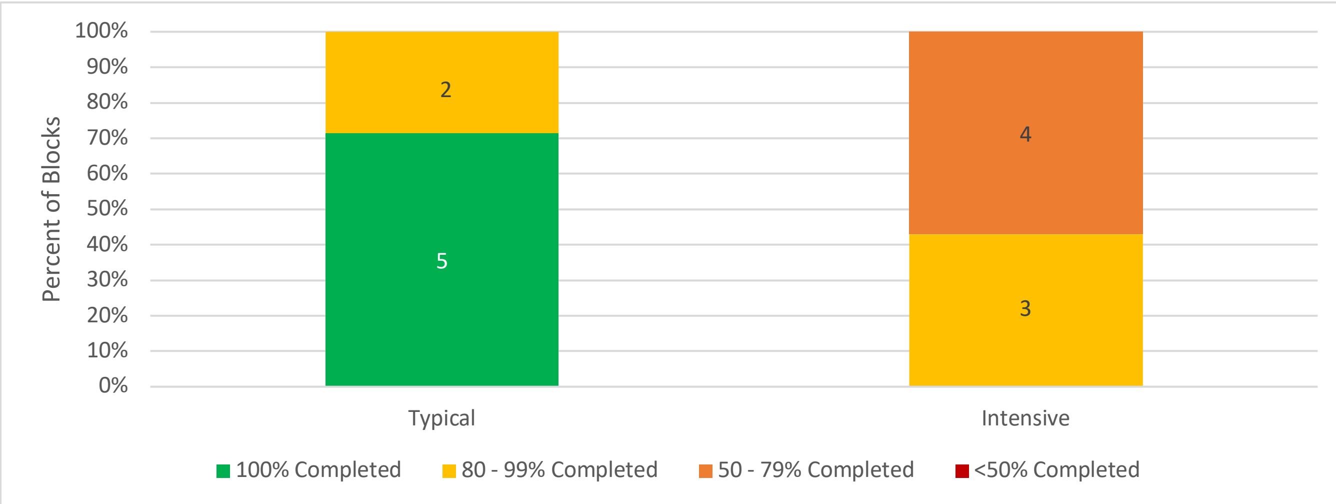
4.2 MCCLELLAN GARAGE

4.2.1 FIXED-ROUTE

The service schedule for McClellan Garage consists of seven weekday blocks, all of which are modeled using electric cutaway specifications.

In the typical scenario, BEBs can complete five out of the seven weekday blocks (71%), as shown in Figure 4-6. The two remaining blocks (29%) are modeled to be able to complete over 80% of their service. The block completion rate drops in the intensive scenario due to increased HVAC energy consumption, with no blocks fully completed by BEBs. Three of the seven blocks (43%) will fail in the intensive scenario after completing at least 80% of their assigned service. The remaining four blocks (57%) will be able to complete 50-79% of the assigned service.

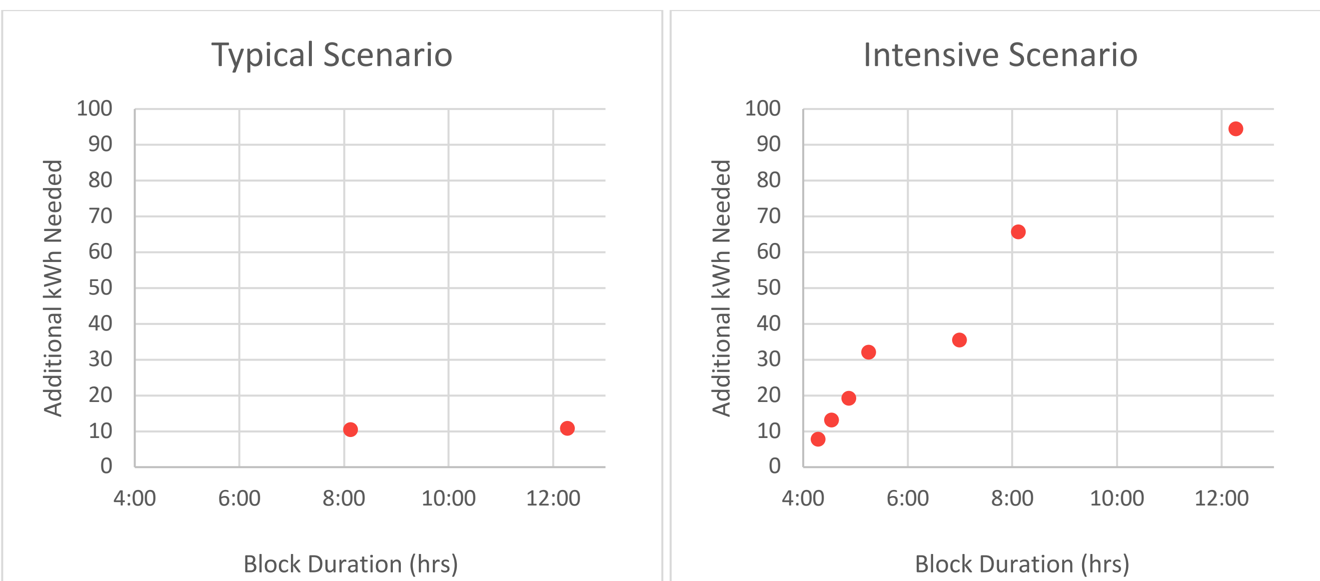
Figure 4-6. McClellan Garage – Block Completion Rate



Source WSP

Figure 4-7 illustrates the additional energy needed to complete the failing blocks. In the typical scenario, failing blocks need a relatively small amount of additional energy to complete service, ranging from 10 to 11 kWh (10% additional battery capacity for each block). Meanwhile, in the intensive scenario, failing blocks require between 8-94 additional kWh to complete service (7%-87% additional battery capacity for each block). See Appendix A for detailed results for each block.

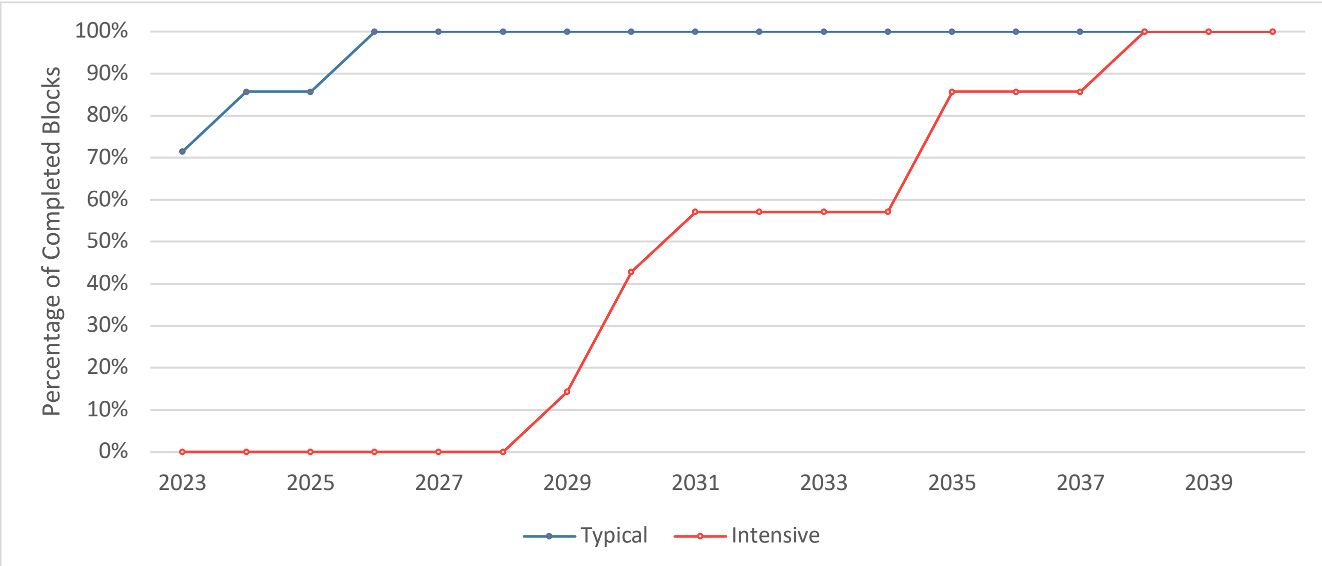
Figure 4-7. McClellan Garage – Additional Energy Needed (kWh) to Complete the Failing Blocks



Source: WSP

Figure 4-8 illustrates the projected future block completion, taking into account the anticipated annual technology growth (3%). Under these conditions, all blocks are expected to be electrified by 2026 in the typical scenario and 2038 in the intensive scenario, assuming the vehicle replacement schedule aligns with technology growth. The substantial gap between the typical and intensive scenarios can be attributed to the considerably lower modeled range in the intensive scenario compared to the typical scenario. The actual electrification timeline may deviate from the service forecast if vehicles need to be replaced by BEBs before the necessary technology is available, or if vehicles have not yet reached the end of their useful life.

Figure 4-8. McClellan Garage – Block Completion Forecast (3% Annual Range Growth Rate)

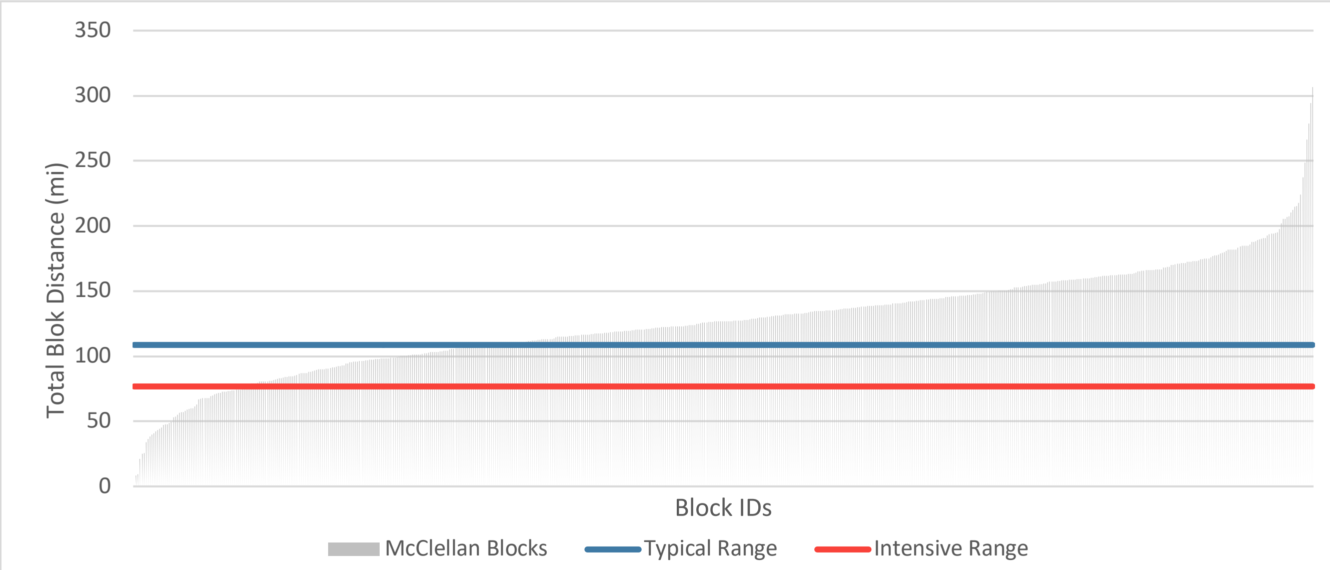


Source: WSP

4.2.2 DEMAND RESPONSE

In March 2023, there were 602 blocks dispatched from the McClellan Garage, with most of them exceeding the modeled electric cutaway range. Approximately 69% of total blocks were longer than the expected typical range of 109 miles, and 91% of the blocks exceeded the expected intensive range of 77 miles. On average, the McClellan Garage's block distance is 127 miles. Figure 4-9 illustrates the comparison between the blocks' lengths and the BEB expected ranges.

Figure 4-9. McClellan Garage – Block Lengths Compared to Modeled BEB Range



Source: WSP

There were 11 to 27 blocks dispatched daily from the McClellan Garage in March 2023. Daily block completion ranged from 8% to 79% in the typical scenario and 0% to 28% in the intensive scenario, depending on the varying daily block length assignments.

In March 2023, the maximum total service miles completed by all vehicles in a single day was 3,211 miles. Assuming the estimated cutaway range, SacRT would need 30-42 electric cutaways to complete the same amount of miles, which means a maximum of four additional vehicles would be required compared to the current fleet, not including spares. Table 4-3 summarizes the daily completion rate for the McClellan Garage.

Table 4-3. McClellan Garage – Demand Response Daily Completion Rate

Number of Blocks (Daily)	Total Number of Vehicles	Typical Scenario Daily Completed Blocks (%)			Intensive Scenario Daily Completed Blocks (%)			Max Total Daily Service Miles	Additional Vehicles Needed	
		Min	Avg	Max	Min	Avg	Max		Typical	Intensive
11-27	38	8%	29%	79%	0%	8%	28%	3,211	0	4

Source: WSP

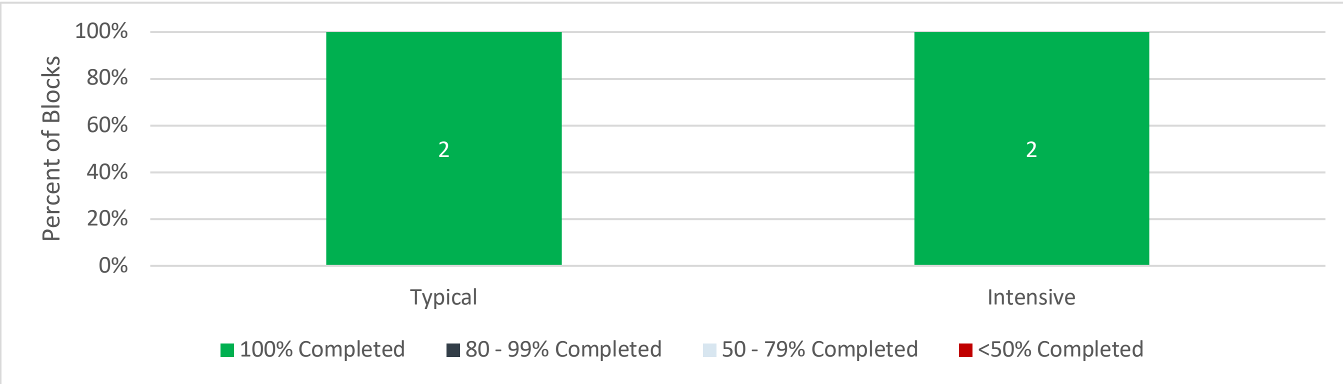
4.3 HAZEL STATION GARAGE

4.3.1 FIXED-ROUTE

The Hazel Station operates fixed-route and the SmaRT Ride micro transit services. The fixed-route service schedule consists of two weekday blocks which serve Route 30, all of which are modeled using electric cutaway specifications.

Both blocks will be able to be fully completed by BEBs in both the typical and intensive scenarios, as shown in Figure 4-10. The blocks are relatively short, with approximately three hours of block duration and 53 miles of block length, which makes them suitable for BEB deployment. See Appendix A for detailed results for each block.

Figure 4-10. Hazel Station Garage – Block Completion Rate



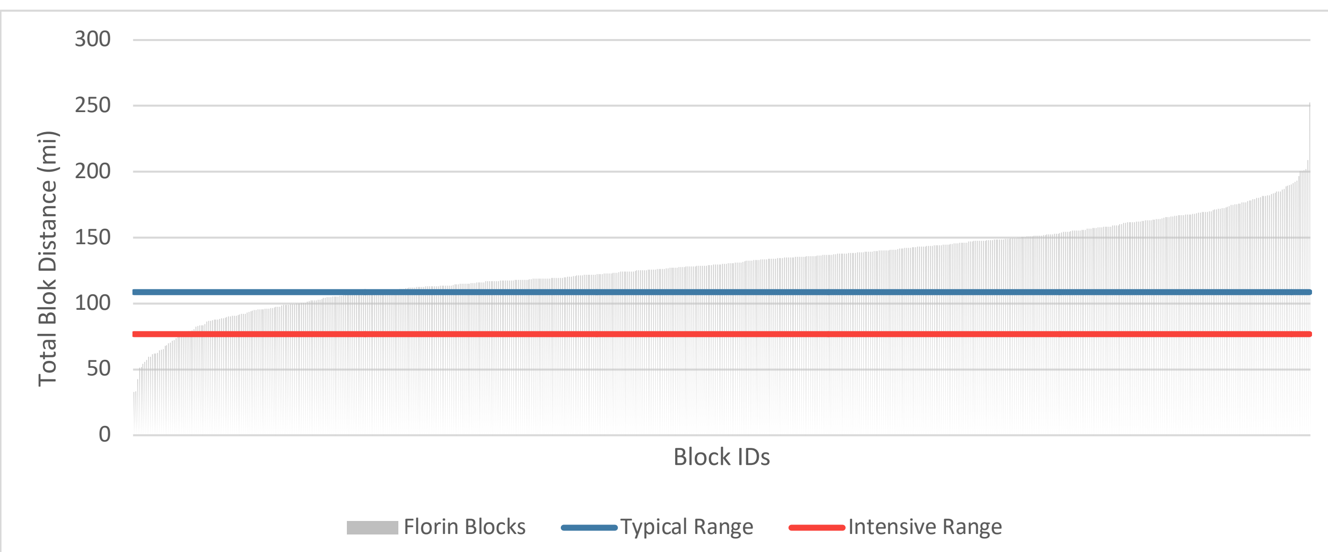
Source WSP

4.4 FLORIN GARAGE

4.4.1 DEMAND RESPONSE

The Florin Garage only operates demand response service. In March 2023, there were 646 blocks dispatched from the Florin Garage, most of which exceeded the modeled electric cutaway range. Approximately 80% of total blocks were longer than the expected typical range of 109 miles, and 96% of the blocks exceeded the expected intensive range of 77 miles. On average, the Florin Garage's block distance is 131 miles. Figure 4-11 illustrates the comparison between the blocks' lengths and the BEB expected ranges.

Figure 4-11. Florin Garage – Block Lengths Compared to Modeled BEB Range



Source: WSP

There were about 24 to 33 blocks dispatched daily from the Florin Garage in March 2023. Daily block completion ranged from 6% to 38% in the typical scenario and 0% to 15% in the intensive scenario, depending on the varying daily block length assignments.

In March 2023, the maximum total service miles completed by all vehicles in a single day was 4,427 miles. Assuming the estimated cutaway range, SacRT would need 41-58 electric cutaways to complete the same amount of miles, which means a maximum of eight additional vehicles would be required compared to the current fleet, not including spares. Table 4-4 summarizes the daily completion rate for the Florin Garage.

Table 4-4. Florin Garage – Demand Response Daily Completion Rate

Number of Blocks (Daily)	Total Number of Vehicles	Typical Scenario Daily Completed Blocks (%)			Intensive Scenario Daily Completed Blocks (%)			Max Total Daily Service Miles	Additional Vehicles Needed	
		Min	Avg	Max	Min	Avg	Max		Typical	Intensive
24-33	50	6%	19%	38%	0%	4%	15%	4,427	0	8

Source: WSP

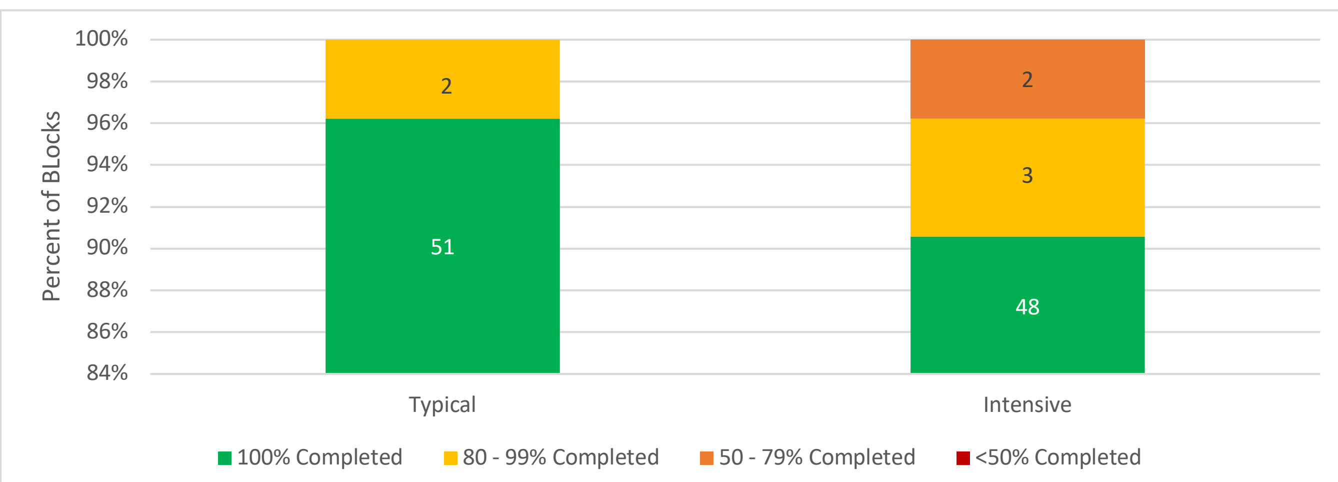
4.5 ELK GROVE GARAGE

4.5.1 FIXED-ROUTE

The service schedule for Elk Grove Garage consists of 53 weekday blocks, all of which are modeled using 40-foot standard BEB specifications.

In the typical scenario, 51 of the 53 weekday blocks (96%) can be completed by BEBs, as shown in Figure 4-12. The two failing blocks (4%) are close to completion, completing at least 80% of their designated courses before failing. The block completion rate decreases in the intensive scenario due to higher HVAC energy consumption. Out of the 53 blocks, 48 (91%) can be fully completed by BEBs, three blocks (6%) fail after completing at least 80% of their courses, and the two remaining blocks (3%) reach 50-79% completion.

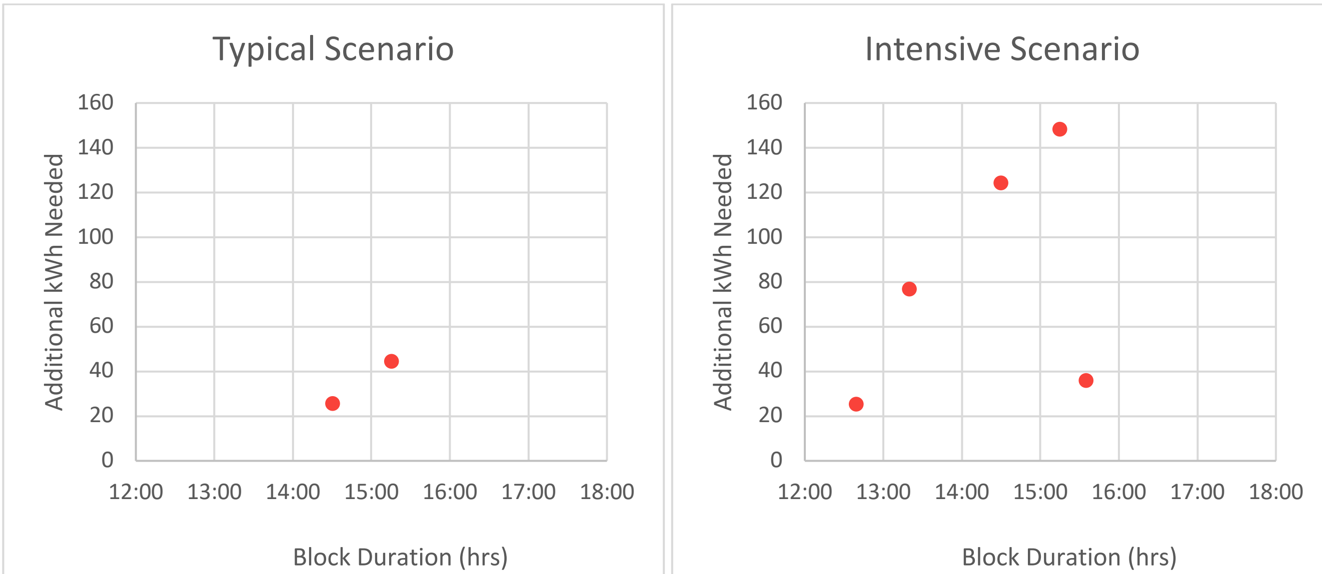
Figure 4-12. Elk Grove Garage - Block Completion Rate



Source WSP

Figure 4-13 illustrates the additional energy needed to complete the failing blocks. In the typical scenario, failing blocks require between 26-45 additional kWh to complete service (6%-10% additional battery capacity per block). Meanwhile, in the intensive scenario, failing blocks require between 26-149 additional kWh to complete service (6%-34% additional battery capacity per block). See Appendix A for detailed results for each block.

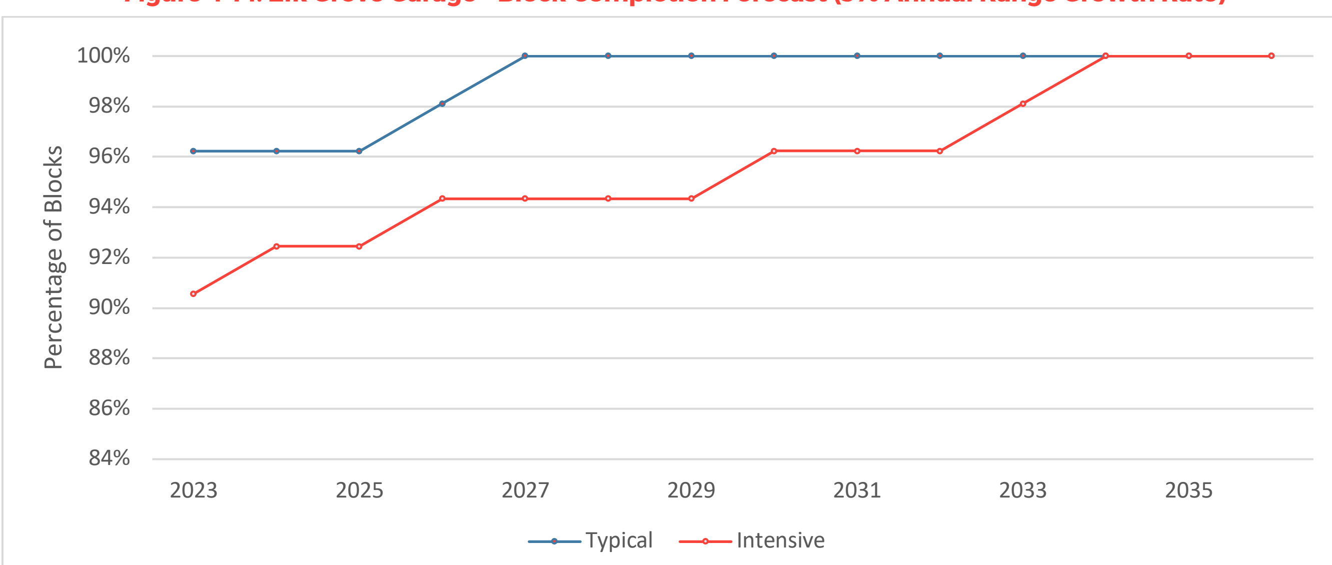
Figure 4-13. Elk Grove Garage - Additional Energy Needed (kWh) to Complete the Failing Blocks



Source: WSP

Figure 4-14 illustrates the projected future block completion, taking into account the anticipated annual technology growth (3%). Under these conditions, all blocks are expected to be electrified by 2027 in the typical scenario and 2034 in the intensive scenario, assuming the vehicle replacement schedule aligns with technology growth. The actual electrification timeline may deviate from the service forecast if vehicles need to be replaced by BEBs before the necessary technology is available, or if vehicles have not yet reached the end of their useful life.

Figure 4-14. Elk Grove Garage – Block Completion Forecast (3% Annual Range Growth Rate)

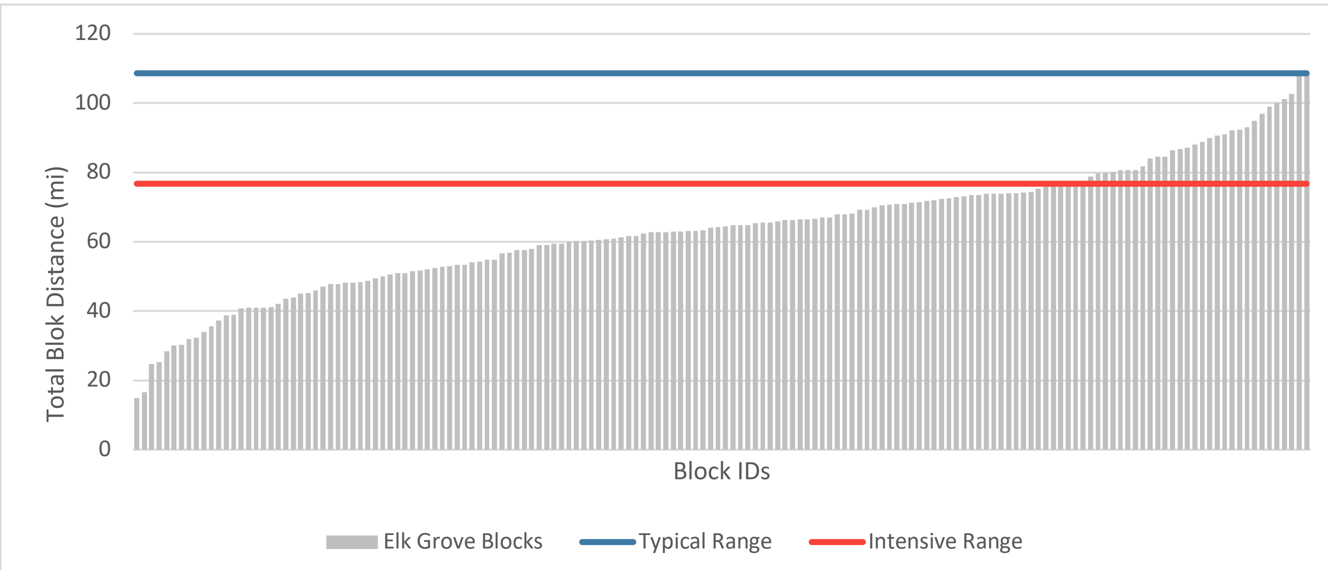


Source: WSP

4.5.2 DEMAND RESPONSE

The Elk Grove Garage operates the eVan demand response service. In March 2023, there were 158 blocks dispatched from the Elk Grove Garage, with most of them within the modeled electric cutaway range. All blocks would be completed with the expected typical range of 109 miles, and only 29% of the blocks would exceed the expected intensive range of 77 miles. On average, the Elk Grove Garage's block distance is 64 miles. Figure 4-15 illustrates the comparison between the blocks' lengths and the BEB expected ranges.

Figure 4-15. Elk Grove Garage – Block Lengths Compared to Modeled BEB Range



Source: WSP

There were about two to seven blocks dispatched daily from the Elk Grove Garage in March 2023. Daily block completion ranged from 100% in the typical scenario and 0% to 100% in the intensive scenario, depending on the varying daily block length assignments.

In March 2023, the maximum total service miles completed by all vehicles in a single day was 486 miles. Assuming the estimated cutaway range, SacRT would need 5-7 electric cutaways to complete the same amount of miles, which means no additional vehicles are needed. Table 4-5 summarizes the daily completion rate for the Elk Grove Garage.

Table 4-5. Elk Grove Garage – Demand Response Daily Completion Rate

Number of Blocks (Daily)	Total Number of Vehicles	Typical Scenario Daily Completed Blocks (%)			Intensive Scenario Daily Completed Blocks (%)			Max Total Daily Service Miles	Additional Vehicles Needed	
		Min	Avg	Max	Min	Avg	Max		Typical	Intensive
2-7	10	100%	100%	100%	0%	81%	100%	486	0	0

Source: WSP

5 CONCLUSION AND NEXT STEPS

The following sections summarize the service modeling analysis findings, explore considerations and strategies to improve range, and outlines the immediate next steps that SacRT should take to continue planning its ZEB transition.

It is important to note that the model's outputs are dependent on its underlying inputs and assumptions and should be used to inform high-level planning. It is strongly recommended that the data from SacRT's eventual operation and experience with BEBs, including energy consumption, performance, pricing, etc., be used to inform future decision-making.

5.1 CONCLUSION

5.1.1 FIXED-ROUTE SERVICE

The modeling results show that the majority of SacRT's service blocks can be completed using existing battery technology. Overall, all blocks can complete at least half of the designated distance with BEBs. The model estimates that current electric cutaway technology will have a range of 77-109 miles, and 40-foot BEBs will have a range of 159-196 miles, depending on the operating scenario. Table 5-1 summarizes the results by garages.

Table 5-1. Summary of Completed Blocks by Garage

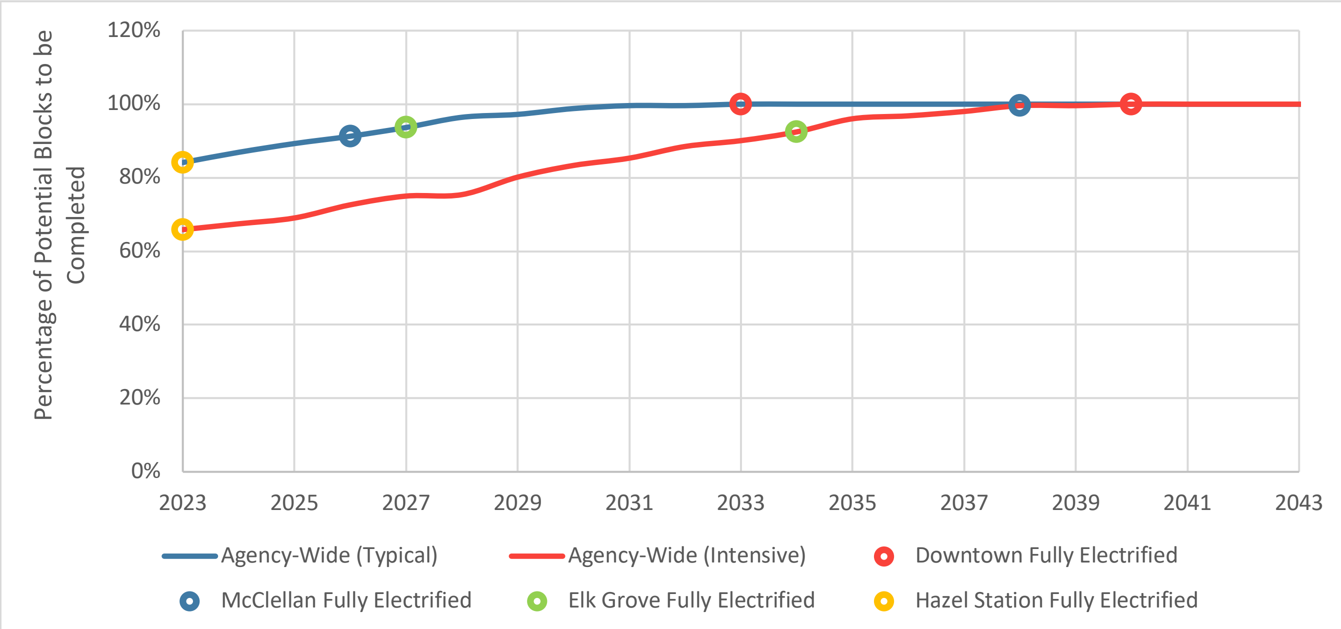
Garage	Day Type	Blocks	Vehicle Type	Blocks Completed	
				Typical	Intensive
Downtown	Weekday	190	40’	155 (82%)	112 (59%)
McClellan	Weekday	7	Cutaway	5 (71%)	0 (0%)
Hazel	Weekday	2	Cutaway	2 (100%)	2 (100%)
Elk Grove	Weekday	53	40’	51 (96%)	48 (91%)

Source: WSP

If the vehicle replacement schedule happens to align with the assumed 3% annual range growth forecast, all garages can be fully electrified by 2033 under the typical scenario, and 2040 under the intensive scenario (without any other mitigation strategies). However, if vehicles need to be replaced by BEBs before the required technology is available, alternative strategies will be required to fully utilize the BEBs (at a 1:1 replacement ratio). Further analysis is needed to confirm the alignment and the necessary steps to ensure a successful transition. Table 5-1 illustrates the agency-wide block completion forecast.

For failing blocks that require a smaller amount of energy to complete service, such as those that require less than 100 additional kWh for 40-foot BEB blocks or less than 25 additional kWh for cutaway blocks, a combination of less capital-intensive strategies is recommended. These may include aligning block transition schedules with the advancement of ZEB technology and utilizing BEBs with better efficiencies and capacities than the ones modeled. More capital-intensive strategies such as service adjustments, opportunity charging, or integration of FCEBs may be explored for blocks that have more demanding range requirements.

Figure 5-1. Agency-Wide Block Completion Forecast (3% Annual Range Growth Rate)



Source: WSP

5.1.2 DEMAND RESPONSE SERVICE

The demand response service analysis compared the modeled expected range of electric cutaways with the actual blocks lengths. The model estimates that current electric cutaway technology will have a range of 109 miles in the typical scenario and 77 miles in the intensive scenario.

The results show that the eVan service (as of March 2023) is well-suited for BEBs. In contrast, most of SacRT Go's blocks present challenges with existing BEB technology. Table 5-2 summarizes the daily block completion findings by garage.

Table 5-2. Demand Response Service and Block Completion Summary

Service	Garage	Number of Blocks (Daily)	Total Number of Vehicles	Average Daily Completed Blocks (%)		Max Total Daily Service Miles	Additional Vehicles Needed	
				Typical	Intensive		Typical	Intensive
SacRT Go	Downtown	10-23	30	20%	6%	3,567	3	17
	McClellan	11-27	38	29%	8%	3,211	0	4
	Florin	24-33	38	19%	4%	4,427	0	8
eVan	Elk Grove	2-7	10	100%	81%	486	0	0

Source: WSP

As SacRT progressively transitions the demand response fleet to BEBs, block assignments will need to be adapted to accommodate vehicle limitations. Longer blocks can be divided and assigned to idle spare vehicles. Additionally, SacRT could consider using one vehicle to complete multiple blocks, provided there is sufficient time for charging between blocks.

To maintain the same level of service, increasing the fleet size may be necessary. Based on the maximum total daily service miles in March 2023, around three additional vehicles would be needed in the typical scenario, while 29 additional vehicles would be required in the intensive scenario. It is crucial to consider that battery technology is expected to continue to advance, which will offer longer range products that are better suited for SacRT's service demands, particularly for the SacRT Go service.

SacRT may also want to consider the deployment of smaller vehicle types, such as electric passenger vans, for demand response services. These vehicles are expected to offer a longer range compared to electric cutaways of the same battery size. At the time of writing, there is a relatively limited selection of electric passenger van models available in the U.S. market, but it's anticipated that the variety will increase over the next few years. The currently available model is advertised as having a range of between 140 and 200 miles. With a Level 2 alternating current (AC) charger, the vehicle can be fully charged in approximately 8.5 hours. A direct current (DC) fast charger can achieve the same in approximately two hours, though actual times may vary based on the charging rate and vehicle's state-of-charge (SOC). If the projection holds true, the extended range of an electric van could potentially enhance the planning and execution of demand response services, offering SacRT increased flexibility and efficiency in future operations.

It is important to highlight that electric vans (for transit) are not subject to CARB ICT regulations but are subject to CARB's Advanced Clean Fleet (ACF) regulation. This separate regulatory framework applies to all vehicles exceeding 8,500 pounds gross vehicle weight rating (GVWR), owned by state and local governments, including passenger vans. As per the ACF guidelines, starting in 2030, all vehicles procured must be either ZE or near-zero emission vehicles (NZEVs), with NZEVs being defined as hybrid-electric vehicles in this context.

5.2 CONSIDERATIONS TO ADRESS RANGE SHORTFALLS

The following sections outline various strategies that can be considered by SacRT to improve block completion rates as it transitions to a 100% BEB fleet.

ENSURE THAT BEBS ARE OPTIMIZED FOR SERVICE REQUIREMENTS

If preferred, SacRT can procure BEBs with larger battery capacities or better fuel economy than the modeled market average. Moreover, the safety buffer can be adjusted as SacRT gains more experience in operating BEBs. It is possible that the modeled 20% safety buffer may not be necessary to address range anxiety. The combination of a larger battery capacity, improved fuel economy, and a smaller safety buffer will lead to longer ranges and enhanced block completion for SacRT service.

It is important to note that some larger batteries are not compatible with fast opportunity charging (with charge rates greater than 300 kW) and can only accept lower charging rates to maintain battery health. The additional battery capacity may also impact the vehicle weight and passenger capacity. Thus, SacRT must ensure that the additional battery capacity does not compromise other required specifications needed to maintain the current level of service.

ALIGN VEHICLE PROCUREMENT WITH EXPECTED TECHNOLOGY GROWTH

Before making service adjustments or investing in capital-intensive strategies such as increasing fleet size and incorporating opportunity charging, SacRT should prioritize deploying BEBs on less demanding service blocks with shorter distances and durations. It's essential to remember that technology is rapidly advancing, and the transition will occur gradually as vehicles are retired/replaced.

If the vehicle replacement schedule happens to align with the assumed 3% annual range growth forecast, all garages can be fully electrified by 2033 in the typical scenario, and 2040 in the intensive scenario (without any other mitigation strategies). However, if vehicles need to be replaced by BEBs before the technology is available, alternative strategies may be required to fully utilize the upcoming BEBs.

Additionally, the CARB ICT regulation requires an increasing proportion of ZEB deliveries, beginning in 2023 for standard buses and in 2026 for cutaways and articulated buses. The ultimate goal is to achieve a fully ZE fleet by 2040. Other mitigation strategies, therefore, may be necessary if SacRT aims to accelerate the transition process to align with the regulation. It is worth noting that SacRT will be able to leverage its existing and future ZEBs (in service) to reduce its overall purchase obligations – as outlined in the CARB ICT regulation. For example, as of March 2023, SacRT operates 18 BEBs, which do not qualify for bonus credits under the regulation but can be counted towards the agency's required BEB procurements in following years.

ADJUST SERVICE TO SUIT BEB LIMITATIONS

Service operations should be reviewed to consider whether the blocks can be modified to better suit BEB operations. For the fixed-route service, splitting blocks would require the bus in service to pull in early and another bus pull out to complete the rest of the block. This strategy increases non-revenue time and demands at least two additional vehicles and operators. SacRT will have to evaluate whether this is a viable option based on resource availability.

The demand response service block assignments will need to be adapted to accommodate vehicle limitations. Longer runs can be divided and assigned to idle spare vehicles. Additionally, SacRT could consider using one vehicle to complete multiple blocks, provided there is sufficient time for charging between blocks. Depending on the trip schedule and location, demand response vehicles can leverage public charging stations during downtime to recharge mid-run, if any are accessible.

INVEST IN CHARGE MANAGEMENT

BEB-tailored service blocking may be optimized by charge management software (CMS). CMS is a digital solution that streamlines BEB charging by creating optimized charging schedules, monitors and controls charging stations, and minimizes energy consumption, thereby improving fleet efficiency and reducing operating costs. CMS can evaluate how many buses are needed to complete service after splitting long blocks – it may be that an additional procurement is not needed, and a bus that completed an AM block and has since recharged at the depot can be pulled out again.

CMS becomes even more critical as charging times for BEBs can vary based on factors such as charging rate, charger configuration, and preferred charging window. Analyzing this information helps determine the optimal charging configurations and identifies the need for additional mitigation strategies to ensure efficient BEB fleet operations.

ASSESS THE NEED FOR OPPORTUNITY CHARGING

Installing opportunity chargers at locations outside of the garages, such as terminals, transit centers, and/or layover sites, will help extend the range of BEBs. However, these strategies will require additional investment in chargers, utility upgrades, land (if necessary), and potentially higher utility rates. If these are being considered by SacRT, a more in-depth analysis should be conducted to assess the timing and most suitable locations for opportunity charging.

CONSIDER FUEL CELL TECHNOLOGY

An alternative ZE technology to BEBs is FCEB technology. FCEBs currently offer longer ranges than BEBs, making them a potential option for blocks that cannot be completed by current BEB technology. Peer transit agencies that operate FCEBs have observed an average range of 280-300 miles comparable to CNG buses.

However, the capital costs for FCEBs and hydrogen fuel costs are typically higher than those for BEBs and electricity. FCEBs also only represent approximately 4% of the standard BEB market and there are currently no cutaway OEMs, deeming them not suitable for the demand response services. Additionally, on-site hydrogen fueling stations require a significant footprint due to the necessary safety setbacks. Further analysis is necessary to evaluate the trade-offs of adopting FCEBs and other mitigation strategies.

5.3 NEXT STEPS

Based on the modeling results and considerations outlined in the previous sections, it is recommended that the following steps are taken to further SacRT's ZE goals:

- **Identify and confirm SacRT's future garage locations.** Based on the *Facilities Master Plan Report* (2022), SacRT is still in the process of identifying and acquiring sites for future garages. Once these sites are confirmed, more in-depth planning for the future ZEB fleet can proceed.
- **Develop a comprehensive ZEB Master Plan.** Once sites are confirmed, SacRT should develop a comprehensive plan that includes a garage construction and phasing schedule informed by SMUD design and construction durations, SacRT procurement requirements and protocols, and other required processes. The facility construction timeline will be used to determine when garages are capable of accepting BEBs, which ultimately informs the required (and forecasted) BEB ranges. This plan will also provide the framework for competitive grants, such as the Federal Transit Administration's Low or No Emission Vehicle Program, to assist with funding the implementation of the plan.
- **Periodically refine the service modeling analysis and align the results with facility construction timeline, vehicle replacement plan, regulations, and projected technology growth.** With the rapid and uncertain changes in ZE technology and service requirements, it is essential that SacRT continually assesses service in relation to the elements noted above. This will help to ensure that SacRT is transitioning in the most time- and cost-efficient manner. Considering that battery technology, in particular, will continue to improve, it is safe to assume that BEBs will come closer to parity with ICEBs over the coming decades. Therefore, modeling results today will present a bleaker future than tomorrow. Periodically revisiting modeling results will enable SacRT to evaluate the most viable solutions to address range shortfalls (within the context of time), such as costs and benefits analysis of adopting FCEBs, installing opportunity chargers, or adjusting service. As previously indicated, SacRT is currently undertaking a FCEB feasibility study, which is expected to enhance the understanding of potential mitigation strategies to be considered in future report iterations.