PEER
Route Analysis & Modeling on the Whatcom Transportation Authority (WTA) Blocks and Routes

WTA Contract Number: 2021-260

Task Order: WTA Zero Emissions Transition Study

PEER Route Analysis & Modeling

Report Prepared for:

Whatcom Transportation Authority (WTA)

May 31, 2023

Revised: July 11, 2023

Revisions

Revision	Issued Date	Affected Pages	Description of Modifications
0	5/31/2023	N/A	Initial Release
1	7/11/2023	12	Added “crosswalk” table to key GTFS BlockID values to WTA block ID values.

Contents

Table of Figures

List of Tables

Definitions

Ambient Temperature*:* The temperature of the surrounding air. For testing purposes, ambient temperature shall be as defined in the Operating Environment.

Desired Temperature*:* The average desired interior temperature of an operating bus.

Operating Environment: The allowable temperature, humidity, rainfall, wind velocity, and the duration of sunshine within the locale in which a bus operates.

State of Charge (SOC): Quantity of electric energy remaining in a battery relative to the maximum rated amp-hour (Ah) capacity of the battery, expressed as a percentage (0% = empty; 100%=full). This is a dynamic measurement used for the energy storage system. A full SOC indicates that the energy storage system cannot accept further charging from the regenerative braking system.

GTFS: Data Specification that allows public transit agencies to publish their transit data in a format that can be consumed by a wide variety of software applications.

Abbreviations

APC: Automatic Passenger Counting

BEB: Battery Electric Bus

BMS: Battery Management System

CMS: Charge Management System

DFAH: Diesel-Fueled Auxiliary Heater

FCEB: Fuel Cell Electric Bus

GTFS: General Transit Feed Specification.

ICE: Internal Combustion Engine

MOAB: Maintenance, Operations, and Administration Building (i.e., WTA's main operating depot)

OEM: Original Equipment Manufacturer

PEER: Performance & Evaluation of Electric Bus Routes

SOC: State of Charge

ZEB: Zero-Emission Bus

1. EXECUTIVE SUMMARY

STV Incorporated (STV) and Transpo Group were tasked by the Whatcom Transportation Authority (WTA), of Bellingham, WA, to prepare a Zero Emissions Fleet Transition Study to map the process for the eventual conversion of the agency's current conventional diesel and hybrid-electric bus fleet to a 100% zero emissions bus fleet. As part of this study STV conducted a Performance and Evaluation of Electric Bus Routes (PEER) Analysis and Modeling simulation. This simulation was done on all existing weekday transit service blocks as if an all battery-electric bus (BEB) fleet were to be deployed. Since a fuel cell electric bus (FCEB) operates similarly to a BEB (in that it is propelled with a high-voltage electric drive system), the simulation results can be easily interpreted by adjusting how much energy is stored on board the vehicle.

The STV team analyzed WTA's routes, the bus specifications, and performed simulations for said buses (at different ambient temperatures) to provide a comparison of energy consumptions, block completions, and remaining State of Charge (SOC) values while the buses operate over the existing service schedules. In addition, using the PEER results the STV team determined the power requirements to recharge BEBs at the WTA's Maintenance, Operations, and Administration Building (MOAB). STV's team further analyzed the incompletable blocks, at a Route level, and provided further feedback as to how the Routes can be optimized to achieve close to 100% completion of the blocks.

Key Findings

Table 1 provides a quick overview of the block completion percentages for operations from the MOAB, under four different ambient temperatures, using the specifications of a Gillig 40-ft transit bus equipped with a new 588 kWh (nominal/advertised) battery. The different ambient temperatures were chosen to reflect what is experienced by the WTA throughout the year in its service area.

TABLE 1: ALL DEPOTS BLOCK COMPLETABILITY, CURRENT BATTERY, GILLIG 40'

Depot	Completability (11°F)	Completability (41°F)	Completability (59°F)	Completability (91°F)
MOAB	67%	81%	90%	89%

From the above table it is evident that the best completability results are in the simulations performed at 59°F. This is due to that ambient temperature causing the least amount of power load being drawn by the HVAC system, which results in having more energy available to drive the bus. Conversely, the worst completability results are in simulations performed at 11°F. This is mainly due to the high heating load drawn by the HVAC system (without a diesel-fueled auxiliary heater (DFAH)) to keep the internal bus temperature at a comfortable level for the passengers.

Throughout the remainder of this report more emphasis will be put on the analyses at 41°F. To reduce the electrical load drawn by the HVAC system during winter operations, BEBs are often equipped with DFAHs, which are programmed to turn on only when the ambient temperature is below 41°F. DFAHs are further explained in section 2.4.

Table 2 details the battery recharging power load estimates for the MOAB. These estimates assume winter condition BEB operations (for BEBs equipped with DFAHs) and current and future battery technologies with <u>service</u> capacities of 470 kWh and 640 kWh, respectively (refer to Section 2.2 for further explanation of "service capacity"). The power load requirements were calculated for three different scenarios. The first scenario is the power required to recharge only the completable-blocks sub-fleet, based on the calculations made above, for BEBs using current technology batteries. The second scenario is the power required to recharge the entire fleet of BEBs if the schedule was re-blocked such that all blocks become completable. The third scenario is the power required to recharge an entire fleet of BEBs with re-blocked schedule, but which use future battery technologies.

TABLE 2: OVERVIEW OF DEPOT POWER LOAD REQUIREMENTS

Depot	Current, Completable Fleet Power Requirements (kW)	Current, Entire Fleet (w/ Re-blocking) Power Requirements (kW)	Future, Entire Fleet (w/ Re-blocking) Power Requirements (kW)
MOAB	910	1,430	1,560

2. ASSUMPTIONS

The PEER model simulates a current-production BEB model to see if it has sufficient operating range to complete each of the blocks in WTA's current service schedule. Inputs consist of GTFS data (supplied by WTA), bus-specific information from the bus's original equipment manufacturer (OEM), and variables selected by the STV team, as listed below:

- Elevation and location of each bus stop
- Passenger loading information
- Four different ambient temperature profiles
    - 91°F ambient temperature for summer operation
    - 59°F ambient temperature for typical spring/fall operations
    - 41°F ambient temperature to simulate winter operation with a DFAH
    - 11°F ambient temperature to simulate winter operation without a DFAH
- 68°F as the interior desired temperature
- Technical data of a Gillig 40-foot EBUS
- GTFS data files for current schedules, blocks, routes, and operating environments, as well as supplementary data indicating block lengths and deadhead distances.
- New, Degraded, and estimated Future battery energy capacities.

2.1 Bus Types Considered

Since WTA's fixed-route bus fleet consists predominantly of 40-ft buses manufactured by Gillig, and that the WTA may continue purchasing buses from Gillig, the Gillig EBUS specification (with 588 kWh nominal battery storage, which went into production in April 2023) was used for the simulations. Other BEB OEM models may also be simulated upon request. Gillig also offers a 686-kWh battery capacity option, but the extra weight of the additional batteries would cause the bus to exceed Washington state's commercial vehicle axle weight limit.

2.2 Battery Technologies and Capacity

The nominal battery capacity referenced in this report is the advertised battery capacity as offered currently by the OEM on the market. The term, "Service Energy," is used to describe the amount of energy that can practically be used regularly. Just like nominal battery capacity, Service Energy is expressed in kWh, but its value is significantly lower because not all the battery capacity can be (or should be) used daily. The industry standard reduction for usable service energy is 20%. *Figure 1* illustrates the usable energy in the Gillig EBUS 588 kWh battery.

This graph also compares the Service Energy of a new battery to that of a degraded battery. Degradation of the battery "removes" an additional 20% of available battery energy. This reduction happens over about six years, but the rate and degree to which the battery degrades is largely dependent on how much stress the battery undergoes in use and charging.

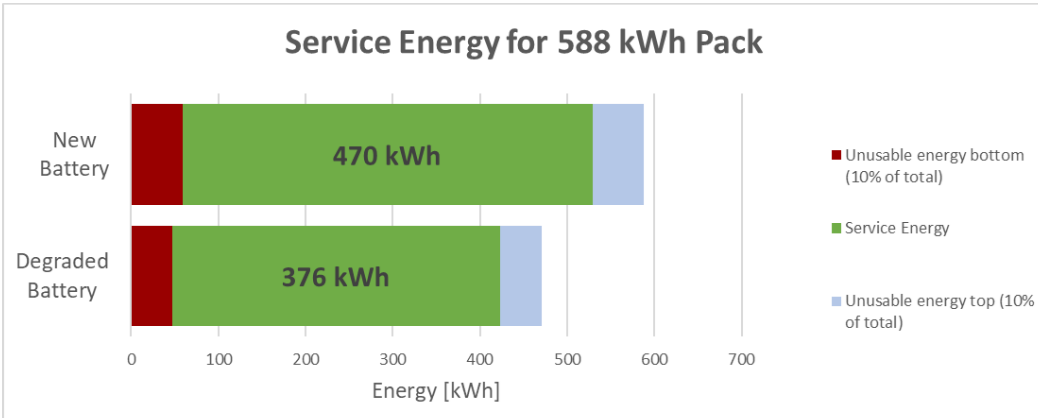

FIGURE 1: REPRESENTATION OF REGULARLY USABLE ENERGY FOR A GILLIG 40-FT BEB

For comparison reference, the Table 3 shows the currently available (as of April 2023) and advertised nominal battery capacities from various bus OEMs.

TABLE 3: MANUFACTURERS BATTERY CAPACITIES PER BUS LENGTH

Manufacturer	Model	Length (ft)	Nominal Battery Capacity (kWh)
ENC	Axess EVO-BE	32, 35, 40	492 (32'), 738 (35', 40')
Gillig	EBUS	35, 40	490, 588, 686
New Flyer	Xcelsior Charge NG	35	345, 435
		40	345, 435, 520
		60	520
Nova Bus	LFSE+	40	564
Proterra	ZX5+	35, 40	492
	ZX5 MAX	40	738

Batteries are assumed to continue to have future improvements in energy density. To account for this, the simulation analysis assumes that batteries will be capable of storing 36% additional energy in the future, while maintaining the same weight. Table 4 shows the future battery capacity and service energy that was used in this analysis, taking into consideration the 20% unusable energy, as well as 20% battery degradation.

TABLE 4: FUTURE BATTERY CAPACITY VS. SERVICE ENERGY

Bus Type	Battery Capacity New Battery (kWh)	% Unusable	Service Energy New Battery (kWh)	Battery Capacity Degraded Battery (kWh)
40-ft BEB	800	20	640	512

Energy Capacity of a FCEB

In a FCEB the drive energy is stored on the vehicle in the form of gaseous hydrogen, inside reinforced cylindrical tank assemblies. The hydrogen is drawn by the fuel cell, which converts it to electricity. With current hydrogen storage tank system technology, the electrical equivalent of a full load of hydrogen fuel on a bus equates to about 1,000 kWh of service "battery" capacity. FCEBs are described in more detail in Section 5.3.

2.3 Temperature Historical Data

The PEER simulation tool uses the historical ambient temperatures for the WTA service region, and desired bus interior temperature, as inputs to calculate the total vehicle energy requirement.

Table 5 summarizes the selected ambient temperatures used for this PEER analysis, per historical weather data from the WTA service region. A high ambient temperature of 91°F was used in the simulations as a worst-case scenario for the needs of cooling the bus interior. Conversely, a low ambient temperature of 11°F was used as a worst-case scenario for the needs of heating the bus interior. Even though these are considered extreme temperatures for the WTA region, it's important to know the operating range of the bus on the most extreme days, since that will dictate whether the bus can be used reliably throughout the year. It should be noted that by using these values the simulation therefore has a built-in safety factor, since in the winter the simulation will assume the temperature of 11°F for the entire day, which often won't be the case. On a typical day, the temperature will rise and fall with the sun creating times where the heater won't have to work as hard. In short, by selecting this worst-case temperature, the simulation is inherently conservative.

TABLE 5: SEASONAL AVERAGE TEMPERATURE VALUES

Temperature Description	Temperature Value
Avg. Summer Temperature	91°F
Avg. Spring Temperature	59°F
Avg. Winter Temperature	11°F
Avg. Winter Temperature (DFAH)	41°F

2.4 Use of Diesel Fueled Auxiliary Heaters

Winter bus operations have unique requirements in that the buses must deal with navigating through occasional snow and ice as well as maintain customer comfort by heating the bus interior. With legacy bus propulsion configurations, the abundance of waste heat available from the internal combustion engine means that the interior heating requirement is of little problem. With the advent of 100% electric propulsion, the energy to heat a BEB's passenger space must be drawn from the BEB's high-voltage battery. This results in a substantial decrease in the driving range of the BEB when compared to its driving range during summertime operations.

The interior of the bus is heated by way of a fluid mixture of water and ethylene glycol (or, water mixed with propylene glycol, a.k.a. antifreeze or engine coolant), which is heated and circulated through the heating system's heat exchangers by electric pumps. Air is then either blown across heat exchangers by electric-driven fans, inside rear-mounted or roof-mounted HVAC units, and/or by the air naturally moving across low-mounted wall-side heat exchangers.

In a conventional diesel bus this fluid is heated by waste combustion heat from the engine as the fluid circulates through the engine block before it is routed through the bus's heating system. With the advent of lower emissions clean-diesel engines their waste heat rejection was reduced, which resulted in the need to add diesel fueled auxiliary heaters (DFAHs) to augment the engine waste heat in service locations with severely cold winter conditions. Such heaters operate like a conventional household water heater that uses natural gas, kerosene, fuel oil, or propane to heat the water inside the tank.

In a BEB this fluid must be heated by an electric heater, much like an electric household water heater uses electricity to heat its water via a resistive element/coil. However, the amount of energy to heat the fluid in this way is significant and robs energy from the battery pack that could otherwise be used to propel the bus. The driving range reduction could be as high as 50%, pending the operating conditions, and could render some service blocks incompletable that are otherwise completable in moderate temperature operating conditions.

Therefore, DFAHs are commonly employed on BEBs which operate in service locations with cold winter weather. In BEBs so equipped, DFAHs typically are installed in tandem with electric fluid heaters.

For a BEB equipped with both types of fluid heaters, electric and diesel-fueled, the electric heater is generally used in ambient temperatures at or above 41°F. The DFAH is then used only when the ambient temperature drops below 41°F. Because of this, a BEB with a DFAH will consume more battery energy at 41°F than it would below 41°F – when the DFAH takes over from the electric heater.

The use of DFAHs changes the outcome of the BEB operational simulations. Therefore, the analysis in this report accounts for two winter operating scenarios. The first scenario is a bus which is not equipped with a DFAH. This scenario's simulation is run at a minimum winter ambient temperature, 11°F. The simulation at this temperature is intended to show the relative importance of using a DFAH, and the viability of eliminating it in the future as battery technology improves.

The second winter operating simulation scenario is run at 41°F, to capture the worst electrical energy consumption that a bus will experience when it is equipped with a DFAH. This scenario is more realistic for the near-term and the current level of battery energy capacity, since DFAHs will almost certainly be used to increase the range during the winter. It's important to note that even though the simulation is run at 41°F for this scenario, the results remain valid for temperatures down to 11°F (or below) because at those lower temperatures the interior heat needed will be provided by the DFAH and will not increase the electrical load on the battery.

2.5 Block Combinations

The analysis of block completion assumes that one bus is completing one block per day. However, this may not reflect how WTA operates its blocks. One way to better reflect WTA's operation, and to optimize a BEB fleet, is to combine blocks such that a single BEB completes more than one block per day.

To conduct this analysis, blocks were combined based on the availability of each bus at the end of an existing block. The analysis described below (next paragraph) examines if an early block in the day can be combined with a later block in the day based on the later block's mileage, energy consumption, start time, and end time. Additionally, the analysis assumes that (1) there will be a 2-hour minimum time between blocks, (2) the bus will be charging at a 130-kW rate at the depot when waiting for the next block, and (3) that there is a 30-minute delay before charging begins. The analysis model considers the maximum battery capacity of the BEB does not charge over that capacity when blocks were combined. Finally, the analysis does not combine blocks that could not be completed with the selected battery condition.

For example, consider a 40-ft bus, with a new, 470 kWh service energy battery, that leaves the MOAB at 9:00 am on Block 1. When it returns at 11:00 am it has depleted half of its energy, or 235 kWh. While the bus is waiting, it will begin charging at 11:30 am and will continue to charge until the next block starts, or until the battery gets fully charged. Block 2 begins at 1:30 pm, returns at 5 pm, and requires 330 kWh of energy to complete that block. Since the bus from Block 1 was charging at the depot, it was able to recharge the energy lost during Block 1, and now it has 470 kWh of service energy to run Block 2. Since Block 2 meets the requirements listed above, the analysis can combine those two blocks together.

The analysis continues to assign additional blocks to a bus in a similar manner until there are no blocks that could be completed with the remaining energy in the battery, or there are no more blocks left in the day. No additional assumptions, such as available driver work hours, were made in this analysis.

3. SIMULATION RESULTS

As described in the executive summary, the PEER model predicts how well BEBs can complete daily blocks under different operating scenarios. A block is considered completed if a BEB has sufficient stored battery power to leave its home operations facility, travel to its starting point, complete all assigned work, and return to its home operations facility. All the blocks from the MOAB were analyzed.

For this report, most modeled runs were conducted simulating winter conditions, when battery energy-draw loads are at their highest via significant, electrically based interior heating. Differentiations from these conditions are noted in each section.

3.1 Block and Range Analysis - New Battery

Table 6 shows the results of the PEER simulation system-wide, using WTA's September 2021 weekday block schedule and buses operating from the MOAB. The table shows the number and percentage of WTA's existing weekday block assignments that could be completed with a Gillig 40-ft BEB with a new battery under different temperatures, as stated previously.

TABLE 6: WTA BLOCK COMPLETION SUMMARY FOR 40-FT BUS, NEW BATTERY

Temperature	Number of Blocks	Blocks Completable	Completion Percentage
11°F (Winter w/o DFAH)	72	48	67%
41°F (Winter w/ DFAH)	72	58	81%
59°F (Spring/Fall)	72	65	90%
91°F (Summer)	72	64	89%

As seen above in the table, the best completability is observed during Spring/Fall temperatures, due to the lower amount of load on the HVAC system, which is a high energy consuming system. Conversely, the worst completability can be seen during peak Winter temperatures due the high demands of the HVAC system on the battery.

Figure 2 shows a representation of every block operating from the MOAB and their completion with each BEB using a DFAH, running in winter. This graph takes into consideration the battery capacity of the bus as well as the 20% unusable portion of the battery. Every horizontal bar on this graph represents a block. The benefit of this graph is the ability to easily see how close various blocks are to completability, and how many buses would be needed to complete the current schedule.

The x-axis is mileage. The blue segments of each bar represent miles traveled on the blocks. The red segments indicate the additional energy (in miles) needed to complete the block (if that block cannot be completed), and the green segments indicate unused energy for a block that could be completed. Due to the length and power requirements of certain blocks, many are unable to be completed with current battery technology.

The driving range (in miles) of a BEB depends on multiple factors, such as passenger loading, ambient temperature, service route, and driver habits. For example, additional passenger loading will increase the weight of the bus, thus requiring more energy for the bus to move. More passengers will also change the energy used by the HVAC. Temperature, as previously discussed, will greatly influence the HVAC energy consumption. The route the BEB travels on can also impact a BEB's energy consumption, depending on traffic conditions, average speed, and topography. The driver of the BEB can also influence the energy consumption rate, depending on how aggressive the driver handles accelerating and braking. Table 7 highlights how the temperature influences the range of a BEB, using the four temperatures previously identified.

TABLE 7: WTA SERVICE RANGE FOR 40-FT BUS, NEW BATTERY

Temperature	Minimum Range (miles)	Maximum Range (miles)
11° F (Winter w/o DFAH)	119.15	189.39
41°F (Winter w/ DFAH)	156.82	227.27
59°F (Spring/Fall)	193.52	261.77
91°F (Summer)	184.55	254.29

3.2 Block IDs vs. Block Names

The route analysis utilizes the "BlockID" data from the GTFS files. Following is a key to help interpret the GTFS BlockID values to WTA's values (Figures 2 through 5, 8, and the 4 figures in the Appendix).

GTFS	WTA		GTFS	WTA		GTFS	WTA		GTFS	WTA
102	1-1		2302	SH:A-1		4202	72X-2		6002	FF-4
402	108-1		2402	SH:B-1		4302	75-2		6102	232-4
502	FF-1		2502	SH:C-1		4402	80X-2		6202	Rngr-4
702	Cascade-1		2602	SH:D-1		4502	SH:A-2		6302	331-4
802	232-1		2702	SH:X-1		4602	SH:B-2		6402	71X-4
902	WM-1		2802	75-11		4702	SH:C-2		6502	72X-4
1102	29-1		2902	75-12		4802	SH:D-2		6602	75-4
1202	Rngr-1		3002	75-13		4902	SH:X-2		6702	232-5
1302	331-1		3102	1-1		5002	FF-3		6802	331-5
1402	Triad-1		3202	FF-2		5102	Cascade-2		6902	71X-5
1502	50-1		3402	72X-8		5202	232-3		7002	72X-5
1602	512-1		3502	232-2		5302	Rngr-3		7102	75-5
1702	525-1		3602	WM-2		5402	331-3		7202	72X-6
1802	LV-1		3702	Rngr-2		5502	Triad-3		7302	75-6
1902	71X-1		3802	331-2		5602	71X-3		7402	72X-7
2002	72X-1		3902	Triad-2		5702	72X-3		7502	75-7/8
2102	75-1		4002	LV-2		5802	75-3		7602	75-9
2202	80X-1		4102	71X-2		5902	80X-3		7702	75-10

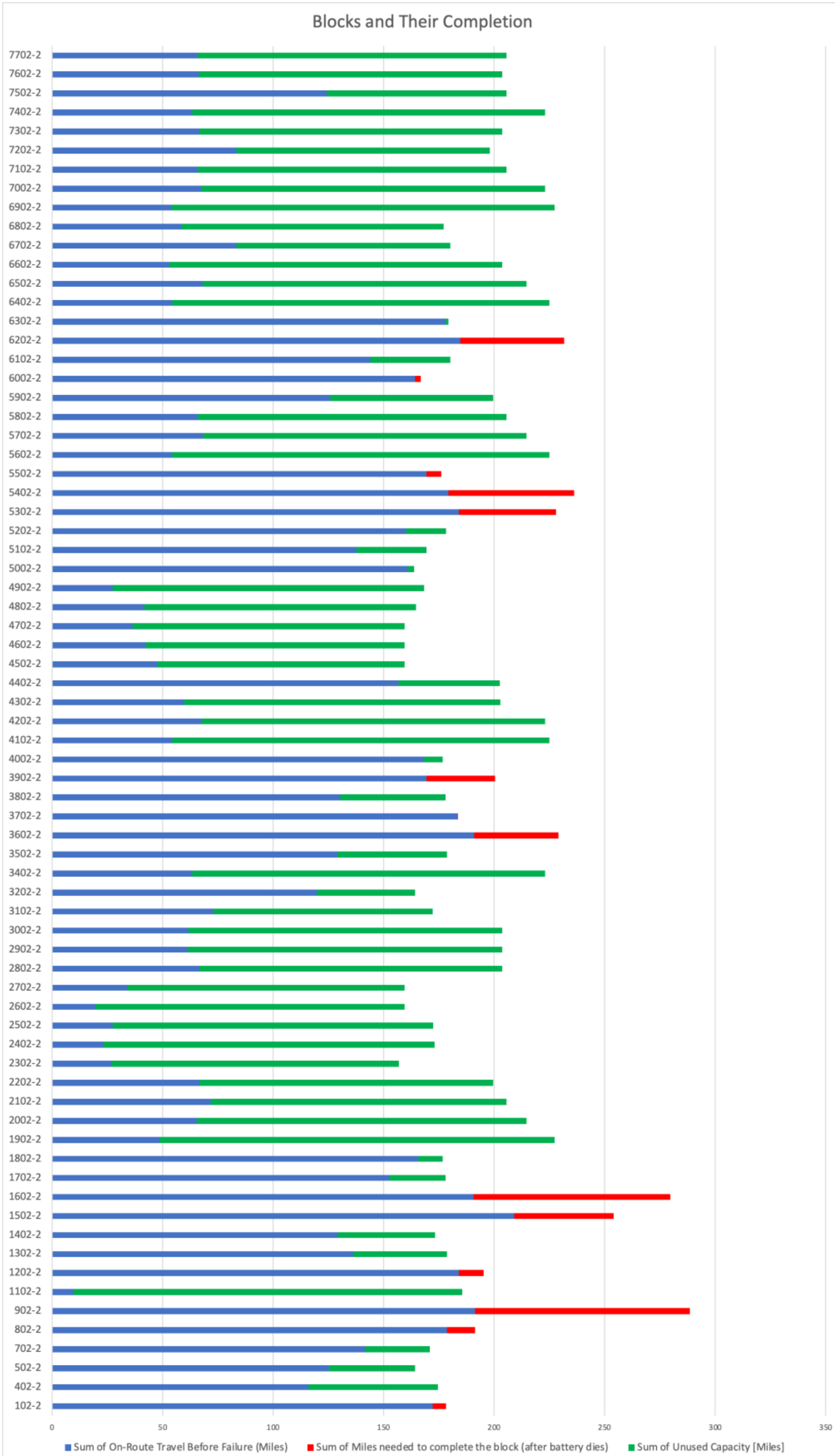

FIGURE 2: WTA BLOCK COMPLETION FOR ALL BLOCKS USING 40-FT BUS AT 41°F, WITH DFAH – NEW BATTERY

3.3 Block and Range Analysis - Degraded Battery

Table 8 is like the one identified in Section 3.1 (Table 7), which shows the results of the PEER simulation system-wide, but with the exception of using a degraded battery. As shown, when the battery is degraded to the industry standard of 20% (as described in Section 2.2), the amount of incompletable blocks increases. The behavior relative to ambient temperature is the same as identified earlier, where the performance is worst at the lowest winter temperatures but is optimal at Spring/Fall temperatures.

Figure 3 is like Figure 2, above, but with a degraded battery capacity

TABLE 8: WTA BLOCK COMPLETION SUMMARY FOR 40-FT BUS, DEGRADED BATTERY

Temperature	Number of Blocks	Blocks Completable	Completion Percentage
11°F (Winter w/o DFAH)	72	41	57%
41°F (Winter w/ DFAH)	72	50	69%
59°F (Spring/Fall)	72	57	79%
91°F (Summer)	72	54	75%

As previously mentioned, the driving range (in miles) of a BEB can be influenced by several factors. Table 9, below, highlights the BEB's range for the four temperatures that were simulated.

TABLE 9: WTA SERVICE RANGE FOR 40-FT BUS, DEGRADED BATTERY

Temperature	Minimum Range (Miles)	Maximum Range (Miles)
11°F (Winter w/o DFAH)	95.32	151.51
41°F (Winter w/ DFAH)	125.46	181.82
59°F (Spring/Fall)	154.82	209.42
91°F (Summer)	147.64	203.43

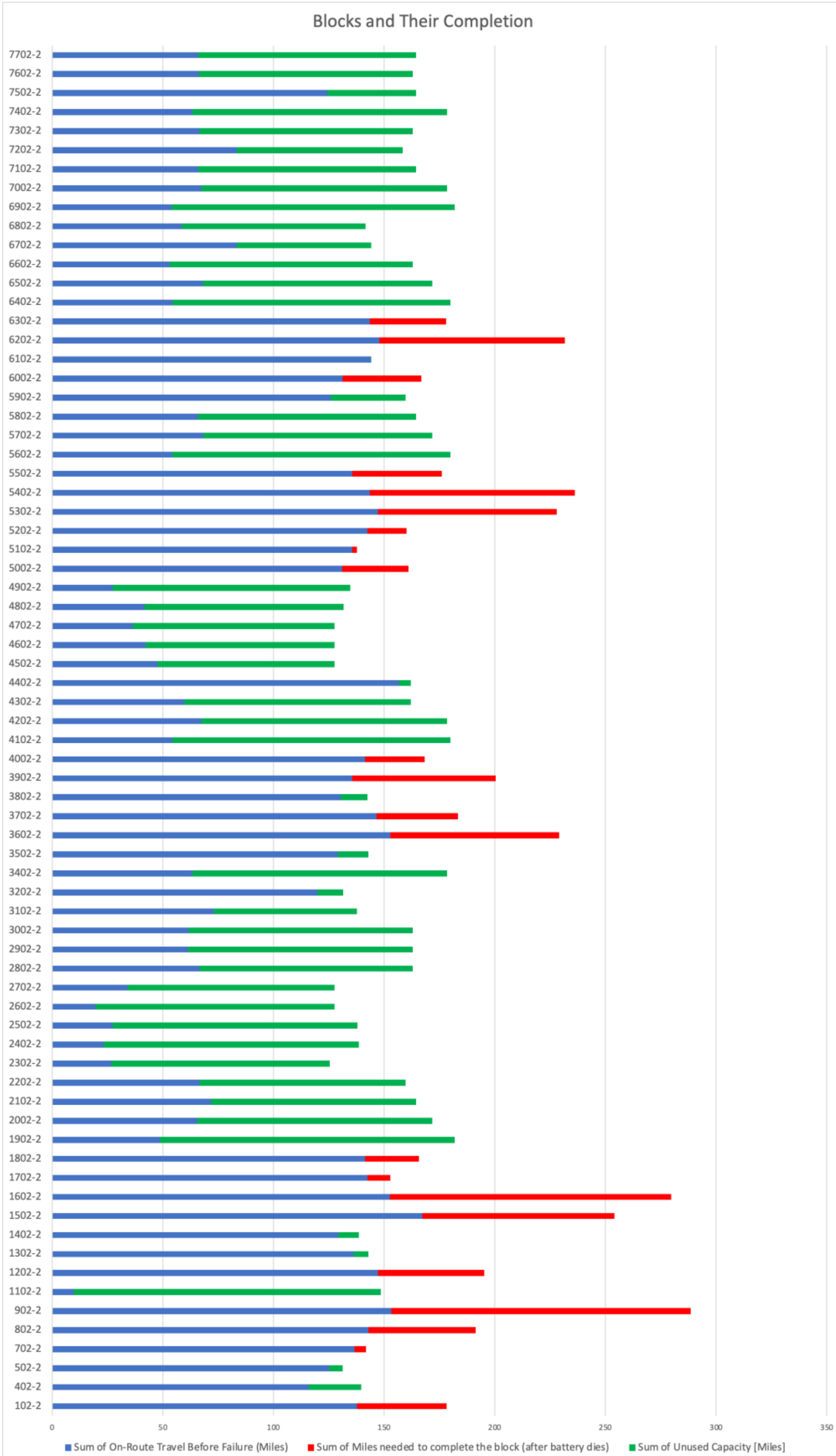

FIGURE 3: WTA BLOCK COMPLETION FOR ALL BLOCKS USING 40-FT BUS AT 41°F, WITH DFAH – DEGRADED BATTERY

3.4 Future Battery Technology

Table 10 shows the results of the PEER simulation system-wide, but with the utilization of future battery technology, as described in Section 2.2.

TABLE 10: WTA BLOCK COMPLETION SUMMARY FOR 40-FT BUS, FUTURE BATTERY

Temperature	Number of Blocks	Blocks Completable	Completion Percentage
11°F (Winter w/o DFAH)	72	62	86%
41°F (Winter w/ DFAH)	72	70	97%
59°F (Spring/Fall)	72	72	100%
91°F (Summer)	72	72	100%

As shown, block completion is significantly improved due to the increased battery capacity, with 100% completion in the Spring/Fall and Summer ambient conditions. As battery technology improves, some of the more strenuous and incompletable blocks will be able to be completed, and more blocks might be combined due to more available energy.

Table 11 identifies the lowest and highest possible ranges associated with the similar temperature ranges.

TABLE 11: WTA SERVICE RANGE FOR 40-FT BUS, FUTURE BATTERY

Temperature	Minimum Range (Miles)	Maximum Range (Miles)
11°F (Winter w/o DFAH)	202	316
41°F (Winter w/ DFAH)	266	386
59°F (Spring/Fall)	329	445
91°F (Summer)	313	432

3.5 Block Combination Analysis

From the rationale presented in Section 2.5, the blocks from the MOAB were combined based on the availability and charge status of each bus at the end of an existing block. The analysis shown in *Figure 4* examines if some early blocks could be combined with later blocks based on mileage, energy consumption, start time, and end time. Blocks that were incompletable are still included in the total number of weekday block combinations.

These graphs show the number and duration of the weekday blocks from the MOAB. The figure on the left is the schedule from the as-received GTFS data. The figure on the right is the combined block schedule. In both figures, with the bar segment color schemes defined earlier for the blue and red being the same, the new, yellow segments represent time at the depot, when the bus can receive a mid-day boost charge.

The figures were generated for winter conditions with the BEBs using DFAHs and operating with a degraded battery.

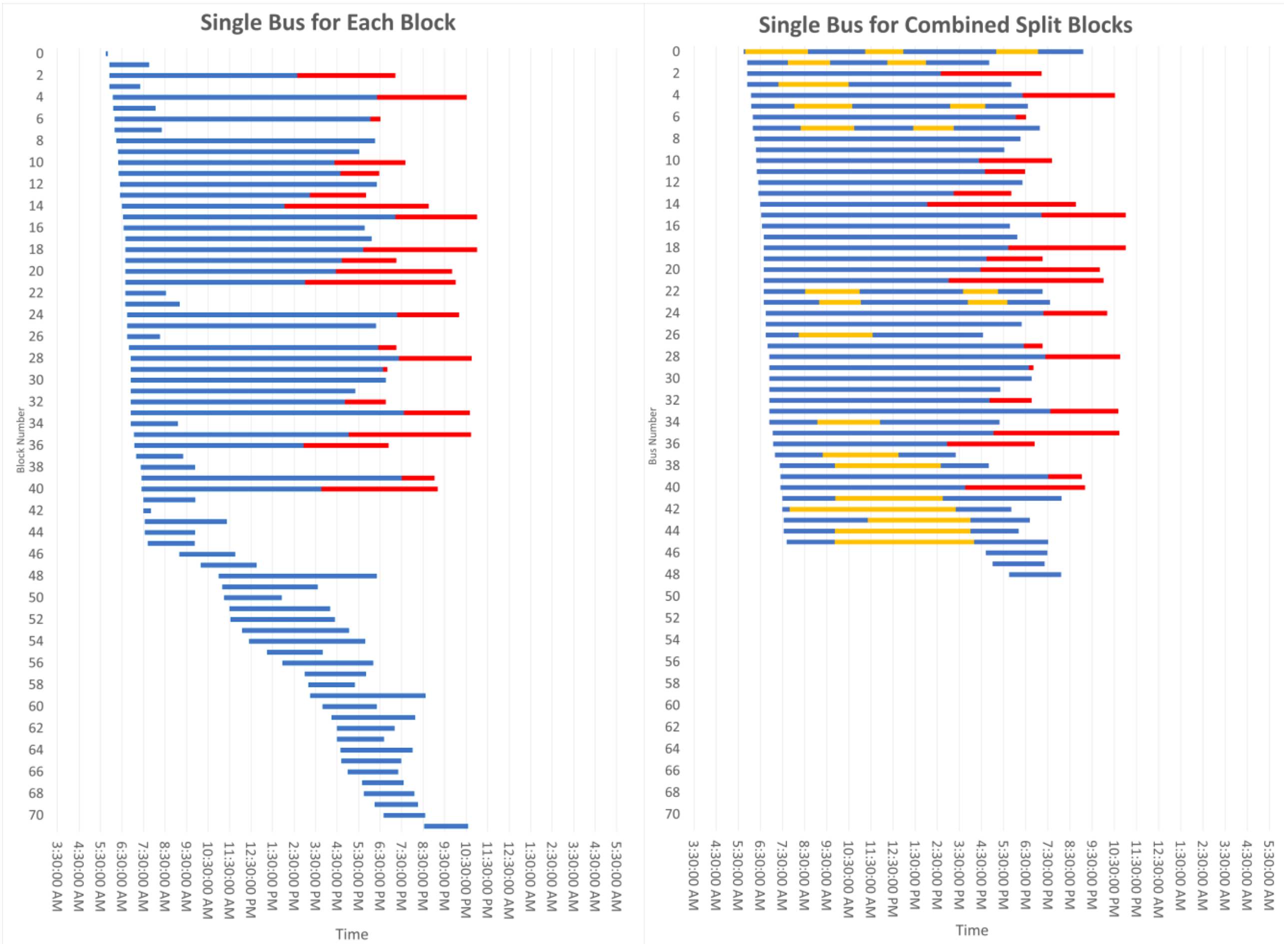

FIGURE 4: WTA ORIGINAL BLOCK SCHEDULE (A) AND COMBINED BLOCK SCHEDULE (B)

This total combined block analysis was conducted at the four ambient temperatures defined earlier, and the block completion percentages are tabulated in Table 11.

TABLE 12: WTA COMBINED BLOCK COMPLETION SUMMARY FOR 40-FT BUS

Temperature	Number of Blocks	Block Combinations	Completable Combined Blocks	Completion Percentage
11°F (Winter w/o DFAH)	72	49	18	37%
41°F (Winter w/ DFAH)	72	49	27	55%
59°F (Spring/Fall)	72	49	34	69%
91°F (Summer)	72	49	31	63%

When the analysis was performed at 41°F, there is a total of 72 individual service blocks, which can be combined into 49 block combinations and completed by 49 vehicles. The number of bars in Figure 5 is indicative of how may buses would be required to complete all blocks in the schedule. However, the graph cannot precisely define how many BEBs will be needed, primarily because there are still blocks that cannot be completed (appearing in red). If these blocks must be completed with today's battery technology, they must be either split into smaller blocks to be handled by more buses (thereby increasing the fleet size), or they must utilize on-route charging, or they must utilize a different ZEB technology such as a hydrogen FCEB. Alternatively, these blocks may be able to be completed with future battery technology.

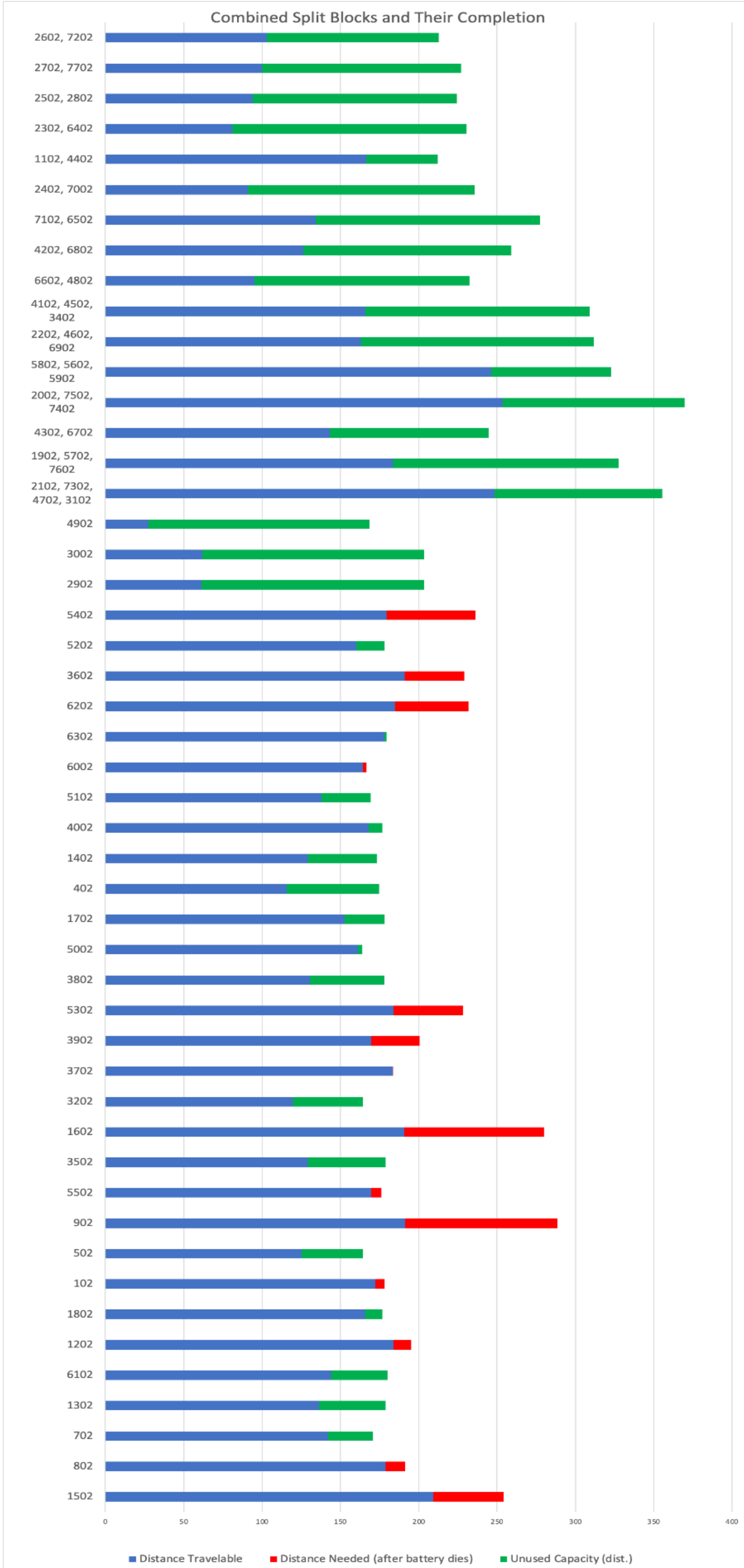

FIGURE 5: WTA COMBINED BLOCK COMPLETION FOR ALL BLOCKS USING 40-FT BUS AT 41°F, WITH DFAH – NEW BATTERY

3.6 Route-Level Analysis

Table 13 represents the analysis conducted from a route-level perspective. The route number, the calculated energy consumption, total number of blocks associated with those routes, and the number and percentage of completable weekday blocks are detailed for all routes operating from the MOAB. This Route performance analysis used the assumption of running at an ambient temperature of 41°F.

TABLE 13: WTA ROUTE COMPLETION FOR 40-FT BUS

Route	Route Short Name	Energy Consumption Rate (kWh/mi)	Number of Blocks	Maximum Distance (mi)	Completable Current	Completable Current (Degraded)	Completable Future	Completable Future (Degraded)	Completion Rate Current	Completion Rate Current (Degraded)	Completion Rate Future	Completion Rate Future (Degraded)
108	108	2.69	1	174.60	1	1	1	1	100.00%	100.00%	100.00%	100.00%
197	197	2.59	2	181.34	2	0	2	2	100.00%	0.00%	100.00%	100.00%
196	196	2.96	2	158.97	2	0	2	2	100.00%	0.00%	100.00%	100.00%
525	525	2.64	2	178.11	2	1	2	2	100.00%	50.00%	100.00%	100.00%
533	533	2.61	2	180.03	2	0	2	2	100.00%	0.00%	100.00%	100.00%
540	540	2.71	2	173.72	2	0	2	2	100.00%	0.00%	100.00%	100.00%
71X	71X	2.03	5	231.85	5	5	5	5	100.00%	100.00%	100.00%	100.00%
48	48	2.15	5	218.63	5	5	5	5	100.00%	100.00%	100.00%	100.00%
72X	72X	2.11	8	222.96	8	8	8	8	100.00%	100.00%	100.00%	100.00%
49	49	2.35	11	199.97	11	10	11	11	100.00%	90.91%	100.00%	100.00%
75	75	2.29	12	205.49	12	12	12	12	100.00%	100.00%	100.00%	100.00%
80X	80X	2.36	3	199.55	3	3	3	3	100.00%	100.00%	100.00%	100.00%
14S	14S	3.00	1	156.82	1	1	1	1	100.00%	100.00%	100.00%	100.00%
80S	80S	2.49	3	189.26	3	3	3	3	100.00%	100.00%	100.00%	100.00%
190S	190S	2.95	9	159.53	9	9	9	9	100.00%	100.00%	100.00%	100.00%
105S	105S	2.58	1	182.20	1	1	1	1	100.00%	100.00%	100.00%	100.00%
232	232	2.85	10	164.82	8	6	10	9	80.00%	60.00%	100.00%	90.00%
331	331	2.41	10	195.27	8	6	10	9	80.00%	60.00%	100.00%	90.00%
15	15	2.92	4	161.00	3	2	4	4	75.00%	50.00%	100.00%	100.00%
24	24	2.66	4	176.63	3	2	4	4	75.00%	50.00%	100.00%	100.00%
14	14	2.91	4	161.68	3	2	4	4	75.00%	50.00%	100.00%	100.00%
1	1	2.73	3	172.23	2	1	3	3	66.67%	33.33%	100.00%	100.00%
50	50	2.25	2	209.08	1	1	2	1	50.00%	50.00%	100.00%	50.00%
107	107	2.72	3	172.64	1	1	3	2	33.33%	33.33%	100.00%	66.67%
190	190	2.91	3	161.75	1	1	3	2	33.33%	33.33%	100.00%	66.67%
26	26	2.43	3	193.70	1	1	2	1	33.33%	33.33%	66.67%	33.33%
29	29	2.53	3	185.62	1	1	2	1	33.33%	33.33%	66.67%	33.33%
4	4	2.52	3	186.83	1	1	3	2	33.33%	33.33%	100.00%	66.67%
3	3	2.66	4	176.99	0	0	4	2	0.00%	0.00%	100.00%	50.00%
105	105	2.51	4	187.32	0	0	4	2	0.00%	0.00%	100.00%	50.00%
27	27	2.51	4	187.13	0	0	4	2	0.00%	0.00%	100.00%	50.00%
512	512	2.47	1	190.64	0	0	0	0	0.00%	0.00%	0.00%	0.00%

3.7 Incompletable Blocks

Table 14 represents the blocks that are not completable, even with future battery technology. Simulations for incompletable blocks were also run for winter at 41°F. As a result, additional planning and considerations will be needed for BEBs to complete these blocks. A possible solution and mitigation plan to address these incomplete blocks is found in Section 5. These distances will require a future battery capacity of larger than 800 kWh to complete.

TABLE 14: WTA INCOMPLETABLE BLOCKS FOR 40-FT BUS

Block ID	Route ID(s)	On-Route Travel Before Failure (miles)	miles needed to complete the block (after battery dies)
902	26, 29	191.43	97.19
1602	512	190.64	89.16

4. RECHARGING POWER AND ENERGY REQUIREMENTS AT THE MOAB

STV's BEB Energy Consumption model is useful in planning the energy demands of a fleet looking to transition to zero emission buses, notably BEBs. Utilizing the results of the block analysis, which determines the SOC remaining after each bus returns to the depot, a peak kW demand can be determined for each half hour period throughout the night. This information can be used to determine feeder cable sizing as well as providing pertinent information essential for an overall assessment of any additional grid system needs.

By compiling the SOC results from all the PEER block analyses the total energy required at the MOAB to fully recharge the BEB fleet can be determined. However, based upon the simulation analysis, there are several blocks that would return with 0% of the service energy, or in some cases, with less than 0%. In such negative-SOC cases, a bus would not be capable of completing the block. Recognizing that a bus would need on-route charging to complete a block that requires more energy than is available from the battery, it is assumed that all buses returning to the depot will have at least 0% SOC. The recharging energy requirements are then calculated based on this criterion.

Additionally, the arrival and departure times from the depot can be determined from the block schedules. This information can all be used to determine the available time at the depot for charging as well as the number of buses at the depot which simultaneously require charging. The following is an example to demonstrate this scenario, and which can help determine the peak power demand needed from the power distribution network.

One important consideration in the presentation of the depot power requirements listed below is that 81% of the currently scheduled weekday blocks can be completed with existing batteries in a 40-ft bus operating in winter conditions (41°F) and with a DFAH. Moreover, with an 800-kWh battery available in the future, 97% of existing blocks should be completable. The remaining incompletable blocks will need to either be restructured or equipped with on-route charging – unless battery capacity improves beyond 800-kWh (or a FCEB is used). These facts impact the power demand analysis, because as batteries grow larger, more energy will be required at the depot to fully recharge them, and less energy will need to be supplied by on-route chargers.

Likewise, the WTA may decide to restructure blocks and possibly increase fleet size to deal with blocks that are not completable. This would reduce the need for on-route chargers but would also increase the energy demand at the depot. This option is discussed in more detail in Section 5.2.

In the following sections depot loading curves are displayed. Each graph displays two approaches to determining the load. The first is the First-In, First-Out (FIFO) approach. The FIFO approach assumes that the buses will begin charging immediately after each returns to the depot. The second approach is the Optimized approach, which attempts to group the charging of the buses such that all the charging is done during off-peak hours when electricity costs are lower, as well as to minimize peaks in demand by level-loading throughout that time. In both approaches, the charging scheme was constrained to finish charging of all buses at least 1 hour before the next day's pull-out departure. However, the actual charging scheme will depend on multiple factors and will likely lie somewhere between the two curves.

Note that both analyses assume that there are enough chargers and dispensers at the depot so that each BEB is connected to a charger. (This may not be the case due to space constraints or other factors.) Note also that if there are insufficient quantity of chargers or dispensers the charge-load curves will change, however such an analysis is outside the scope of this report.

The blue curve represents charging being done on a FIFO basis. In this example, the peak power demand occurs in the early evening, which may occur when the demand charge is the highest.

The green curve represents an optimum charging scenario, which could occur between 11PM and 6AM, and which may result in lower (or, no) demand charges for electricity. Another benefit of group charging during this period is that it may reduce other costs, such as in labor resources that might be needed throughout the day to support charging requirements.

The red curve represents the power demand when performing mid-day charging between blocks without any optimization. Like the FIFO charging scheme, the power demand represented by the red curve assumes that the bus will begin its charge as soon as it returns to the depot and then end when fully charged, or when scheduled to pull-out for another block.

The yellow curve represents the power demand when performing mid-day charging between blocks, but with charging optimization (to lower the peak power needed to charge the buses).

For this analysis a charging rate of 130 kW was used. The chargers are assumed to have a rated capacity of 200 kW. However, it is not realistic to assume that the batteries charge at the same rate during the entire charging duration, since the vehicles' Battery Management Systems (BMSs) reduce kW draw as the battery SOC increases from about 80% to 100%. Thus, the buses were assumed to have gained a constant rate of 65 kWh of battery capacity every half hour, or 130 kWh of battery capacity every hour.

Figure 6 is the loading graph for the MOAB, during a winter day which has a typical schedule, and temperatures of 41°F or below, using 40-ft buses equipped with current-technology batteries and diesel fueled auxiliary heaters. This graph represents the load for the completable-block fleet. (Recall that the Completable-Block Fleet refers to buses that can complete all assigned blocks and return to their respective depot on a single charge, without assistance from on route charging.)

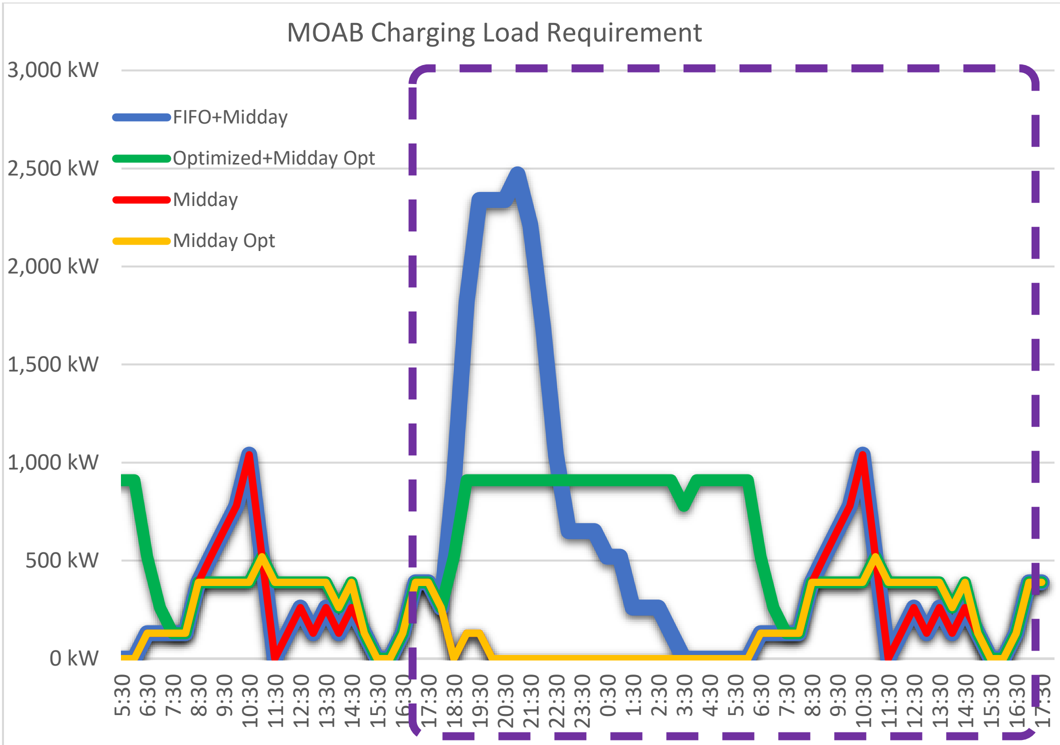

FIGURE 6: MOAB CHARGING LOAD CURVES FOR ALL BLOCKS (COMPLETABLE FLEET)

These curves will change as battery capacity increases since more kWh will need to be put into the batteries at the MOAB to run the entire fleet (and less energy would be needed from on-route chargers).

5. ADDRESSING INCOMPLETABLE BLOCKS

5.1 On-Route Charging

On-route charging involves utilizing layover time a bus may have at the end of a trip (during its operating block) for charging. This requires the installation of on-route charging infrastructure at the terminal station(s). On-route infrastructure generally includes pantographs, charging cabinets, gantries to support pantographs, and similar improvements. In this scenario, the pantograph makes conductive contact with a cross-rail system on the bus.

Alternatively, wireless induction charging could be utilized at on-route charging stations. Induction chargers manifest energy transfer by running electrical current through a “sending” coil of wire in the charger plate, which induces a magnetic field. If another coil is nearby (e.g., a receiving coil, mounted to the bottom of the bus), the induced magnetic field from the sending coil will therefore induce an electric current into the receiving coil on the bus.

Advantages of on-route charging include additional energy gained during the block, and less power load at the depot. The additional energy gained from on-route charging can help alleviate operating range concerns with current battery technology and can allow for additional block completions. Conversely, on-route charging may allow for similar block completions with a smaller battery capacity on the BEB.

Some disadvantages of on-route charging include cost of installation, cost of installation location parcel, flexibility in service, and possible obsolescence. The cost of on-route chargers includes not only the chargers themselves, but the additional electrical infrastructure and their maintenance. Additionally, pantograph on-route chargers have a minimum height requirement, which may limit where chargers can be installed. Also, if on-route chargers are necessary for block completion, BEBs servicing those blocks may miss their charging time if unforeseen circumstances arise. This may be detrimental to the block completion and result in disruption of service. Finally, on-route chargers may quickly become obsolete as battery technology improves and BEBs no longer need on-route chargers to complete blocks.

5.2 Theoretical Re-Blocking

Restructuring blocks is another possible solution to address the incompletable blocks. One approach to restructuring blocks is to examine the blocks that cannot be completed and split them such that two, or more, BEBs can service those split blocks. An example of an approach to block splitting is shown in Figure 7.

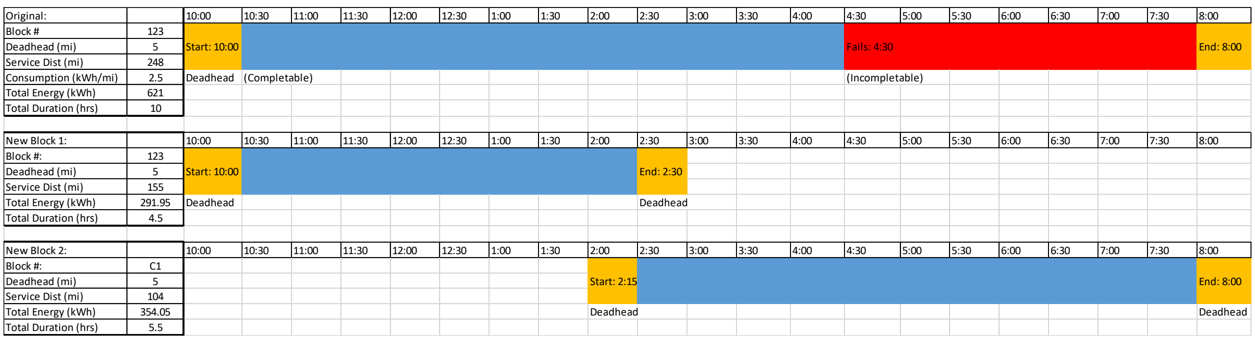

FIGURE 7: BLOCK SPLITTING EXAMPLE

The top bar graph shows a block that starts at 10 am and ends at 8:00 pm. This block requires 621 kWh of energy, more than a 470-kWh service energy BEB can provide. Here, it is assumed that this block cannot be split between 2:30 pm and 7:30 pm, due to rush-hour service needs, but that it can be split at any other time. Thus, the block can be split such that one bus will leave the garage at 10 am and return at 2:30 pm, servicing the completable portion of the block. A second bus will leave at 2:15 pm, 15 minutes before the first bus arrives to account for deadhead travel time, and then service the remainder of the original block, arriving back at the garage at 8:00 pm.

This process can then be repeated for the remaining incompletable blocks. Additionally, to minimize the necessary number of buses to service all blocks, these newly created blocks can be combined with the completable blocks and the modified blocks in a similar manner described in Section 2.5. The result of this exercise would be an entire schedule that can theoretically be completed with a given battery size.

Advantages of re-blocking include impact to service and infrastructure cost. Re-blocking the incompletable blocks will allow for the same level of service as it is currently. This assumes that blocks are split such that one bus ends at the end of a trip and the subsequent bus starts at the beginning of the trip where the previous bus ended. Additionally, the infrastructure cost for re-blocking could involve additional buses and depot chargers to accommodate the additional buses needed, which may cost less compared to other solutions for incompletable blocks (e.g. on-route chargers).

Disadvantages of re-blocking include garage limitations and service and operator scheduling concerns. Re-blocking may require additional BEBs compared to the current number of buses. Thus, if garages are already at maximum capacity, these additional BEBs may not fit and would need to be parked elsewhere, which will impact deadhead distance. Re-blocking can also impact operations from a management and scheduling perspective, as this will greatly affect driver assignments for blocks.

Using the methodology described above, the incompletable blocks can be split into two or more blocks. This block splitting process assumes that the energy consumption rate is constant throughout the block. It also assumes that blocks can be split at any point, except during PM rush-hour periods, which occurs between 2:30 PM and 7:30 PM. To account for deadhead travel time, it was assumed that deadhead distance is the same as the original block and requires 15 minutes of deadhead travel time.

These new, theoretical split blocks can then be combined with the completable blocks (using the methodology described in Section 2.5) to create a new, theoretical combined block schedule that can be completed with BEBs equipped with future-technology batteries.

Additionally, these theoretical combined blocks can be placed in energy categories based on the maximum energy of each combined block string, ranging from 400 kWh to 800 kWh, in 50 kWh increments (see Figure 9). These theoretical combinations can then be graphed based on the number of blocks that fit in these categories. These graphs are representative of the theoretical mixed fleet needed to support the theoretical schedule.

5.2.1 WTA Re-Blocking Analysis

A re-blocking analysis was performed to determine the incompletable blocks in the future, which were then split based on the criteria as described above. The analysis below assumes 40-ft BEBs with 800-kWh batteries, operating in winter conditions and with DAFHs. Incompletable blocks were split and then combined with the original completable blocks using the methodology described in Section 2.5. In Figure 8 the chart on the left shows the schedule with the original and new blocks. The chart on the right shows the combined block schedule. The chart on the right represents a schedule that has been built and optimized for battery electric buses and is 100% completable.

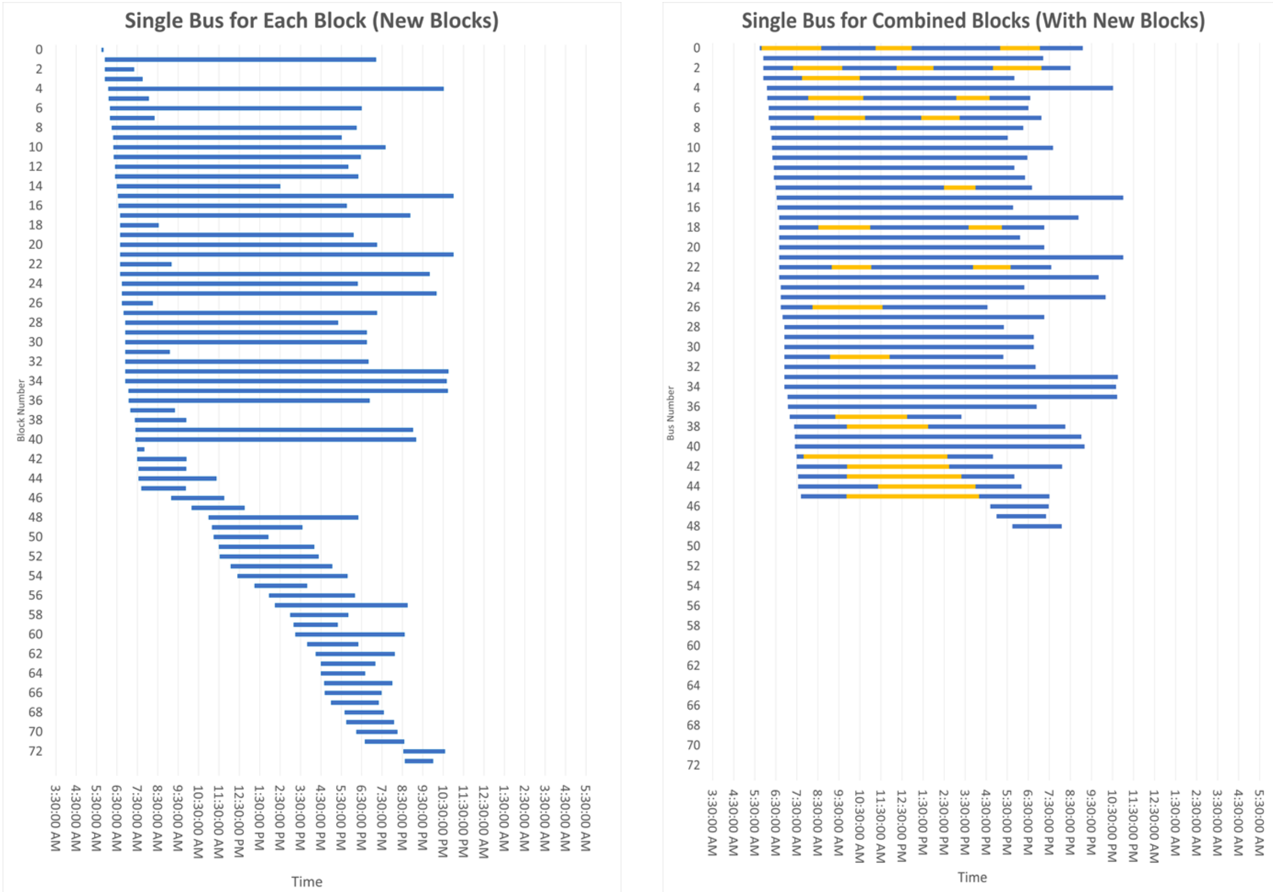

FIGURE 8: WTA THEORETICAL BLOCKS (A) AND COMBINED THEORETICAL BLOCKS (B) WITH FUTURE BATTERY

Table 15 shows the number of original blocks, the number of incompletable blocks with a future battery, the number of blocks found in the newly created completable schedule (which are referred to as theoretical blocks), and the total number of block combinations – when operating under different weather conditions.

TABLE 15: WTA THEORETICAL COMBINED BLOCK COMPLETION SUMMARY FOR 40-FT BUS WITH FUTURE BATTERY

Temperature	Number of Original Blocks	Number of Incompletable Blocks	Number of Theoretical Blocks	Number of Vehicles Required (Block Combinations)
11°F (Winter w/o DFAH)	72	10	82	49
41°F (Winter w/ DFAH)	72	2	74	49
59°F (Spring/Fall)	72	0	72	49
91°F (Summer)	72	0	72	49

This table shows that, when operating at 41°F, a total of 49 buses are needed to complete the 72 WTA weekday blocks. Note that at 59°F and 91°F all scheduled blocks are completable and thus do not require any re-blocking.

Figure 9 indicates the number of buses needed for operation at 41°F, and the corresponding minimum battery capacities needed for the 49 buses specified above. Notice that even though this schedule was generated based on a future battery technology of 800 kWh, many buses in the schedule do not need to have such a large battery.

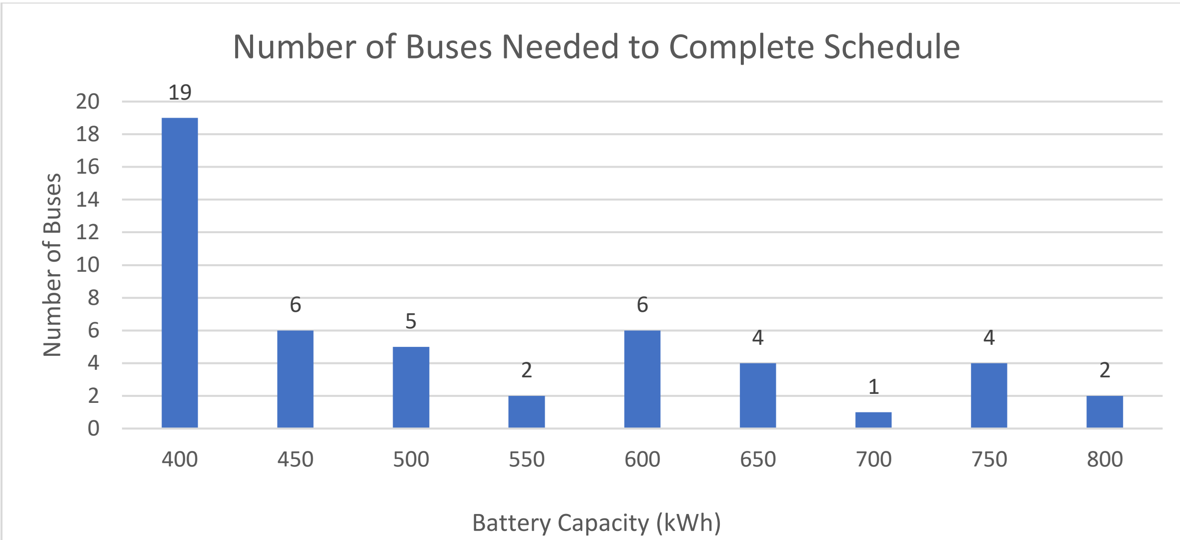

FIGURE 9: WTA NUMBER OF BUSES NEEDED FOR THEORETICAL BLOCK COMPLETION WITH FUTURE BATTERY

Figure 9 indicates that of the 49 buses, 2 of them need to have a battery capacity of 800 kWh. The remaining 72 buses can have a battery capacity of 750 kWh or lower and still complete the theoretical schedule shown in Figure 8b.

Figure 10 represents the recharging energy load at the MOAB, for the entire BEB fleet, using the combined theoretical blocks as shown above and by making the same assumptions as describe in Section 4.

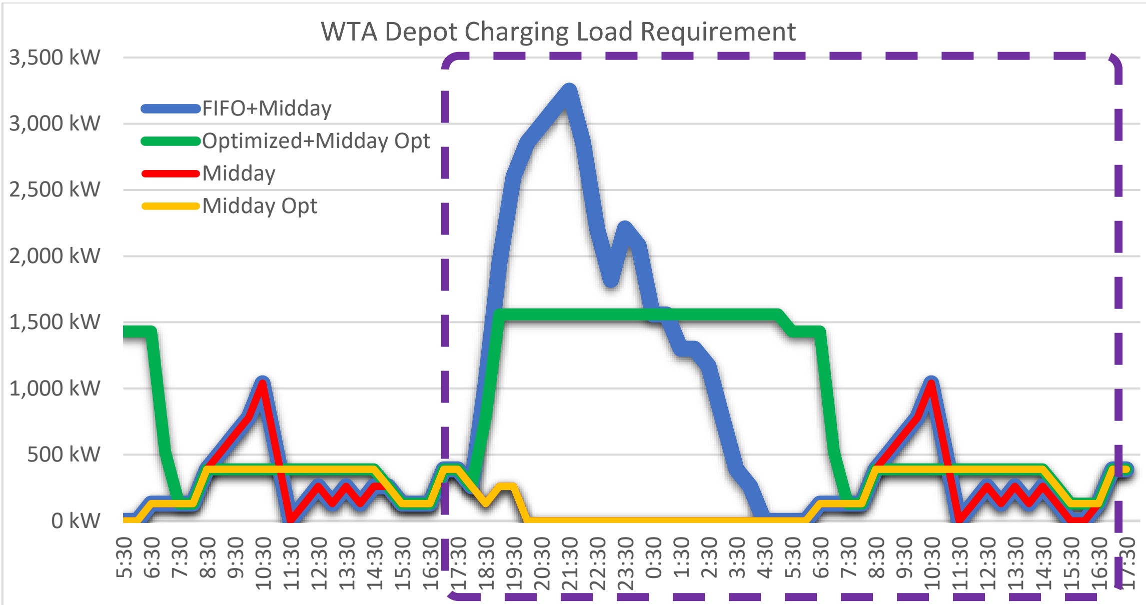

FIGURE 10: WTA CHARGING LOAD CURVES FOR ALL BLOCKS WITH FUTURE BATTERY TECHNOLOGY WITH FUTURE BATTERY

5.3 Alternative Fuels

A third approach to addressing incompletable blocks is to use fuel cell electric buses (FCEBs) in place of BEBs. The fuel cells used in FCEBs are composed of an anode, some electrolyte, and a cathode. Fuel at the anode is oxidized from a catalyst, which turns the fuel into a positively charged ion and a negatively charged electron. For FCEBs, the anode catalyst is platinum powder, and the fuel is hydrogen. The electrolyte filters the positive ions from the negative electrons, allowing for the ions to travel from the anode to the cathode through the electrolyte. The electrons travel to the cathode via a wire, which generates the electric current. At the cathode, the ions and electrons reunite and react with an additional chemical and a catalyst, which produces a byproduct. For FCEBs, the additional chemical is oxygen, the cathode catalyst is nickel, and the byproduct is water.

Advantages of FCEBs include increased range and reduced refueling time. FCEBs have a higher energy density when compared to the lithium-ion batteries used in BEBs. As a result, FCEBs can travel a farther distance at full capacity when compared to BEBs. Additionally, FCEBs have quicker refueling times compared to BEBs. Due to limitations in charging technology, BEBs require a few hours to charge when depleted. Quicker charging will also degrade the battery at a faster rate. FCEBs, however, can be refueled similarly to a diesel or CNG bus, in a matter of minutes.

Disadvantages of FCEBs include infrastructure costs and safety risks. To operate FCEBs, hydrogen needs to be delivered to, and stored at, the garage, which will require additional infrastructure and space. If a mixed FCEB and BEB fleet is operated, additional space and infrastructure is needed to support both types of buses. Additionally, storage of hydrogen may add additional fire safety concerns that may require additional personnel training and equipment.

5.4 Future Battery Technologies

Current BEBs utilize lithium-ion based batteries and liquid electrolytes. New Flyer offers batteries with an energy density of 210 Wh/kg and a volume density of 260 Wh/l. Research suggests that the theoretical maximum energy density of lithium-ion batteries is 250-270 Wh/kg. This implies that improvements to lithium-ion energy density will be minor, and any additional energy will come from additional batteries added to the bus. This will impact the performance of the BEB, as additional batteries will result in additional weight.

Thus, to increase the energy density of batteries, there has been considerable research in developing batteries that utilize solid electrolytes. These solid electrolytes are made with ceramics and solid polymers. Current research indicates that these solid-state batteries may contain 900 Wh/kg, which is a 350% increase in energy density. Figure 11 details the energy density improvements that can be achieved with solid-state batteries compared to current batteries.

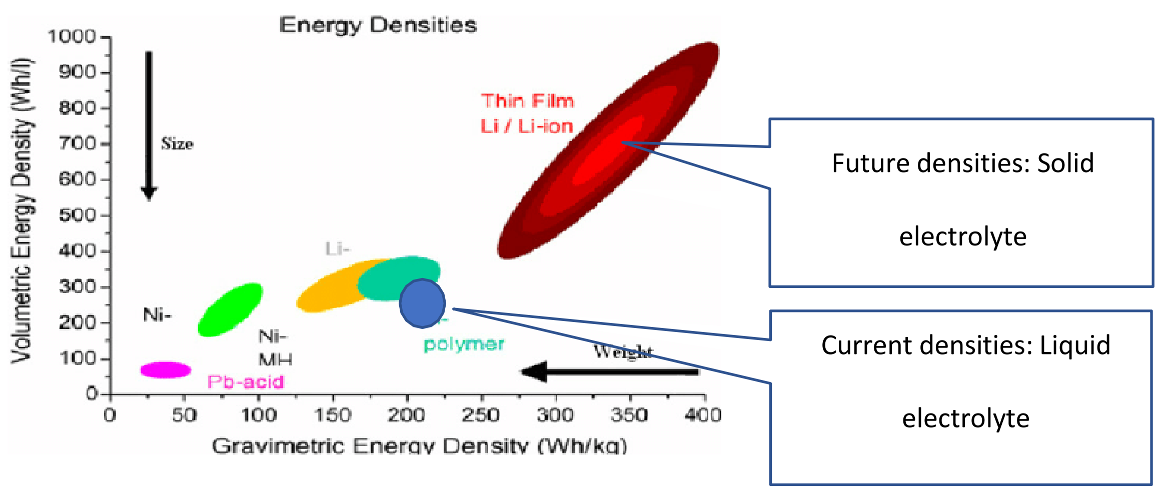

FIGURE 11: ENERGY DENSITY OF BATTERY TECHNOLOGY COMPARISON

The main advantage of future battery technology is increased performance. The increase in energy density, such as in solid-state batteries, allows for much higher energy capacities within the same envelope as current batteries. Additionally, current energy capacities can be achieved with a smaller envelope. These changes in energy density will allow for the bus to travel much farther and with minimal impact to the weight of the bus.

Disadvantages of future technology include time, cost, and power demand. Since there is still research currently underway with solid-state batteries, it is difficult to determine when solid-state batteries will enter the market. The current forecast predicts that solid-state batteries will be available for mass production in at least six years. Additionally, BEBs equipped with these solid-state batteries will most likely come at a premium cost due to the increased manufacturing costs of these new batteries. Power demands will also increase as the battery capacity increases. Additional power infrastructure and chargers may be needed to ensure that improved buses are fully charged.

6. BATTERY BEST PRACTICES

The battery of an electric bus is the most expensive component of the vehicle. Due to the importance and cost of the battery, extra care should be given to preserve the health of the battery to maximize its operational life and maintain bus performance. There are many factors that influence battery degradation in electric buses such as temperature, charging methods, depth of discharge, and average state of charge.

The first good measure for preserving the health of the battery of an electric bus is temperature control. The optimal temperature for lithium-ion batteries is 59°F (15°C) to 86°F (30°C). Higher temperatures affect the chemical reactions within the battery and colder temperatures affect energy storage. Thus, it is ideal to park the bus under shaded areas during warmer days or sheltered in a garage during colder days. [1,2]

Various charging methods also affect the battery in different ways. For example, high power charging makes battery cells wear out faster. Unless the battery is optimized for fast charging, lower currents will help preserve the health of the battery better. Additionally, the depth of discharge and average state of charge are another factor of battery health. It is often ideal for the battery to have smaller charging cycles whenever possible. For instance, lower cycle heights are better such as going from 50% to 0% 2000 times rather than going from 100% to 0% 1000 times. The average state of charge also affects the battery health. A best practice is to have batteries operate at around 50% on average rather than to operate at 100%. [1,2]

However, with current battery technology, degradation is inevitable and will have a negative impact on bus operations, even with preventive measures. Thus, it is important to consider replacing the battery when performance is no longer comparable to a new battery. The average operational life of a transit bus is 12 years. With current battery technology, replacements should be expected every 6-7 years for peak performance. A battery overhaul varies in costs, especially within the next few years as the price per kWh of a lithium-ion battery pack is projected to decrease. Current estimated costs per kWh in a battery pack for an electric bus range from $100 to $160 per kWh but may decrease to $61 per kWh by 2030 [3]. As a result, the current cost to replace a 525-kWh battery during the operational life of an electric bus is about $52,500-$84,000. It should be noted though that some OEMs provide warranties for battery replacements halfway through the operational life of the electric bus.

Battery technology was previously mentioned as the primary factor for battery replacements. However, this problem may be mitigated or obsolete in the upcoming years when battery technology improves. For example, future electric bus technology includes lithium-ion battery packs with capacities as high as 700 kWh which are also smaller and lighter compared to current battery packs. Another battery technology being developed are solid-state batteries, as discussed in Section 5.4 [5]. Although functionally like lithium-ion batteries, these types of batteries use a solid electrolyte layer, generally made up of ceramics or polymers, as the medium through which the ions move between the anode and the cathode. By contrast, lithium-ion batteries use a liquid electrolyte layer during this process, but this liquid layer contributes immensely to the battery's size. The electrolyte layer in solid-state batteries can be made very thin, and as result offer greater energy density in a lighter, more compact battery. The latest research shows that solid state batteries can have an energy density 2-2.5 times higher than current lithium-ion batteries, which can provide further range and weight reductions to a battery electric bus (BEB), allowing for even better performance. However, this battery technology is still under research and is not expected to be fully introduced for another 5-10 years. Until solid-state battery technology matures, current lithium-ion batteries are expected to continue to improve and be the primary energy storage system into the near future. [6,7]

Another option for degraded batteries is recycling. There are a few processes being developed for recovering many of the expensive or rarer components in degraded batteries which can then be used to manufacture new batteries, such as pyrometallurgy (metal extraction with heat) and hydrometallurgy (metal extraction with liquids). Processes like these can create a closed loop system where batteries can be recycled and reused repeatedly, at a fraction of the cost to produce new batteries. In fact, one battery recycling company, Li-Cycle, was able to successfully recycle 95% of materials from lithium-ion batteries, provided by New Flyer, with their Spoke & Hub technology [9]. Thus, recycling processes and technologies can be sought as a cost-saving measure for battery replacements or newly manufactured batteries. [8,10]

7. CONCLUSION AND RECOMMENDATIONS

This study utilized a PEER route simulation and block analysis to predict the energy consumption of a fleet of zero-emission buses (ZEBs) – specifically, battery-electric bus (BEBs) – as they travel along specific routes and blocks, under varying conditions, and whether the routes included within the blocks can be completed. The study also provided the total energy usage and remaining State of Charge (SOC) for a BEB returning to the MOAB facility, and the power demand needed to return the bus batteries to a full SOC.

The graphs that are included show the peak facility energy required for those blocks that are currently completable (by BEBs with today's battery technology). This is provided to assist in determining suitability of existing electrical services to support the initial procurements of BEBs. Also included are graphs for energy needs for the future conversion of the entire fleet to BEBs. As battery energy density increases, the number of completable blocks will also increase. The details of the specific blocks that will then be completable are provided within the report.

When moving toward BEBs it is important to consider the use of a charge management system (CMS) to avoid peak demand charges. It is also important to have real-time telematics data which will help make operational and financial decisions that will affect the total operating costs of a BEB solution.

REFERENCES

1. How to avoid battery degradation in electric buses | Automotive World
2. Top 4 Factors That Influence Battery Degradation In Electric Buses & How To avoid them - ViriCiti
3. Electrifying Transit: A Guidebook for Implementing Battery Electric Buses (nrel.gov)
4. UK battery electric bus operation: Examining battery degradation, carbon emissions and cost | Elsevier Enhanced Reader
5. Global Electric Bus Battery Market 2022-2027 | June 2022 Updated (mobilityforesights.com)
6. What Is A Solid-State Battery? A Comparison between Li-ion vs. Solid-State Batteries (gallonelectric.com)
7. Solid-state batteries: how they work | Flash Battery
8. VW Wants to Recycle EV Batteries Multiple Times (autoweek.com)
9. New Flyer electric bus batteries recycled with Li-Cycle - Li-Cycle
10. Electric Car Battery Recycling: Can Lithium Batteries be Recycled? | CarsGuide
11. SPEC_40_001A_Q2_2022_V4_4.5.22-2.pdf (proterra.com)
12. NF-ChargeNG-Brochure-v06 (newflyer.com)
13. Bus: K11M - BYD USA

APPENDICES

- **Gillig 40' Analysis: Simulation at 11°F (Winter, for BEBs Equipped w/o DFAHs)**

Bus Size	Block ID	Day	Route ID(s)	Energy Consumption rate (kWh/mi)	Energy Required For Completion (kWh)	SOC	Traveled Distance (in miles)	On-Route Travel Before Failure (Miles)	Miles needed to complete the block (after battery dies)	Unused Capacity [Miles]	Sufficient kWh to complete block?	SOC (Future Battery Technology)	Sufficient kWh to complete block in the future?
Gillig 40'	2102	Weekday	75	2.711589922	194.8744467	58.57	71.87	71.87	0.00	101.61	WILL COMPLETE BLOCK	69.55	WILL COMPLETE BLOCK
Gillig 40'	1902	Weekday	71X, 48	2.524501336	122.835852	73.89	48.66	48.66	0.00	137.68	WILL COMPLETE BLOCK	80.81	WILL COMPLETE BLOCK
Gillig 40'	4302	Weekday	75, 49	2.865669661	171.0364301	63.64	59.68	59.68	0.00	104.47	WILL COMPLETE BLOCK	73.28	WILL COMPLETE BLOCK
Gillig 40'	1502	Weekday	50	2.766307569	702.9172584	-49.43	254.10	170.05	84.05	0.00	INSUFFICIENT KWH	-9.83	INSUFFICIENT KWH
Gillig 40'	802	Weekday	331, 232	3.381614423	647.0189191	-37.55	191.33	139.11	52.23	0.00	INSUFFICIENT KWH	-1.10	INSUFFICIENT KWH
Gillig 40'	2002	Weekday	72X, 49	2.662424458	174.5799088	62.89	65.57	65.57	0.00	111.11	WILL COMPLETE BLOCK	72.72	WILL COMPLETE BLOCK
Gillig 40'	5802	Weekday	75	2.711589922	179.2109759	61.90	66.09	66.09	0.00	107.39	WILL COMPLETE BLOCK	72.00	WILL COMPLETE BLOCK
Gillig 40'	702	Weekday	1, 197, 196	3.549859781	503.4496388	-7.03	141.82	132.51	9.31	0.00	INSUFFICIENT KWH	21.34	WILL COMPLETE BLOCK
Gillig 40'	1302	Weekday	232, 331	3.381614423	460.5894963	2.09	136.20	136.20	0.00	2.90	WILL COMPLETE BLOCK	28.03	WILL COMPLETE BLOCK
Gillig 40'	6102	Weekday	26, 331, 232	3.333341104	479.8302094	-2.00	143.95	141.12	2.83	0.00	INSUFFICIENT KWH	25.03	WILL COMPLETE BLOCK
Gillig 40'	1202	Weekday	27, 3, 105	3.222793884	628.9994957	-33.72	195.17	145.96	49.21	0.00	INSUFFICIENT KWH	1.72	WILL COMPLETE BLOCK
Gillig 40'	1802	Weekday	540, 533	3.373010608	559.3137054	-18.90	165.82	139.46	26.36	0.00	INSUFFICIENT KWH	12.61	WILL COMPLETE BLOCK
Gillig 40'	502	Weekday	15, 24, 14	3.762738228	471.0268167	-0.13	125.18	125.02	0.17	0.00	INSUFFICIENT KWH	26.40	WILL COMPLETE BLOCK
Gillig 40'	102	Weekday	1	3.47922777	619.9673222	-31.80	178.19	135.20	42.99	0.00	INSUFFICIENT KWH	3.13	WILL COMPLETE BLOCK
Gillig 40'	902	Weekday	26, 29	2.989251124	862.7437013	-83.41	288.62	157.36	131.25	0.00	INSUFFICIENT KWH	-34.80	INSUFFICIENT KWH
Gillig 40'	5502	Weekday	190, 4, 107	3.636014029	640.1317922	-36.08	176.05	129.37	46.68	0.00	INSUFFICIENT KWH	-0.02	INSUFFICIENT KWH
Gillig 40'	3502	Weekday	331, 232	3.381614423	436.7265162	7.16	129.15	129.15	0.00	9.96	WILL COMPLETE BLOCK	31.76	WILL COMPLETE BLOCK
Gillig 40'	4102	Weekday	48, 71X	2.565133616	139.5479008	70.33	54.40	54.40	0.00	128.98	WILL COMPLETE BLOCK	78.20	WILL COMPLETE BLOCK
Gillig 40'	2202	Weekday	80X	2.601202806	173.5645499	63.10	66.72	66.72	0.00	114.11	WILL COMPLETE BLOCK	72.88	WILL COMPLETE BLOCK
Gillig 40'	3202	Weekday	14, 15, 24	3.760012272	450.5214761	4.23	119.82	119.82	0.00	5.29	WILL COMPLETE BLOCK	29.61	WILL COMPLETE BLOCK
Gillig 40'	3702	Weekday	3, 105, 27	3.248200848	595.4987675	-26.59	183.33	144.82	38.51	0.00	INSUFFICIENT KWH	6.95	WILL COMPLETE BLOCK
Gillig 40'	3902	Weekday	107, 190, 4	3.636014029	728.5729244	-54.88	200.38	129.37	71.00	0.00	INSUFFICIENT KWH	-13.84	INSUFFICIENT KWH
Gillig 40'	5302	Weekday	3, 27, 105	3.219610907	734.3083123	-56.10	228.07	146.10	81.97	0.00	INSUFFICIENT KWH	-14.74	INSUFFICIENT KWH
Gillig 40'	1602	Weekday	512	3.053588969	854.385085	-81.63	279.80	154.05	125.75	0.00	INSUFFICIENT KWH	-33.50	INSUFFICIENT KWH
Gillig 40'	6602	Weekday	75, 49	2.814309748	149.3948767	68.24	53.08	53.08	0.00	114.06	WILL COMPLETE BLOCK	76.66	WILL COMPLETE BLOCK
Gillig 40'	3802	Weekday	232, 331	3.395916658	442.9285717	5.84	130.43	130.43	0.00	8.09	WILL COMPLETE BLOCK	30.79	WILL COMPLETE BLOCK
Gillig 40'	5002	Weekday	15, 14, 24	3.770645196	607.2704208	-29.10	161.05	124.75	36.30	0.00	INSUFFICIENT KWH	5.11	WILL COMPLETE BLOCK
Gillig 40'	1702	Weekday	525	3.368540048	514.5217079	-9.38	152.74	139.65	13.10	0.00	INSUFFICIENT KWH	19.61	WILL COMPLETE BLOCK
Gillig 40'	4202	Weekday	72X	2.483761988	167.6590593	64.36	67.50	67.50	0.00	121.89	WILL COMPLETE BLOCK	73.80	WILL COMPLETE BLOCK
Gillig 40'	402	Weekday	108	3.52229368	408.4010094	13.18	115.95	115.95	0.00	17.60	WILL COMPLETE BLOCK	36.19	WILL COMPLETE BLOCK
Gillig 40'	1402	Weekday	4, 107, 190	3.549304231	458.9420224	2.44	129.30	129.30	0.00	3.23	WILL COMPLETE BLOCK	28.29	WILL COMPLETE BLOCK
Gillig 40'	5102	Weekday	196, 197	3.632263794	500.160359	-6.33	137.70	129.51	8.19	0.00	INSUFFICIENT KWH	21.85	WILL COMPLETE BLOCK
Gillig 40'	4002	Weekday	540, 533	3.370975283	567.1037374	-20.56	168.23	139.54	28.69	0.00	INSUFFICIENT KWH	11.39	WILL COMPLETE BLOCK
Gillig 40'	6302	Weekday	49, 232, 331	3.369136319	599.6523341	-27.48	177.98	139.62	38.36	0.00	INSUFFICIENT KWH	6.30	WILL COMPLETE BLOCK
Gillig 40'	6002	Weekday	15, 24, 14	3.762738228	627.3825642	-33.37	166.74	125.02	41.72	0.00	INSUFFICIENT KWH	1.97	WILL COMPLETE BLOCK
Gillig 40'	6202	Weekday	105, 3, 27	3.227500952	747.9793992	-59.01	231.75	145.75	86.00	0.00	INSUFFICIENT KWH	-16.87	INSUFFICIENT KWH
Gillig 40'	3602	Weekday	29, 26	3.009333323	689.5757036	-46.59	229.15	156.31	72.83	0.00	INSUFFICIENT KWH	-7.75	INSUFFICIENT KWH
Gillig 40'	7102	Weekday	75	2.711589922	179.2109759	61.90	66.09	66.09	0.00	107.39	WILL COMPLETE BLOCK	72.00	WILL COMPLETE BLOCK
Gillig 40'	2402	Weekday	80S, 190S	3.541525134	82.36081976	82.49	23.26	23.26	0.00	109.57	WILL COMPLETE BLOCK	87.13	WILL COMPLETE BLOCK
Gillig 40'	5202	Weekday	232, 331	3.3936283	543.4665224	-15.53	160.14	138.61	21.53	0.00	INSUFFICIENT KWH	15.08	WILL COMPLETE BLOCK
Gillig 40'	5402	Weekday	331, 232	3.369600546	795.7607858	-69.17	236.16	139.60	96.56	0.00	INSUFFICIENT KWH	-24.34	INSUFFICIENT KWH
Gillig 40'	1102	Weekday	29	3.230237506	31.45354173	93.31	9.74	9.74	0.00	135.89	WILL COMPLETE BLOCK	95.09	WILL COMPLETE BLOCK
Gillig 40'	2302	Weekday	14S	3.947842872	105.7184908	77.53	26.78	26.78	0.00	92.37	WILL COMPLETE BLOCK	83.48	WILL COMPLETE BLOCK
Gillig 40'	2502	Weekday	105S, 190S	3.581608041	98.56652921	79.05	27.52	27.52	0.00	103.82	WILL COMPLETE BLOCK	84.60	WILL COMPLETE BLOCK
Gillig 40'	2702	Weekday	190S	3.882991939	132.1107697	71.92	34.02	34.02	0.00	87.12	WILL COMPLETE BLOCK	79.36	WILL COMPLETE BLOCK
Gillig 40'	2602	Weekday	190S	3.882991939	76.79522098	83.67	19.78	19.78	0.00	101.37	WILL COMPLETE BLOCK	88.00	WILL COMPLETE BLOCK
Gillig 40'	7302	Weekday	75, 49	2.814309748	187.8220517	60.07	66.74	66.74	0.00	100.41	WILL COMPLETE BLOCK	70.65	WILL COMPLETE BLOCK
Gillig 40'	5702	Weekday	72X, 49	2.662424458	181.9158776	61.33	68.33	68.33	0.00	108.35	WILL COMPLETE BLOCK	71.58	WILL COMPLETE BLOCK
Gillig 40'	6702	Weekday	331, 232	3.354310157	279.6712052	40.55	83.38	83.38	0.00	56.86	WILL COMPLETE BLOCK	56.30	WILL COMPLETE BLOCK
Gillig 40'	7502	Weekday	75	2.711589922	337.3710818	28.28	124.42	124.42	0.00	49.06	WILL COMPLETE BLOCK	47.29	WILL COMPLETE BLOCK
Gillig 40'	5602	Weekday	48, 71X	2.565133616	139.5479008	70.33	54.40	54.40	0.00	128.98	WILL COMPLETE BLOCK	78.20	WILL COMPLETE BLOCK
Gillig 40'	4602	Weekday	190S	3.882991939	164.5447978	65.02	42.38	42.38	0.00	78.77	WILL COMPLETE BLOCK	74.29	WILL COMPLETE BLOCK
Gillig 40'	4502	Weekday	190S	3.882991939	185.3731156	60.59	47.74	47.74	0.00	73.40	WILL COMPLETE BLOCK	71.04	WILL COMPLETE BLOCK
Gillig 40'	4802	Weekday	190S, 80S	3.746405217	157.1428898	66.59	41.94	41.94	0.00	83.62	WILL COMPLETE BLOCK	75.45	WILL COMPLETE BLOCK
Gillig 40'	6802	Weekday	232, 331	3.414986304	200.5973442	57.36	58.74	58.74	0.00	79.01	WILL COMPLETE BLOCK	68.66	WILL COMPLETE BLOCK
Gillig 40'	6502	Weekday	49, 72X	2.662424458	181.3579964	61.45	68.12	68.12	0.00	108.56	WILL COMPLETE BLOCK	71.66	WILL COMPLETE BLOCK
Gillig 40'	4702	Weekday	190S	3.882991939	141.6059705	69.90	36.47	36.47	0.00	84.68	WILL COMPLETE BLOCK	77.87	WILL COMPLETE BLOCK
Gillig 40'	7602	Weekday	49, 75	2.814309748	187.2323446	60.20	66.53	66.53	0.00	100.62	WILL COMPLETE BLOCK	70.74	WILL COMPLETE BLOCK
Gillig 40'	7002	Weekday	72X	2.483761988	167.6590593	64.36	67.50	67.50	0.00	121.89	WILL COMPLETE BLOCK	73.80	WILL COMPLETE BLOCK
Gillig 40'	4402	Weekday	80X, 50	2.656237727	416.1739511	11.53	156.68	156.68	0.00	20.41	WILL COMPLETE BLOCK	34.97	WILL COMPLETE BLOCK
Gillig 40'	6402	Weekday	48, 71X	2.565133616	139.5479008	70.33	54.40	54.40	0.00	128.98	WILL COMPLETE BLOCK	78.20	WILL COMPLETE BLOCK
Gillig 40'	5902	Weekday	80X	2.601202806	327.3971556	30.40	125.86	125.86	0.00	54.98	WILL COMPLETE BLOCK	48.84	WILL COMPLETE BLOCK
Gillig 40'	7702	Weekday	75	2.711589922	178.7294136	62.00	65.91	65.91	0.00	107.56	WILL COMPLETE BLOCK	72.07	WILL COMPLETE BLOCK
Gillig 40'	2802	Weekday	49, 75	2.814309748	187.7321494	60.09	66.71	66.71	0.00	100.44	WILL COMPLETE BLOCK	70.67	WILL COMPLETE BLOCK
Gillig 40'	7202	Weekday	72X, 525	2.926151018	243.9328853	48.14	83.36	83.36	0.00	77.39	WILL COMPLETE BLOCK	61.89	WILL COMPLETE BLOCK
Gillig 40'	4902	Weekday	190S, 80S	3.655347402	100.288019	78.68	27.44	27.44	0.00	101.25	WILL COMPLETE BLOCK	84.33	WILL COMPLETE BLOCK
Gillig 40'	2902	Weekday	49, 75	2.814309748	172.9270075	63.24	61.45	61.45	0.00	105.70	WILL COMPLETE BLOCK	72.98	WILL COMPLETE BLOCK
Gillig 40'	7402	Weekday	72X	2.483761988	157.6757138	66.48	63.48	63.48	0.00	125.91	WILL COMPLETE BLOCK	75.36	WILL COMPLETE BLOCK
Gillig 40'	3002	Weekday	49, 75	2.814309748	173.4724367	63.12	61.64	61.64	0.00	105.51	WILL COMPLETE BLOCK	72.89	WILL COMPLETE BLOCK
Gillig 40'	6902	Weekday	71X, 48	2.524501336	136.451175	70.99	54.05	54.05	0.00	132.28	WILL COMPLETE BLOCK	78.68	WILL COMPLETE BLOCK
Gillig 40'	3402	Weekday	72X	2.483761988	157.6757138	66.48	63.48	63.48	0.00	125.91	WILL COMPLETE BLOCK	75.36	WILL COMPLETE BLOCK
Gillig 40'	3102	Weekday	1	3.47922777	254.620194	45.87	73.18	73.18	0.00	62.02	WILL COMPLETE BLOCK	60.22	WILL COMPLETE BLOCK

- **Gillig 40’ Analysis: Simulation at 41°F (Winter, for BEBs Equipped w/ DFAH)**

Bus Size	Block ID	Day	Route ID(s)	Energy Consumption rate (kWh/mi)	Energy Required For Completion (kWh)	SOC	Traveled Distance (in miles)	On-Route Travel Before Failure (Miles)	Miles needed to complete the block (after battery dies)	Unused Capacity [Miles]	Sufficient kWh to complete block?	SOC (Future Battery Technology)	Sufficient kWh to complete block in the future?
Gillig 40'	2102	Weekday	75	2.711589922	194.8744467	58.57	71.87	71.87	0.00	101.61	WILL COMPLETE BLOCK	69.55	WILL COMPLETE BLOCK
Gillig 40'	1902	Weekday	71X, 48	2.524501336	122.835852	73.89	48.66	48.66	0.00	137.68	WILL COMPLETE BLOCK	80.81	WILL COMPLETE BLOCK
Gillig 40'	4302	Weekday	75, 49	2.865669661	171.0364301	63.64	59.68	59.68	0.00	104.47	WILL COMPLETE BLOCK	73.28	WILL COMPLETE BLOCK
Gillig 40'	1502	Weekday	50	2.766307569	702.9172584	-49.43	254.10	170.05	84.05	0.00	INSUFFICIENT KWH	-9.83	INSUFFICIENT KWH
Gillig 40'	802	Weekday	331, 232	3.381614423	647.0189191	-37.55	191.33	139.11	52.23	0.00	INSUFFICIENT KWH	-1.10	INSUFFICIENT KWH
Gillig 40'	2002	Weekday	72X, 49	2.662424458	174.5799088	62.89	65.57	65.57	0.00	111.11	WILL COMPLETE BLOCK	72.72	WILL COMPLETE BLOCK
Gillig 40'	5802	Weekday	75	2.711589922	179.2109759	61.90	66.09	66.09	0.00	107.39	WILL COMPLETE BLOCK	72.00	WILL COMPLETE BLOCK
Gillig 40'	702	Weekday	1, 197, 196	3.549859781	503.4496388	-7.03	141.82	132.51	9.31	0.00	INSUFFICIENT KWH	21.34	WILL COMPLETE BLOCK
Gillig 40'	1302	Weekday	232, 331	3.381614423	460.5894963	2.09	136.20	136.20	0.00	2.90	WILL COMPLETE BLOCK	28.03	WILL COMPLETE BLOCK
Gillig 40'	6102	Weekday	26, 331, 232	3.333341104	479.8302094	-2.00	143.95	141.12	2.83	0.00	INSUFFICIENT KWH	25.03	WILL COMPLETE BLOCK
Gillig 40'	1202	Weekday	27, 3, 105	3.222793884	628.9994957	-33.72	195.17	145.96	49.21	0.00	INSUFFICIENT KWH	1.72	WILL COMPLETE BLOCK
Gillig 40'	1802	Weekday	540, 533	3.373010608	559.3137054	-18.90	165.82	139.46	26.36	0.00	INSUFFICIENT KWH	12.61	WILL COMPLETE BLOCK
Gillig 40'	502	Weekday	15, 24, 14	3.762738228	471.0268167	-0.13	125.18	125.02	0.17	0.00	INSUFFICIENT KWH	26.40	WILL COMPLETE BLOCK
Gillig 40'	102	Weekday	1	3.47922777	619.9673222	-31.80	178.19	135.20	42.99	0.00	INSUFFICIENT KWH	3.13	WILL COMPLETE BLOCK
Gillig 40'	902	Weekday	26, 29	2.989251124	862.7437013	-83.41	288.62	157.36	131.25	0.00	INSUFFICIENT KWH	-34.80	INSUFFICIENT KWH
Gillig 40'	5502	Weekday	190, 4, 107	3.636014029	640.1317922	-36.08	176.05	129.37	46.68	0.00	INSUFFICIENT KWH	-0.02	INSUFFICIENT KWH
Gillig 40'	3502	Weekday	331, 232	3.381614423	436.7265162	7.16	129.15	129.15	0.00	9.96	WILL COMPLETE BLOCK	31.76	WILL COMPLETE BLOCK
Gillig 40'	4102	Weekday	48, 71X	2.565133616	139.5479008	70.33	54.40	54.40	0.00	128.98	WILL COMPLETE BLOCK	78.20	WILL COMPLETE BLOCK
Gillig 40'	2202	Weekday	80X	2.601202806	173.5645499	63.10	66.72	66.72	0.00	114.11	WILL COMPLETE BLOCK	72.88	WILL COMPLETE BLOCK
Gillig 40'	3202	Weekday	14, 15, 24	3.760012272	450.5214761	4.23	119.82	119.82	0.00	5.29	WILL COMPLETE BLOCK	29.61	WILL COMPLETE BLOCK
Gillig 40'	3702	Weekday	3, 105, 27	3.248200848	595.4987675	-26.59	183.33	144.82	38.51	0.00	INSUFFICIENT KWH	6.95	WILL COMPLETE BLOCK
Gillig 40'	3902	Weekday	107, 190, 4	3.636014029	728.5729244	-54.88	200.38	129.37	71.00	0.00	INSUFFICIENT KWH	-13.84	INSUFFICIENT KWH
Gillig 40'	5302	Weekday	3, 27, 105	3.219610907	734.3083123	-56.10	228.07	146.10	81.97	0.00	INSUFFICIENT KWH	-14.74	INSUFFICIENT KWH
Gillig 40'	1602	Weekday	512	3.053588969	854.385085	-81.63	279.80	154.05	125.75	0.00	INSUFFICIENT KWH	-33.50	INSUFFICIENT KWH
Gillig 40'	6602	Weekday	75, 49	2.814309748	149.3948767	68.24	53.08	53.08	0.00	114.06	WILL COMPLETE BLOCK	76.66	WILL COMPLETE BLOCK
Gillig 40'	3802	Weekday	232, 331	3.395916658	442.9285717	5.84	130.43	130.43	0.00	8.09	WILL COMPLETE BLOCK	30.79	WILL COMPLETE BLOCK
Gillig 40'	5002	Weekday	15, 14, 24	3.770645196	607.2704208	-29.10	161.05	124.75	36.30	0.00	INSUFFICIENT KWH	5.11	WILL COMPLETE BLOCK
Gillig 40'	1702	Weekday	525	3.368540048	514.5217079	-9.38	152.74	139.65	13.10	0.00	INSUFFICIENT KWH	19.61	WILL COMPLETE BLOCK
Gillig 40'	4202	Weekday	72X	2.483761988	167.6590593	64.36	67.50	67.50	0.00	121.89	WILL COMPLETE BLOCK	73.80	WILL COMPLETE BLOCK
Gillig 40'	402	Weekday	108	3.52229368	408.4010094	13.18	115.95	115.95	0.00	17.60	WILL COMPLETE BLOCK	36.19	WILL COMPLETE BLOCK
Gillig 40'	1402	Weekday	4, 107, 190	3.549304231	458.9420224	2.44	129.30	129.30	0.00	3.23	WILL COMPLETE BLOCK	28.29	WILL COMPLETE BLOCK
Gillig 40'	5102	Weekday	196, 197	3.632263794	500.160359	-6.33	137.70	129.51	8.19	0.00	INSUFFICIENT KWH	21.85	WILL COMPLETE BLOCK
Gillig 40'	4002	Weekday	540, 533	3.370975283	567.1037374	-20.56	168.23	139.54	28.69	0.00	INSUFFICIENT KWH	11.39	WILL COMPLETE BLOCK
Gillig 40'	6302	Weekday	49, 232, 331	3.369136319	599.6523341	-27.48	177.98	139.62	38.36	0.00	INSUFFICIENT KWH	6.30	WILL COMPLETE BLOCK
Gillig 40'	6002	Weekday	15, 24, 14	3.762738228	627.3825642	-33.37	166.74	125.02	41.72	0.00	INSUFFICIENT KWH	1.97	WILL COMPLETE BLOCK
Gillig 40'	6202	Weekday	105, 3, 27	3.227500952	747.9793992	-59.01	231.75	145.75	86.00	0.00	INSUFFICIENT KWH	-16.87	INSUFFICIENT KWH
Gillig 40'	3602	Weekday	29, 26	3.009333323	689.5757036	-46.59	229.15	156.31	72.83	0.00	INSUFFICIENT KWH	-7.75	INSUFFICIENT KWH
Gillig 40'	7102	Weekday	75	2.711589922	179.2109759	61.90	66.09	66.09	0.00	107.39	WILL COMPLETE BLOCK	72.00	WILL COMPLETE BLOCK
Gillig 40'	2402	Weekday	80S, 190S	3.541525134	82.36081976	82.49	23.26	23.26	0.00	109.57	WILL COMPLETE BLOCK	87.13	WILL COMPLETE BLOCK
Gillig 40'	5202	Weekday	232, 331	3.3936283	543.4665224	-15.53	160.14	138.61	21.53	0.00	INSUFFICIENT KWH	15.08	WILL COMPLETE BLOCK
Gillig 40'	5402	Weekday	331, 232	3.369600546	795.7607858	-69.17	236.16	139.60	96.56	0.00	INSUFFICIENT KWH	-24.34	INSUFFICIENT KWH
Gillig 40'	1102	Weekday	29	3.230237506	31.45354173	93.31	9.74	9.74	0.00	135.89	WILL COMPLETE BLOCK	95.09	WILL COMPLETE BLOCK
Gillig 40'	2302	Weekday	14S	3.947842872	105.7184908	77.53	26.78	26.78	0.00	92.37	WILL COMPLETE BLOCK	83.48	WILL COMPLETE BLOCK
Gillig 40'	2502	Weekday	105S, 190S	3.581608041	98.56652921	79.05	27.52	27.52	0.00	103.82	WILL COMPLETE BLOCK	84.60	WILL COMPLETE BLOCK
Gillig 40'	2702	Weekday	190S	3.882991939	132.1107697	71.92	34.02	34.02	0.00	87.12	WILL COMPLETE BLOCK	79.36	WILL COMPLETE BLOCK
Gillig 40'	2602	Weekday	190S	3.882991939	76.79522098	83.67	19.78	19.78	0.00	101.37	WILL COMPLETE BLOCK	88.00	WILL COMPLETE BLOCK
Gillig 40'	7302	Weekday	75, 49	2.814309748	187.8220517	60.07	66.74	66.74	0.00	100.41	WILL COMPLETE BLOCK	70.65	WILL COMPLETE BLOCK
Gillig 40'	5702	Weekday	72X, 49	2.662424458	181.9158776	61.33	68.33	68.33	0.00	108.35	WILL COMPLETE BLOCK	71.58	WILL COMPLETE BLOCK
Gillig 40'	6702	Weekday	331, 232	3.354310157	279.6712052	40.55	83.38	83.38	0.00	56.86	WILL COMPLETE BLOCK	56.30	WILL COMPLETE BLOCK
Gillig 40'	7502	Weekday	75	2.711589922	337.3710818	28.28	124.42	124.42	0.00	49.06	WILL COMPLETE BLOCK	47.29	WILL COMPLETE BLOCK
Gillig 40'	5602	Weekday	48, 71X	2.565133616	139.5479008	70.33	54.40	54.40	0.00	128.98	WILL COMPLETE BLOCK	78.20	WILL COMPLETE BLOCK
Gillig 40'	4602	Weekday	190S	3.882991939	164.5447978	65.02	42.38	42.38	0.00	78.77	WILL COMPLETE BLOCK	74.29	WILL COMPLETE BLOCK
Gillig 40'	4502	Weekday	190S	3.882991939	185.3731156	60.59	47.74	47.74	0.00	73.40	WILL COMPLETE BLOCK	71.04	WILL COMPLETE BLOCK
Gillig 40'	4802	Weekday	190S, 80S	3.746405217	157.1428898	66.59	41.94	41.94	0.00	83.62	WILL COMPLETE BLOCK	75.45	WILL COMPLETE BLOCK
Gillig 40'	6802	Weekday	232, 331	3.414986304	200.5973442	57.36	58.74	58.74	0.00	79.01	WILL COMPLETE BLOCK	68.66	WILL COMPLETE BLOCK
Gillig 40'	6502	Weekday	49, 72X	2.662424458	181.3579964	61.45	68.12	68.12	0.00	108.56	WILL COMPLETE BLOCK	71.66	WILL COMPLETE BLOCK
Gillig 40'	4702	Weekday	190S	3.882991939	141.6059705	69.90	36.47	36.47	0.00	84.68	WILL COMPLETE BLOCK	77.87	WILL COMPLETE BLOCK
Gillig 40'	7602	Weekday	49, 75	2.814309748	187.2323446	60.20	66.53	66.53	0.00	100.62	WILL COMPLETE BLOCK	70.74	WILL COMPLETE BLOCK
Gillig 40'	7002	Weekday	72X	2.483761988	167.6590593	64.36	67.50	67.50	0.00	121.89	WILL COMPLETE BLOCK	73.80	WILL COMPLETE BLOCK
Gillig 40'	4402	Weekday	80X, 50	2.656237727	416.1739511	11.53	156.68	156.68	0.00	20.41	WILL COMPLETE BLOCK	34.97	WILL COMPLETE BLOCK
Gillig 40'	6402	Weekday	48, 71X	2.565133616	139.5479008	70.33	54.40	54.40	0.00	128.98	WILL COMPLETE BLOCK	78.20	WILL COMPLETE BLOCK
Gillig 40'	5902	Weekday	80X	2.601202806	327.3971556	30.40	125.86	125.86	0.00	54.98	WILL COMPLETE BLOCK	48.84	WILL COMPLETE BLOCK
Gillig 40'	7702	Weekday	75	2.711589922	178.7294136	62.00	65.91	65.91	0.00	107.56	WILL COMPLETE BLOCK	72.07	WILL COMPLETE BLOCK
Gillig 40'	2802	Weekday	49, 75	2.814309748	187.7321494	60.09	66.71	66.71	0.00	100.44	WILL COMPLETE BLOCK	70.67	WILL COMPLETE BLOCK
Gillig 40'	7202	Weekday	72X, 525	2.926151018	243.9328853	48.14	83.36	83.36	0.00	77.39	WILL COMPLETE BLOCK	61.89	WILL COMPLETE BLOCK
Gillig 40'	4902	Weekday	190S, 80S	3.655347402	100.288019	78.68	27.44	27.44	0.00	101.25	WILL COMPLETE BLOCK	84.33	WILL COMPLETE BLOCK
Gillig 40'	2902	Weekday	49, 75	2.814309748	172.9270075	63.24	61.45	61.45	0.00	105.70	WILL COMPLETE BLOCK	72.98	WILL COMPLETE BLOCK
Gillig 40'	7402	Weekday	72X	2.483761988	157.6757138	66.48	63.48	63.48	0.00	125.91	WILL COMPLETE BLOCK	75.36	WILL COMPLETE BLOCK
Gillig 40'	3002	Weekday	49, 75	2.814309748	173.4724367	63.12	61.64	61.64	0.00	105.51	WILL COMPLETE BLOCK	72.89	WILL COMPLETE BLOCK
Gillig 40'	6902	Weekday	71X, 48	2.524501336	136.451175	70.99	54.05	54.05	0.00	132.28	WILL COMPLETE BLOCK	78.68	WILL COMPLETE BLOCK
Gillig 40'	3402	Weekday	72X	2.483761988	157.6757138	66.48	63.48	63.48	0.00	125.91	WILL COMPLETE BLOCK	75.36	WILL COMPLETE BLOCK
Gillig 40'	3102	Weekday	1	3.47922777	254.620194	45.87	73.18	73.18	0.00	62.02	WILL COMPLETE BLOCK	60.22	WILL COMPLETE BLOCK

- **Gillig 40’ Analysis: Simulation at 59°F (Spring/Fall)**

Bus Size	Block ID	Day	Route ID(s)	Energy Consumption rate (kWh/mi)	Energy Required For Completion (kWh)	SOC	Traveled Distance (in miles)	On-Route Travel Before Failure (Miles)	Miles needed to complete the block (after battery dies)	Unused Capacity [Miles]	Sufficient kWh to complete block?	SOC (Future Battery Technology)	Sufficient kWh to complete block in the future?
Gillig 40'	2102	Weekday	75	2.035734375	146.3025831	68.90	71.87	71.87	0.00	159.20	WILL COMPLETE BLOCK	77.14	WILL COMPLETE BLOCK
Gillig 40'	1902	Weekday	71X, 48	1.796968895	87.43596295	81.41	48.66	48.66	0.00	213.12	WILL COMPLETE BLOCK	86.34	WILL COMPLETE BLOCK
Gillig 40'	4302	Weekday	75, 49	1.993823644	119.0006242	74.70	59.68	59.68	0.00	176.24	WILL COMPLETE BLOCK	81.41	WILL COMPLETE BLOCK
Gillig 40'	1502	Weekday	50	1.939957791	492.9422263	-4.79	254.10	242.48	11.62	0.00	INSUFFICIENT KWH	22.98	WILL COMPLETE BLOCK
Gillig 40'	802	Weekday	331, 232	2.181462288	417.3886182	11.27	191.33	191.33	0.00	24.30	WILL COMPLETE BLOCK	34.78	WILL COMPLETE BLOCK
Gillig 40'	2002	Weekday	72X, 49	1.907563402	125.0823263	73.41	65.57	65.57	0.00	181.03	WILL COMPLETE BLOCK	80.46	WILL COMPLETE BLOCK
Gillig 40'	5802	Weekday	75	2.035734375	134.5431848	71.40	66.09	66.09	0.00	164.98	WILL COMPLETE BLOCK	78.98	WILL COMPLETE BLOCK
Gillig 40'	702	Weekday	1, 197, 196	2.273442878	322.4251284	31.46	141.82	141.82	0.00	65.09	WILL COMPLETE BLOCK	49.62	WILL COMPLETE BLOCK
Gillig 40'	1302	Weekday	232, 331	2.181462288	297.1239445	36.84	136.20	136.20	0.00	79.43	WILL COMPLETE BLOCK	53.57	WILL COMPLETE BLOCK
Gillig 40'	6102	Weekday	26, 331, 232	2.177942522	313.512054	33.35	143.95	143.95	0.00	72.03	WILL COMPLETE BLOCK	51.01	WILL COMPLETE BLOCK
Gillig 40'	1202	Weekday	27, 3, 105	2.156273685	420.8444937	10.53	195.17	195.17	0.00	22.98	WILL COMPLETE BLOCK	34.24	WILL COMPLETE BLOCK
Gillig 40'	1802	Weekday	540, 533	2.235816441	370.7438024	21.19	165.82	165.82	0.00	44.57	WILL COMPLETE BLOCK	42.07	WILL COMPLETE BLOCK
Gillig 40'	502	Weekday	15, 24, 14	2.326599824	291.2482459	38.08	125.18	125.18	0.00	77.00	WILL COMPLETE BLOCK	54.49	WILL COMPLETE BLOCK
Gillig 40'	102	Weekday	1	2.282355601	406.6953886	13.54	178.19	178.19	0.00	27.91	WILL COMPLETE BLOCK	36.45	WILL COMPLETE BLOCK
Gillig 40'	902	Weekday	26, 29	2.138146925	617.1019816	-31.19	288.62	220.00	68.61	0.00	INSUFFICIENT KWH	3.58	WILL COMPLETE BLOCK
Gillig 40'	5502	Weekday	190, 4, 107	2.258742416	397.6587601	15.46	176.05	176.05	0.00	32.20	WILL COMPLETE BLOCK	37.87	WILL COMPLETE BLOCK
Gillig 40'	3502	Weekday	331, 232	2.181462288	281.7300573	40.11	129.15	129.15	0.00	86.49	WILL COMPLETE BLOCK	55.98	WILL COMPLETE BLOCK
Gillig 40'	4102	Weekday	48, 71X	1.805293858	98.21124585	79.12	54.40	54.40	0.00	206.17	WILL COMPLETE BLOCK	84.65	WILL COMPLETE BLOCK
Gillig 40'	2202	Weekday	80X	2.210942005	147.524504	68.64	66.72	66.72	0.00	146.04	WILL COMPLETE BLOCK	76.95	WILL COMPLETE BLOCK
Gillig 40'	3202	Weekday	14, 15, 24	2.325111632	278.5929004	40.78	119.82	119.82	0.00	82.49	WILL COMPLETE BLOCK	56.47	WILL COMPLETE BLOCK
Gillig 40'	3702	Weekday	3, 105, 27	2.156742771	395.3997064	15.94	183.33	183.33	0.00	34.77	WILL COMPLETE BLOCK	38.22	WILL COMPLETE BLOCK
Gillig 40'	3902	Weekday	107, 190, 4	2.258742416	452.5996198	3.78	200.38	200.38	0.00	7.88	WILL COMPLETE BLOCK	29.28	WILL COMPLETE BLOCK
Gillig 40'	5302	Weekday	3, 27, 105	2.159340221	492.4885396	-4.70	228.07	217.84	10.23	0.00	INSUFFICIENT KWH	23.05	WILL COMPLETE BLOCK
Gillig 40'	1602	Weekday	512	2.11587945	592.0167588	-25.85	279.80	222.32	57.48	0.00	INSUFFICIENT KWH	7.50	WILL COMPLETE BLOCK
Gillig 40'	6602	Weekday	75, 49	2.007793888	106.5817721	77.34	53.08	53.08	0.00	181.20	WILL COMPLETE BLOCK	83.35	WILL COMPLETE BLOCK
Gillig 40'	3802	Weekday	232, 331	2.189836976	285.6198964	39.28	130.43	130.43	0.00	84.38	WILL COMPLETE BLOCK	55.37	WILL COMPLETE BLOCK
Gillig 40'	5002	Weekday	15, 14, 24	2.330140103	375.2740148	20.22	161.05	161.05	0.00	40.82	WILL COMPLETE BLOCK	41.36	WILL COMPLETE BLOCK
Gillig 40'	1702	Weekday	525	2.204596138	336.7371485	28.41	152.74	152.74	0.00	60.63	WILL COMPLETE BLOCK	47.38	WILL COMPLETE BLOCK
Gillig 40'	4202	Weekday	72X	1.885388646	127.267624	72.94	67.50	67.50	0.00	182.00	WILL COMPLETE BLOCK	80.11	WILL COMPLETE BLOCK
Gillig 40'	402	Weekday	108	2.197393687	254.782219	45.84	115.95	115.95	0.00	98.12	WILL COMPLETE BLOCK	60.19	WILL COMPLETE BLOCK
Gillig 40'	1402	Weekday	4, 107, 190	2.2149961	286.4095957	39.11	129.30	129.30	0.00	83.07	WILL COMPLETE BLOCK	55.25	WILL COMPLETE BLOCK
Gillig 40'	5102	Weekday	196, 197	2.263044702	311.6197817	33.75	137.70	137.70	0.00	70.16	WILL COMPLETE BLOCK	51.31	WILL COMPLETE BLOCK
Gillig 40'	4002	Weekday	540, 533	2.234002382	375.8292464	20.10	168.23	168.23	0.00	42.33	WILL COMPLETE BLOCK	41.28	WILL COMPLETE BLOCK
Gillig 40'	6302	Weekday	49, 232, 331	2.173546792	386.8565364	17.76	177.98	177.98	0.00	38.44	WILL COMPLETE BLOCK	39.55	WILL COMPLETE BLOCK
Gillig 40'	6002	Weekday	15, 24, 14	2.326599824	387.9271091	17.53	166.74	166.74	0.00	35.45	WILL COMPLETE BLOCK	39.39	WILL COMPLETE BLOCK
Gillig 40'	6202	Weekday	105, 3, 27	2.136546969	495.1487675	-5.26	231.75	220.17	11.58	0.00	INSUFFICIENT KWH	22.63	WILL COMPLETE BLOCK
Gillig 40'	3602	Weekday	29, 26	2.136342991	489.5337483	-4.07	229.15	220.19	8.96	0.00	INSUFFICIENT KWH	23.51	WILL COMPLETE BLOCK
Gillig 40'	7102	Weekday	75	2.035734375	134.5431848	71.40	66.09	66.09	0.00	164.98	WILL COMPLETE BLOCK	78.98	WILL COMPLETE BLOCK
Gillig 40'	2402	Weekday	80S, 190S	2.222484462	51.68554091	89.01	23.26	23.26	0.00	188.40	WILL COMPLETE BLOCK	91.92	WILL COMPLETE BLOCK
Gillig 40'	5202	Weekday	232, 331	2.188497026	350.4729342	25.49	160.14	160.14	0.00	54.80	WILL COMPLETE BLOCK	45.24	WILL COMPLETE BLOCK
Gillig 40'	5402	Weekday	331, 232	2.17442755	513.5101778	-9.16	236.16	216.33	19.83	0.00	INSUFFICIENT KWH	19.76	WILL COMPLETE BLOCK
Gillig 40'	1102	Weekday	29	2.116499716	20.60882892	95.62	9.74	9.74	0.00	212.52	WILL COMPLETE BLOCK	96.78	WILL COMPLETE BLOCK
Gillig 40'	2302	Weekday	14S	2.430705727	65.09138015	86.16	26.78	26.78	0.00	166.75	WILL COMPLETE BLOCK	89.83	WILL COMPLETE BLOCK
Gillig 40'	2502	Weekday	105S, 190S	2.216770838	61.00595182	87.03	27.52	27.52	0.00	184.68	WILL COMPLETE BLOCK	90.47	WILL COMPLETE BLOCK
Gillig 40'	2702	Weekday	190S	2.388149303	81.25184074	82.73	34.02	34.02	0.00	162.95	WILL COMPLETE BLOCK	87.30	WILL COMPLETE BLOCK
Gillig 40'	2602	Weekday	190S	2.388149303	47.23122178	89.96	19.78	19.78	0.00	177.20	WILL COMPLETE BLOCK	92.62	WILL COMPLETE BLOCK
Gillig 40'	7302	Weekday	75, 49	2.007793888	133.9966106	71.51	66.74	66.74	0.00	167.55	WILL COMPLETE BLOCK	79.06	WILL COMPLETE BLOCK
Gillig 40'	5702	Weekday	72X, 49	1.907563402	130.3383723	72.29	68.33	68.33	0.00	178.27	WILL COMPLETE BLOCK	79.63	WILL COMPLETE BLOCK
Gillig 40'	6702	Weekday	331, 232	2.165474247	180.5500279	61.62	83.38	83.38	0.00	133.85	WILL COMPLETE BLOCK	71.79	WILL COMPLETE BLOCK
Gillig 40'	7502	Weekday	75	2.035734375	253.282365	46.16	124.42	124.42	0.00	106.65	WILL COMPLETE BLOCK	60.42	WILL COMPLETE BLOCK
Gillig 40'	5602	Weekday	48, 71X	1.805293858	98.21124585	79.12	54.40	54.40	0.00	206.17	WILL COMPLETE BLOCK	84.65	WILL COMPLETE BLOCK
Gillig 40'	4602	Weekday	190S	2.388149303	101.1996807	78.49	42.38	42.38	0.00	154.60	WILL COMPLETE BLOCK	84.19	WILL COMPLETE BLOCK
Gillig 40'	4502	Weekday	190S	2.388149303	114.0096822	75.76	47.74	47.74	0.00	149.23	WILL COMPLETE BLOCK	82.19	WILL COMPLETE BLOCK
Gillig 40'	4802	Weekday	190S, 80S	2.321883366	97.3913501	79.30	41.94	41.94	0.00	160.65	WILL COMPLETE BLOCK	84.78	WILL COMPLETE BLOCK
Gillig 40'	6802	Weekday	232, 331	2.201003227	129.2876055	72.52	58.74	58.74	0.00	154.98	WILL COMPLETE BLOCK	79.80	WILL COMPLETE BLOCK
Gillig 40'	6502	Weekday	49, 72X	1.907563402	129.9386638	72.38	68.12	68.12	0.00	178.48	WILL COMPLETE BLOCK	79.70	WILL COMPLETE BLOCK
Gillig 40'	4702	Weekday	190S	2.388149303	87.0916564	81.49	36.47	36.47	0.00	160.50	WILL COMPLETE BLOCK	86.39	WILL COMPLETE BLOCK
Gillig 40'	7602	Weekday	49, 75	2.007793888	133.5758999	71.60	66.53	66.53	0.00	167.76	WILL COMPLETE BLOCK	79.13	WILL COMPLETE BLOCK
Gillig 40'	7002	Weekday	72X	1.885388646	127.267624	72.94	67.50	67.50	0.00	182.00	WILL COMPLETE BLOCK	80.11	WILL COMPLETE BLOCK
Gillig 40'	4402	Weekday	80X, 50	2.120613933	332.2534992	29.37	156.68	156.68	0.00	65.14	WILL COMPLETE BLOCK	48.09	WILL COMPLETE BLOCK
Gillig 40'	6402	Weekday	48, 71X	1.805293858	98.21124585	79.12	54.40	54.40	0.00	206.17	WILL COMPLETE BLOCK	84.65	WILL COMPLETE BLOCK
Gillig 40'	5902	Weekday	80X	2.210942005	278.2774653	40.84	125.86	125.86	0.00	86.90	WILL COMPLETE BLOCK	56.52	WILL COMPLETE BLOCK
Gillig 40'	7702	Weekday	75	2.035734375	134.1816504	71.47	65.91	65.91	0.00	165.16	WILL COMPLETE BLOCK	79.03	WILL COMPLETE BLOCK
Gillig 40'	2802	Weekday	49, 75	2.007793888	133.9324722	71.53	66.71	66.71	0.00	167.58	WILL COMPLETE BLOCK	79.07	WILL COMPLETE BLOCK
Gillig 40'	7202	Weekday	72X, 525	2.044992392	170.4768112	63.76	83.36	83.36	0.00	146.66	WILL COMPLETE BLOCK	73.36	WILL COMPLETE BLOCK
Gillig 40'	4902	Weekday	190S, 80S	2.277706076	62.49108638	86.72	27.44	27.44	0.00	179.09	WILL COMPLETE BLOCK	90.24	WILL COMPLETE BLOCK
Gillig 40'	2902	Weekday	49, 75	2.007793888	123.3701404	73.77	61.45	61.45	0.00	172.84	WILL COMPLETE BLOCK	80.72	WILL COMPLETE BLOCK
Gillig 40'	7402	Weekday	72X	1.885388646	119.6894074	74.56	63.48	63.48	0.00	186.02	WILL COMPLETE BLOCK	81.30	WILL COMPLETE BLOCK
Gillig 40'	3002	Weekday	49, 75	2.007793888	123.7592622	73.69	61.64	61.64	0.00	172.65	WILL COMPLETE BLOCK	80.66	WILL COMPLETE BLOCK
Gillig 40'	6902	Weekday	71X, 48	1.796968895	97.12750541	79.35	54.05	54.05	0.00	207.72	WILL COMPLETE BLOCK	84.82	WILL COMPLETE BLOCK
Gillig 40'	3402	Weekday	72X	1.885388646	119.6894074	74.56	63.48	63.48	0.00	186.02	WILL COMPLETE BLOCK	81.30	WILL COMPLETE BLOCK
Gillig 40'	3102	Weekday	1	2.282355601	167.0295434	64.49	73.18	73.18	0.00	132.92	WILL COMPLETE BLOCK	73.90	WILL COMPLETE BLOCK

- **Gillig 40’ Analysis: Simulation at 91°F (Summer)**

Bus Size	Block ID	Day	Route ID(s)	Energy Consumption rate (kWh/mi)	Energy Required For Completion (kWh)	SOC	Traveled Distance (in miles)	On-Route Travel Before Failure (Miles)	Miles needed to complete the block (after battery dies)	Unused Capacity [Miles]	Sufficient kWh to complete block?	SOC (Future Battery Technology)	Sufficient kWh to complete block in the future?
Gillig 40'	2102	Weekday	75	2.086177726	149.9278068	68.13	71.87	71.87	0.00	153.62	WILL COMPLETE BLOCK	76.57	WILL COMPLETE BLOCK
Gillig 40'	1902	Weekday	71X, 48	1.849847398	90.00889721	80.87	48.66	48.66	0.00	205.63	WILL COMPLETE BLOCK	85.94	WILL COMPLETE BLOCK
Gillig 40'	4302	Weekday	75, 49	2.056823063	122.7607212	73.90	59.68	59.68	0.00	169.02	WILL COMPLETE BLOCK	80.82	WILL COMPLETE BLOCK
Gillig 40'	1502	Weekday	50	1.999986082	508.1953826	-8.03	254.10	235.20	18.90	0.00	INSUFFICIENT KWH	20.59	WILL COMPLETE BLOCK
Gillig 40'	802	Weekday	331, 232	2.277552226	435.7739218	7.36	191.33	191.33	0.00	15.20	WILL COMPLETE BLOCK	31.91	WILL COMPLETE BLOCK
Gillig 40'	2002	Weekday	72X, 49	1.963354403	128.7406415	72.63	65.57	65.57	0.00	174.02	WILL COMPLETE BLOCK	79.88	WILL COMPLETE BLOCK
Gillig 40'	5802	Weekday	75	2.086177726	137.8770231	70.69	66.09	66.09	0.00	159.39	WILL COMPLETE BLOCK	78.46	WILL COMPLETE BLOCK
Gillig 40'	702	Weekday	1, 197, 196	2.371775882	336.3709512	28.49	141.82	141.82	0.00	56.51	WILL COMPLETE BLOCK	47.44	WILL COMPLETE BLOCK
Gillig 40'	1302	Weekday	232, 331	2.277552226	310.2117808	34.05	136.20	136.20	0.00	70.33	WILL COMPLETE BLOCK	51.53	WILL COMPLETE BLOCK
Gillig 40'	6102	Weekday	26, 331, 232	2.269972933	326.7597146	30.54	143.95	143.95	0.00	63.28	WILL COMPLETE BLOCK	48.94	WILL COMPLETE BLOCK
Gillig 40'	1202	Weekday	27, 3, 105	2.238154494	436.8253444	7.14	195.17	195.17	0.00	15.00	WILL COMPLETE BLOCK	31.75	WILL COMPLETE BLOCK
Gillig 40'	1802	Weekday	540, 533	2.318240191	384.4113352	18.28	165.82	165.82	0.00	37.09	WILL COMPLETE BLOCK	39.94	WILL COMPLETE BLOCK
Gillig 40'	502	Weekday	15, 24, 14	2.440513772	305.5082133	35.05	125.18	125.18	0.00	67.56	WILL COMPLETE BLOCK	52.26	WILL COMPLETE BLOCK
Gillig 40'	102	Weekday	1	2.373556693	422.9466089	10.09	178.19	178.19	0.00	19.99	WILL COMPLETE BLOCK	33.91	WILL COMPLETE BLOCK
Gillig 40'	902	Weekday	26, 29	2.202877775	635.784297	-35.16	288.62	213.54	75.08	0.00	INSUFFICIENT KWH	0.66	WILL COMPLETE BLOCK
Gillig 40'	5502	Weekday	190, 4, 107	2.365540721	416.4609403	11.47	176.05	176.05	0.00	22.80	WILL COMPLETE BLOCK	34.93	WILL COMPLETE BLOCK
Gillig 40'	3502	Weekday	331, 232	2.277552226	294.1398174	37.47	129.15	129.15	0.00	77.39	WILL COMPLETE BLOCK	54.04	WILL COMPLETE BLOCK
Gillig 40'	4102	Weekday	48, 71X	1.859698889	101.1709778	78.49	54.40	54.40	0.00	198.54	WILL COMPLETE BLOCK	84.19	WILL COMPLETE BLOCK
Gillig 40'	2202	Weekday	80X	2.24008417	149.4690071	68.23	66.72	66.72	0.00	143.27	WILL COMPLETE BLOCK	76.65	WILL COMPLETE BLOCK
Gillig 40'	3202	Weekday	14, 15, 24	2.438880942	292.2246425	37.88	119.82	119.82	0.00	73.06	WILL COMPLETE BLOCK	54.34	WILL COMPLETE BLOCK
Gillig 40'	3702	Weekday	3, 105, 27	2.240486119	410.7525319	12.68	183.33	183.33	0.00	26.62	WILL COMPLETE BLOCK	35.82	WILL COMPLETE BLOCK
Gillig 40'	3902	Weekday	107, 190, 4	2.365540721	473.9995246	-0.77	200.38	198.86	1.52	0.00	INSUFFICIENT KWH	25.94	WILL COMPLETE BLOCK
Gillig 40'	5302	Weekday	3, 27, 105	2.240755983	511.057327	-8.64	228.07	209.93	18.14	0.00	INSUFFICIENT KWH	20.15	WILL COMPLETE BLOCK
Gillig 40'	1602	Weekday	512	2.187771094	612.1318262	-30.13	279.80	215.01	64.78	0.00	INSUFFICIENT KWH	4.35	WILL COMPLETE BLOCK
Gillig 40'	6602	Weekday	75, 49	2.066607951	109.7038591	76.68	53.08	53.08	0.00	174.54	WILL COMPLETE BLOCK	82.86	WILL COMPLETE BLOCK
Gillig 40'	3802	Weekday	232, 331	2.286601345	298.2408491	36.60	130.43	130.43	0.00	75.29	WILL COMPLETE BLOCK	53.40	WILL COMPLETE BLOCK
Gillig 40'	5002	Weekday	15, 14, 24	2.4444742	393.687764	16.31	161.05	161.05	0.00	31.38	WILL COMPLETE BLOCK	38.49	WILL COMPLETE BLOCK
Gillig 40'	1702	Weekday	525	2.289333503	349.6802078	25.66	152.74	152.74	0.00	52.73	WILL COMPLETE BLOCK	45.36	WILL COMPLETE BLOCK
Gillig 40'	4202	Weekday	72X	1.931297405	130.3665599	72.29	67.50	67.50	0.00	176.06	WILL COMPLETE BLOCK	79.63	WILL COMPLETE BLOCK
Gillig 40'	402	Weekday	108	2.299689534	266.6431627	43.32	115.95	115.95	0.00	88.60	WILL COMPLETE BLOCK	58.34	WILL COMPLETE BLOCK
Gillig 40'	1402	Weekday	4, 107, 190	2.316552561	299.5413321	36.32	129.30	129.30	0.00	73.76	WILL COMPLETE BLOCK	53.20	WILL COMPLETE BLOCK
Gillig 40'	5102	Weekday	196, 197	2.36969827	326.3059086	30.63	137.70	137.70	0.00	60.81	WILL COMPLETE BLOCK	49.01	WILL COMPLETE BLOCK
Gillig 40'	4002	Weekday	540, 533	2.316384976	389.6885818	17.16	168.23	168.23	0.00	34.84	WILL COMPLETE BLOCK	39.11	WILL COMPLETE BLOCK
Gillig 40'	6302	Weekday	49, 232, 331	2.268928645	403.8329795	14.15	177.98	177.98	0.00	29.34	WILL COMPLETE BLOCK	36.90	WILL COMPLETE BLOCK
Gillig 40'	6002	Weekday	15, 24, 14	2.440513772	406.9206242	13.49	166.74	166.74	0.00	26.01	WILL COMPLETE BLOCK	36.42	WILL COMPLETE BLOCK
Gillig 40'	6202	Weekday	105, 3, 27	2.220241823	514.5452069	-9.38	231.75	211.87	19.88	0.00	INSUFFICIENT KWH	19.60	WILL COMPLETE BLOCK
Gillig 40'	3602	Weekday	29, 26	2.203126324	504.8368599	-7.32	229.15	213.51	15.63	0.00	INSUFFICIENT KWH	21.12	WILL COMPLETE BLOCK
Gillig 40'	7102	Weekday	75	2.086177726	137.8770231	70.69	66.09	66.09	0.00	159.39	WILL COMPLETE BLOCK	78.46	WILL COMPLETE BLOCK
Gillig 40'	2402	Weekday	80S, 190S	2.326541948	54.10547569	88.50	23.26	23.26	0.00	178.93	WILL COMPLETE BLOCK	91.55	WILL COMPLETE BLOCK
Gillig 40'	5202	Weekday	232, 331	2.285153486	365.9518097	22.20	160.14	160.14	0.00	45.71	WILL COMPLETE BLOCK	42.82	WILL COMPLETE BLOCK
Gillig 40'	5402	Weekday	331, 232	2.269950966	536.0688721	-13.96	236.16	207.23	28.93	0.00	INSUFFICIENT KWH	16.24	WILL COMPLETE BLOCK
Gillig 40'	1102	Weekday	29	2.205860367	21.47895347	95.43	9.74	9.74	0.00	203.51	WILL COMPLETE BLOCK	96.64	WILL COMPLETE BLOCK
Gillig 40'	2302	Weekday	14S	2.548837566	68.25480892	85.49	26.78	26.78	0.00	157.78	WILL COMPLETE BLOCK	89.34	WILL COMPLETE BLOCK
Gillig 40'	2502	Weekday	105S, 190S	2.319353344	63.82904174	86.43	27.52	27.52	0.00	175.29	WILL COMPLETE BLOCK	90.03	WILL COMPLETE BLOCK
Gillig 40'	2702	Weekday	190S	2.508949231	85.36180847	81.85	34.02	34.02	0.00	153.47	WILL COMPLETE BLOCK	86.66	WILL COMPLETE BLOCK
Gillig 40'	2602	Weekday	190S	2.508949231	49.62032208	89.45	19.78	19.78	0.00	167.71	WILL COMPLETE BLOCK	92.25	WILL COMPLETE BLOCK
Gillig 40'	7302	Weekday	75, 49	2.066607951	137.9217571	70.68	66.74	66.74	0.00	160.88	WILL COMPLETE BLOCK	78.45	WILL COMPLETE BLOCK
Gillig 40'	5702	Weekday	72X, 49	1.963354403	134.1504125	71.48	68.33	68.33	0.00	171.26	WILL COMPLETE BLOCK	79.04	WILL COMPLETE BLOCK
Gillig 40'	6702	Weekday	331, 232	2.260276635	188.4543352	59.94	83.38	83.38	0.00	124.74	WILL COMPLETE BLOCK	70.55	WILL COMPLETE BLOCK
Gillig 40'	7502	Weekday	75	2.086177726	259.5584349	44.82	124.42	124.42	0.00	101.07	WILL COMPLETE BLOCK	59.44	WILL COMPLETE BLOCK
Gillig 40'	5602	Weekday	48, 71X	1.859698889	101.1709778	78.49	54.40	54.40	0.00	198.54	WILL COMPLETE BLOCK	84.19	WILL COMPLETE BLOCK
Gillig 40'	4602	Weekday	190S	2.508949231	106.3186714	77.40	42.38	42.38	0.00	145.11	WILL COMPLETE BLOCK	83.39	WILL COMPLETE BLOCK
Gillig 40'	4502	Weekday	190S	2.508949231	119.7766422	74.54	47.74	47.74	0.00	139.75	WILL COMPLETE BLOCK	81.28	WILL COMPLETE BLOCK
Gillig 40'	4802	Weekday	190S, 80S	2.435986318	102.1773961	78.28	41.94	41.94	0.00	151.16	WILL COMPLETE BLOCK	84.03	WILL COMPLETE BLOCK
Gillig 40'	6802	Weekday	232, 331	2.298666836	135.0243959	71.30	58.74	58.74	0.00	145.90	WILL COMPLETE BLOCK	78.90	WILL COMPLETE BLOCK
Gillig 40'	6502	Weekday	49, 72X	1.963354403	133.7390136	71.57	68.12	68.12	0.00	171.47	WILL COMPLETE BLOCK	79.10	WILL COMPLETE BLOCK
Gillig 40'	4702	Weekday	190S	2.508949231	91.49701994	80.55	36.47	36.47	0.00	151.02	WILL COMPLETE BLOCK	85.70	WILL COMPLETE BLOCK
Gillig 40'	7602	Weekday	49, 75	2.066607951	137.4887225	70.77	66.53	66.53	0.00	161.09	WILL COMPLETE BLOCK	78.52	WILL COMPLETE BLOCK
Gillig 40'	7002	Weekday	72X	1.931297405	130.3665599	72.29	67.50	67.50	0.00	176.06	WILL COMPLETE BLOCK	79.63	WILL COMPLETE BLOCK
Gillig 40'	4402	Weekday	80X, 50	2.160051474	338.4324932	28.05	156.68	156.68	0.00	61.09	WILL COMPLETE BLOCK	47.12	WILL COMPLETE BLOCK
Gillig 40'	6402	Weekday	48, 71X	1.859698889	101.1709778	78.49	54.40	54.40	0.00	198.54	WILL COMPLETE BLOCK	84.19	WILL COMPLETE BLOCK
Gillig 40'	5902	Weekday	80X	2.24008417	281.9454077	40.06	125.86	125.86	0.00	84.13	WILL COMPLETE BLOCK	55.95	WILL COMPLETE BLOCK
Gillig 40'	7702	Weekday	75	2.086177726	137.5065302	70.77	65.91	65.91	0.00	159.57	WILL COMPLETE BLOCK	78.51	WILL COMPLETE BLOCK
Gillig 40'	2802	Weekday	49, 75	2.066607951	137.8557399	70.69	66.71	66.71	0.00	160.91	WILL COMPLETE BLOCK	78.46	WILL COMPLETE BLOCK
Gillig 40'	7202	Weekday	72X, 525	2.110315454	175.9223412	62.60	83.36	83.36	0.00	139.54	WILL COMPLETE BLOCK	72.51	WILL COMPLETE BLOCK
Gillig 40'	4902	Weekday	190S, 80S	2.387344376	65.49912002	86.08	27.44	27.44	0.00	169.60	WILL COMPLETE BLOCK	89.77	WILL COMPLETE BLOCK
Gillig 40'	2902	Weekday	49, 75	2.066607951	126.984007	73.01	61.45	61.45	0.00	166.17	WILL COMPLETE BLOCK	80.16	WILL COMPLETE BLOCK
Gillig 40'	7402	Weekday	72X	1.931297405	122.6038156	73.94	63.48	63.48	0.00	180.08	WILL COMPLETE BLOCK	80.84	WILL COMPLETE BLOCK
Gillig 40'	3002	Weekday	49, 75	2.066607951	127.3845273	72.92	61.64	61.64	0.00	165.98	WILL COMPLETE BLOCK	80.10	WILL COMPLETE BLOCK
Gillig 40'	6902	Weekday	71X, 48	1.849847398	99.98562783	78.74	54.05	54.05	0.00	200.24	WILL COMPLETE BLOCK	84.38	WILL COMPLETE BLOCK
Gillig 40'	3402	Weekday	72X	1.931297405	122.6038156	73.94	63.48	63.48	0.00	180.08	WILL COMPLETE BLOCK	80.84	WILL COMPLETE BLOCK
Gillig 40'	3102	Weekday	1	2.373556693	173.7039095	63.07	73.18	73.18	0.00	125.00	WILL COMPLETE BLOCK	72.86	WILL COMPLETE BLOCK