FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

UTA Paratransit Vehicle Accessory Electrification Project: Eparc System Deployment and Validation Study

AUGUST 2020

FTA Report No. 0171
Federal Transit Administration

PREPARED BY

Matt Boothe and Alexis Hedges
Center for Transportation and the Environment

U.S. Department of Transportation
Federal Transit Administration

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Federal Transit Administration
Office of Research, Demonstration and Innovation
U.S. Department of Transportation
1200 New Jersey Avenue, SE
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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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13. ABSTRACT

The Center for Transportation and the Environment (CTE) partnered with the University of Texas Center for Electromechanics (UT-CEM), Utah Transit Authority (UTA), Mobile Climate Control, and Transworld Associates to develop a system that will electrify the auxiliary loads of a paratransit vehicle to improve efficiency and passenger comfort by eliminating engine idling during passenger pickups. The project team is responsible for system design, demonstration, and reporting of results. The project received funding as part of the FTA Bus Efficiency Enhancements Research and Demonstration Projects.

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ABSTRACT

The Center for Transportation and the Environment (CTE) partnered with the University of Texas Center for Electromechanics (UT-CEM), Utah Transit Authority (UTA), Mobile Climate Control, and Transworld Associates to develop a system that will electrify the auxiliary loads of a paratransit vehicle to improve efficiency and passenger comfort by eliminating engine idling during passenger pickups. The project team is responsible for system design, demonstration, and reporting of results. The project received funding as part of the FTA Bus Efficiency Enhancements Research and Demonstration Projects.

EXECUTIVE SUMMARY

The purpose of this project was to develop a means by which to electrify the heating and cooling loads for a paratransit vehicle to eliminate engine idling during passenger loading and unloading operations, as idling can represent a significant amount of service time for paratransit vehicles. The Federal Transit Administration (FTA) awarded funding to the Center for Transportation and the Environment (CTE) and project partners Utah Transit Authority (UTA), University of Texas at Austin Center for Electromechanics, Mobile Climate Control, and Transworld Associates to complete this study, with UTA acting as a third-party evaluator.

The results of the effort were inconclusive for emissions reductions, although idling time was reduced by 19%. UTA operated two paratransit vehicles retrofitted with the electrified auxiliary system in service. The goal was to test the functionality of the system as applied in service to observe an overall improvement in fuel consumption as a result of the eliminated idling load. The alternator installed to charge the battery will slightly increase fuel consumption while driving, but the elimination of idling was expected to result in a net reduction in fuel consumption. The team also hoped to reduce or eliminate paratransit vehicle idling, which should not only result in reduced maintenance costs but also reduce paratransit rider exposure to engine noise and harmful diesel emissions. The project team observed a reduction in time spent idling and a decrease, on average, in fuel consumption; however, there were some months during which fuel consumption increased compared to the period before the test. Potential sources were that the vehicles were older than the average age of the fleet and reduced vehicle availability resulted in a different duty cycle than the comparison fleet. The reasons for reduced availability are discussed later in the report.

Despite the problems with availability and the inconclusive results on fuel economy, the team believes that the reduction in idle time alone is proof that the system shows promise. Furthermore, the team received substantial positive feedback about the Mobile Climate Control heating and cooling system developed under this project. This system should have broad application beyond this project and should find applications in hybrid and fully electric paratransit buses to come. The independent evaluation by UTA also found the technology promising despite the project's problems.

SECTION

1

Introduction

This report summarizes the results of a project to develop a system for paratransit buses to electrify the heating, ventilation, and air conditioning (HVAC) system to improve efficiency and comfort and reduce engine idling. The developed system, deemed Eparc, can be retrofitted onto existing diesel-powered paratransit buses. After the retrofit, the buses are still diesel-powered, but the diesel engine can be turned off during passenger loading and unloading while still operating the electrified HVAC system.

This project was funded as part of the Federal Transit Administration (FTA) Bus Efficiency Enhancements Research and Demonstration (BEERD) Program. The BEERD Program was developed "to promote the development and demonstration of targeted energy efficiency-enhancing technologies—specifically enhanced Electrification of Accessories and improvements in Thermal Management of Bus Bodies—for buses utilized in public transportation."[1] The program also aims to produce overall favorable impacts on the transit-riding public and participants in the industry as well as advancing the US Department of Transportation's (USDOT) research goals. Finally, "this program invests in promising technologies that could help save energy, reduce emissions, and bring cost-savings to transit providers across the country."

Background

Idling engines to power accessories on vehicles wastes fuel, increases emissions, and causes unnecessary wear and tear on engines. Paratransit vehicle operations differ from fixed-route operations due to the mission of transporting people who are physically incapable of using scheduled operations. Therefore, these vehicles have a demonstrated tendency to idle at stops for 20–25% of their daily use, according to the team's partner, the Utah Transit Agency (UTA). The bus engine idles to power lighting, communications equipment, and passenger lifting devices. Engine idling is also necessary to power air conditioning and heating systems during these stops.

Diesel exhaust has been shown to cause significant eye and nasal irritation after one hour of exposure as well as several long-term effects such as reduced lung function and other non-cancerous effects from prolonged exposure.[2] Long-term exposure to diesel exhaust also has a demonstrated association with a not-insignificant increase in lung cancer risk. Reductions in idling emissions on paratransit vehicles can, therefore, have a significant positive effect due to the

[1]https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Report_No._0091.pdf.
[2]https://ww3.arb.ca.gov/toxics/dieseltac/de-fnds.htm.

large amount of time in service spent idling. This improvement would benefit not only the riders who rely on paratransit for everyday mobility but also the operators who spend a significant amount of time assisting passengers.

Reducing engine idling time also offers the potential to reduce fuel costs. The BAE HybriDrive System uses electrified accessories to attain a fuel economy improvement of 10–20% compared to traditional mechanically-driven accessories.[3] By electrifying the HVAC system in paratransit vehicles, the project team aimed to allow paratransit operators to reduce engine run time to realize significant fuel and maintenance savings in the long run. Reducing idling time is also expected to reduce maintenance costs. Idling an engine causes large amounts of wear and tear that can be eliminated by operating the stationary air conditioning and heating from an auxiliary battery as opposed to from the engine.

FTA awarded funding to six project partners to design, build, and test an auxiliary power unit (APU)-driven idling reduction system to improve fuel efficiency of the vehicle. The Eparc system was expected to improve fuel efficiency and maintainability by eliminating the idling load on the engine and, instead, powering the HVAC load from a high-voltage battery. When the bus restarts and is underway, the high-voltage battery recharges using power supplied by a high-voltage alternator.

The project provided the team with the unique opportunity to build and test the reduced idling system for a paratransit vehicle to assess technology readiness and estimate achievable benefits.

Partners

Six organizations contributed to the project—the Center for Transportation and the Environment (CTE), the Utah Transit Authority (UTA), the University of Texas at Austin Center for Electromechanics (CEM), Transworld Associates (TWA), Mobile Climate Control (MCC), and third-party evaluator University of Utah (UoU).

Center for Transportation and the Environment

CTE is a non-profit, 501(c)(3), member-based organization that facilitates the development of technologies to improve the sustainability of transportation systems. It relies on the experience and resources of members and project partners to successfully develop, demonstrate, and deploy advanced transportation technologies across an array of markets. Recognizing the value of working collaboratively in a team environment, CTE manages large, technical, multi-partner grants, contracts, and cooperative agreements. The centralized,

[3] https://www.hybridrive.com/pdfs/HybriDrive%C2%AE%20Electrified%20Accessories%20brochure.

structured management of its work program enables team members to concentrate on exceeding project goals and ensure production of deliverables in a clear and well-coordinated manner. CTE also provides technical support to project teams such as technical oversight, risk analysis, and mitigation strategies.

Since 1993, CTE has managed a portfolio of more than $400 million in Federal, State, and local cost-shared research, development, and demonstration projects involving more than 100 organizations in the advanced transportation technology field. It has facilitated and leveraged funding for its projects and initiatives from Federal, State, and local entities including the U.S. Departments of Defense (DOD), Energy (DOE), Interior (DOI), and Transportation (DOT) as well as from the U.S. Army and NASA, the California Air Resources Board, and the California Energy Commission, among others. CTE maintains offices in Atlanta, GA; Berkeley, CA; Los Angeles, CA; and St. Paul, MN.

CTE managed the project and assisted in the development of the Eparc system. It also provided technical assistance in the field, specifically to test the vehicles before delivery and collect data on alternator failures.

Utah Transit Authority

UTA provides more than 42 million rides per year in an area with a growing population and an increased reliance on mass transit and currently employs more than 2,200 people, with 856 direct vehicle/train operators. It provides regular fixed-route service, commuter bus, bus rapid transit (BRT), light rail, commuter rail, paratransit, and transportation demand management carpool and vanpool services. All buses and trains are wheelchair accessible, and bicycles can be transported on buses and trains.

UTA serves its six-county area with 592 buses that include 496 fixed-route buses and 96 paratransit buses. During the next nine years, the agency plans to replace more than 360 buses using FTA formula and local funds. UTA operates 98 bus routes, 3 TRAX light rail lines, 1 BRT service, and 1 commuter rail line and is in the construction phases of a new streetcar line. It is completing studies and environmental work on additional BRT and streetcar lines.

Robust bus service is a key part of the system that enables the great growth UTA has seen in its expanding rail system—supporting and feeding 60 rail stations and 19,421,608 rail passengers in 2012.

For this project, UTA operated, maintained, and collected operational data on the retrofitted vehicles and upfitted a second bus to test of the feasibility of field retrofits of the Eparc system.

University of Texas at Austin Center for Electromechanics

CEM is a research center world-renowned for development and demonstration of advanced energy storage and power generation systems; it teams with companies to get the technology to market, and its annual budget addresses both development programs and active technology transfer programs.

CEM conducts research and public outreach programs, educates students, and transfers research results to industry for commercialization. Research projects in the transportation sector include fuel-efficient hybrid-electric vehicles and trains, zero-emission fuel-cell vehicles including hydrogen generation technologies, active suspension for improved ride control, and advanced vehicle energy storage for improved fuel economy and reduced emissions. Research projects in the Electric Power, Defense, and Space sectors include advanced generators with large-scale energy storage, electric grid control, electric aircraft launch for the next-generation all-electric ships, advanced wheeled and tracked military vehicles, and space power with integrated attitude control.

CEM has completed multiple programs funded by US DOT and DOD to advance hydrogen-powered, hybrid-electric vehicles, including state-of-the-art energy storage (chemical batteries, ultracapacitors, and flywheels) for improved vehicle performance. It also recently led the systems design and simulation for demonstration tasks in an FTA program to develop a Bus Exportable Power Supply (BEPS) system for emergency response. CEM's 140,000 square foot laboratory features extensive prototype testing and assembly facilities.

CEM led the system design efforts and requirements definition for the paratransit bus and integration of the prototype vehicle APU and provided the kit and instructions to UTA for upfitting the second vehicle in the field.

Transworld Associates

TWA is a consultancy that provides advice and inspection services to transit agencies purchasing buses, especially zero-emission buses. It also facilitates relationships between U.S. and European manufacturers of bus equipment.

TWA provided advice on component selection, system design, and integration of the system into the paratransit buses and analyzed some of the data collected during the demonstration.

Mobile Climate Control

MCC is a global company that develops, designs, manufactures, and services heating, defrosting, ventilation, air conditioning, and refrigeration systems for the commercial vehicle industry. This includes both combustion engine and electrically-powered city and transit, coach and tourist, school, shuttle and mini buses; vocational trucks; construction, compact, agricultural, forestry, mining, material handling, side-by-side, utility, and military or defense vehicles; and battery and electronics cooling.

MCC is part of the VBG Group, an international industrial group with more than 1,400 employees in 18 countries. VBG is a long-term owner that provides active management of the its four wholly-owned divisions through considerable industry expertise, a strong corporate culture, and financial resilience. VBG's divisions—VBG Truck Equipment, Edscha Trailer Systems, Ringfeder Power Transmission, and Mobile Climate Control—develop, manufacture, market, and sell products under strong, well-known brands all over the world.

MCC developed a high voltage heating and cooling system sized for paratransit vehicles for the project.

University of Utah

As a major urban campus located in Salt Lake City, UoU provides comprehensive instructional undergraduate and graduate opportunities focusing on sustainably-built environments. The Department of Civil & Environmental Engineering is part of the College of Engineering at UoU, and the mission of the Transportation Engineering program is to provide the highest-quality environment in fostering education, research, and training in transportation science and engineering by creating opportunities for creative and critical thinking. The objective is to build technical expertise and leadership skills in UoU's students while encouraging them to strive for innovation. UoU aims to develop life-long learning skills by way of experimental training and hands-on schooling that will ultimately benefit the state of Utah, the nation, and the world. UoU trains students in areas relevant to urban science, big-data applications in transportation, and smart-city systems.

UoU worked with UTA throughout the demonstration to collect bus operational data and assessed vehicle performance as a third-party evaluator.

Purpose

The purpose of the project was to design and deploy paratransit anti-idling technology to lower operating costs, improve fuel economy, and improve air quality for vulnerable populations. The Eparc system was installed on UTA paratransit vehicles, and data were collected while the vehicles operated in service.

Approach

The project approach was to develop system requirements based on assessment of the paratransit service at UTA, design a system to meet those requirements and then integrate and test that prototype system in a lab at CEM and in a diesel paratransit bus at CEM. Once the prototype worked bus worked correctly at

CEM, it was delivered to UTA. A second bus was integrated by UTA to assess the feasibility of field retrofits. An in-service demonstration with both buses followed.

The elements of the project are summarized below, and Appendix A has further details of the workplan.

- **System Design, Build, Install, and Tuning** – This milestone included assessing the requirements of the vehicle, developing the components of the system, designing the system as a whole, and debugging and testing the system on a prototype vehicle in service at UTA.
- **Demonstration Vehicle Build** – This milestone required the production of a second demonstrator vehicle assembled by UTA based on the prototype vehicle developed in the previous task. This also included continued debugging and testing while demonstrating the vehicle in service.
- **In-Service Demonstration** – UTA operated and maintained both the prototype and demonstrator buses and collected operational data. It also integrated the second vehicle on site using a kit provided by CEM.
- **Test and Independent Evaluation** – UTA tested both vehicles in service for the qualitative effectiveness of the system. UoU reviewed the data collected during the in-service testing to determine effectiveness for efficiency improvements.
- **Project Management** – CTE managed the project through a kick-off meeting, quarterly reporting to FTA, continued data collection and reporting, and development of the final report.

SECTION

2

Technical Description

The Eparc project aimed to enhance the efficiency of paratransit buses through the electrification of HVAC systems using a purpose-built APU that included a high-voltage alternator and electrical energy storage system. Additional upgrades to the vehicle included a newly-designed HVAC system with a high-voltage electric refrigerant compressor, which replaced the traditional belt-driven compressor tied to the engine.

Design Goals and Expected System Benefits

Air conditioner load represents one of the greatest opportunities for improving fuel economy from traditionally mechanically-driven accessories. This is especially true in paratransit applications, as there are long dwell times for passenger loading and unloading. During this time, the engine will typically run for the sole purpose of maintaining cabin temperature. By electrifying the air conditioner and using an advanced high-voltage alternator and energy storage system coupled to a high-voltage HVAC compressor, the Eparc system allows paratransit operators to greatly reduce engine run time during passenger stops to realize fuel, emissions, and maintenance savings.

The Eparc system design coupled the electric air conditioning system to an advanced APU by using currently-available and off-the-shelf commercial components. While at passenger stops, the vehicle's engine can be shut off while the battery energy storage system powers the HVAC system and other auxiliary loads, such as the wheelchair ramp and lights. The battery system was sized to be capable of cooling or heating the cabin for 30+ minutes without an additional recharge from the high-voltage alternator. When the operator resumes driving or the engine is turned on, the belt-driven alternator recharges the batteries.

The Eparc vehicle retrofit was intended to improve operational efficiency and reduce emissions for paratransit vehicle operators and to eliminate idling at passenger stops, improve fuel economy, and reduce engine maintenance.

Eparc System Design

The Eparc system electrifies the accessories onboard a paratransit bus, along with the HVAC, using a high-voltage battery recharged with an alternator or, alternatively, a plug-in charger. During vehicle stops, the engine is turned off to reduce vehicle emissions, improve fuel economy, and reduce engine idle time. While the engine is off, the HVAC system uses energy stored in the high-voltage battery to provide HVAC during loading and unloading.

The Eparc system consists of an engine-driven high-voltage alternator, a high-voltage battery for energy storage, and high-voltage HVAC air compressor and auxiliary heater elements. The high-voltage alternator is installed as a belt-driven engine accessory using the existing engine belt system where the traditional compressor had been previously installed. The team installed a shore-powered high-voltage battery charger for charging the battery overnight while the bus is not used. The shore charger helped to not only replenish any of the energy used during the day that was not recharged in service but also to troubleshoot problems encountered during the in-service testing. Figure 2-1 shows an electrical schematic of the Eparc system and all main components.

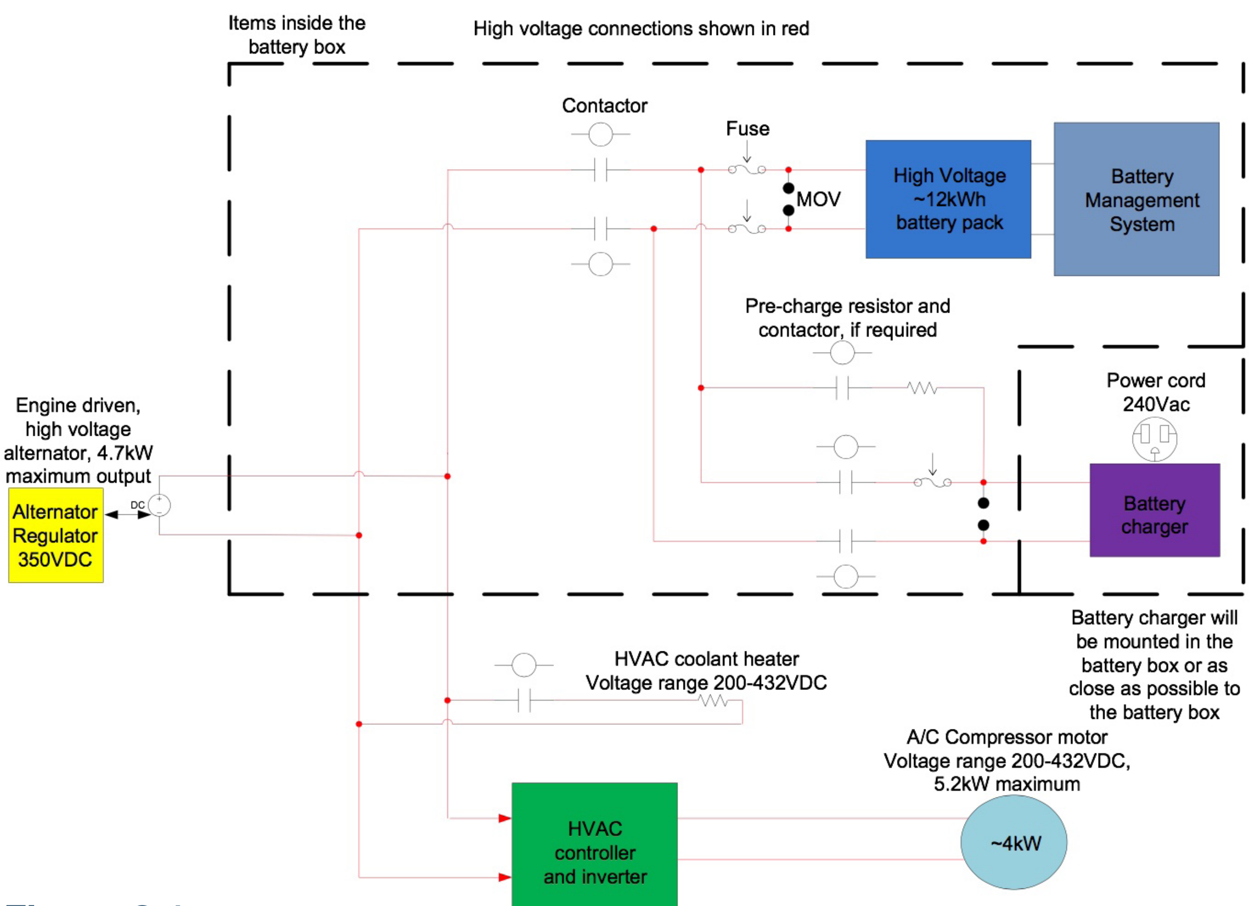


Figure 2-1

Eparc system schematic

To size these components, a system model was simulated using Matlab and Simulink software to study the trade-offs in battery energy storage size and alternator size with respect to drive cycles and expected loads. The project team collected drive cycle data in January 2016 after the project team's kick-off meeting at UTA on two morning service routes. The routes generally stayed at speeds below 45 mph and included several passenger stops that were 1–9 minutes in duration. In one instance, the bus stopped for 15 minutes prior to the second segment of the route, but in this case, the vehicle engine was shut down by the driver. During this visit, CEM also performed several driving and loading scenarios to gain further information. This included noting shift points during acceleration, measuring fuel consumption at various speeds, monitoring the 12 VDC accessory load (both with and without the lift operation), and determining how long the engine coolant could be recirculated while maintaining warmth in the bus cabin.

Upon collecting these data, the project team was unsure if the drive cycle was representative of normal operations, as the duration of the stops was less than anticipated. UTA was able to provide further details showing the amount of time spent at each stop for an entire month for its paratransit fleet. The results are shown in Table 2-1.

Table 2-1

Stop Duration for UTA Paratransit Fleet, December 2015

No. of Events	Duration (min)	% of Events
2570	2–5	68.8%
813	5–10	21.8%
252	10–15	6.7%
63	15–20	1.7%
25	20–25	0.7%
8	25–30	0.2%
6	30–60	0.2%
0	60+	0.0%

The information in Table 2-1 indicates that less than 3% of the drive cycle spends more than 15 minutes at a stop. A battery energy storage sized to deliver 20 minutes of operation would be able to operate idle-free on 99% of passenger stops. Thus, the team used 20 minutes of idle-free operation as its design criteria and, noting that the batteries could withstand an occasional deep discharge, the design goal was to provide power for 30 minutes on rare occasions.

CEM used the duty cycle data and other operational profile information to develop a simulation of the vehicle. Figure 2-2 shows the expected duty cycle from the alternator during a drive cycle. The alternator power is a function of engine speed, which is tied to the vehicle speed and transmission gearing. In this duty cycle, the alternator provides an average power of 3.3 kW. Thus, to maintain a charge sustaining operation, the HVAC compressor or heating element must not draw more than 3.3 kW, on average.

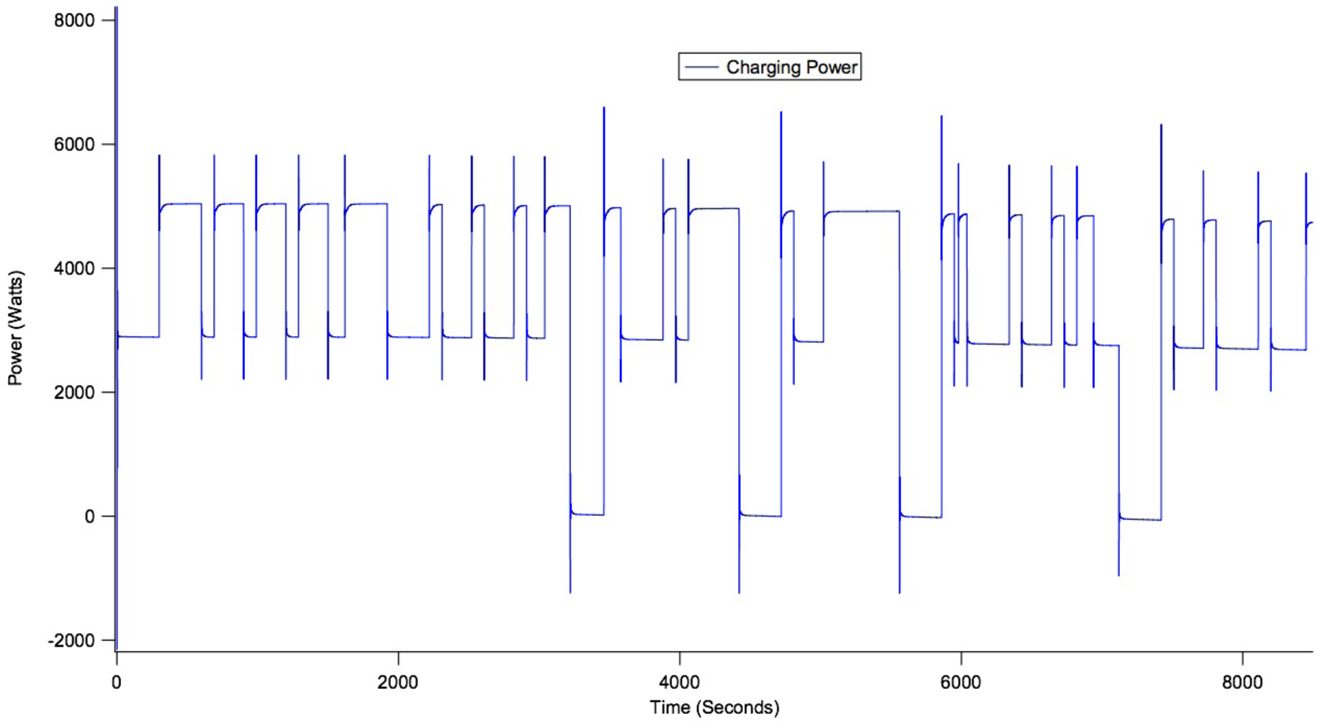


Figure 2-2

Simulated duty cycle of alternator during driving

This modeling activity was used to define the major Eparc system components. The team was able to identify a suitable battery pack, alternator, heater, and HVAC compressor that would operate from the same nominal level of 380 VDC. The project team sized the system so that it would be able to power the HVAC and allow the existing 12 VDC systems, such as the wheelchair lift, to still function as designed.

The selected battery pack was a 12 kWh, 394 V unit from Enerdel that includes a ground fault detection circuit, circuit protection devices, and a control contactor all in one enclosure that is rated for vehicle mounting. The team was able to mount the battery pack at the rear of the bus, under the floor. Figure 2-3 are photos of the Enerdel 12 kWh battery pack and the Enerdel battery pack mounted under the vehicle.

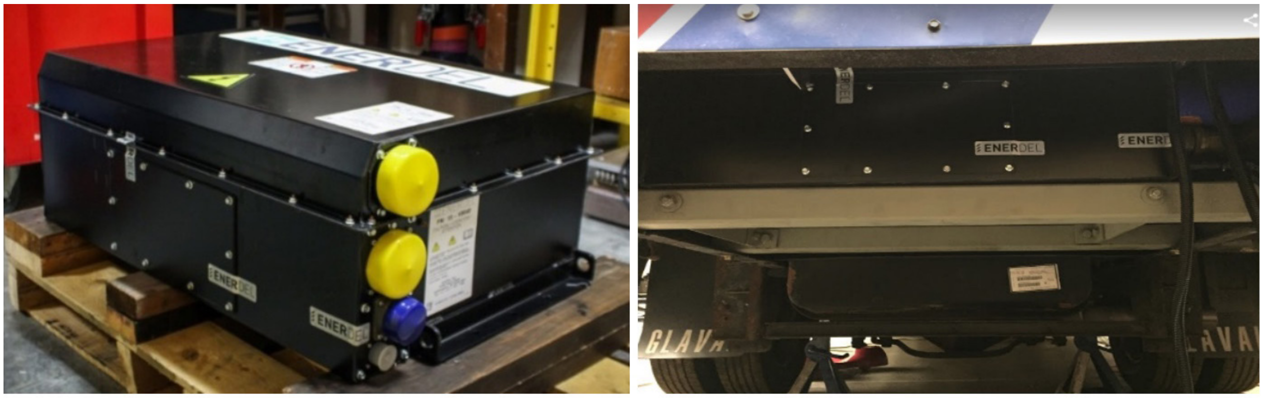


Figure 2-3

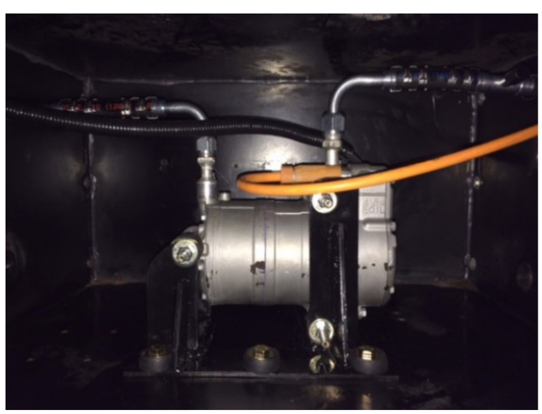
Enerdel lithium-ion battery pack upon arrival (left) and installed under rear of bus (right)

The high-voltage alternator is an engine belt-driven C. E. Niehoff unit and produces power over a wide range of engine speeds. The alternator was based on an existing low voltage design and modified by Niehoff for higher-voltage output. One challenge for the alternator is the wide operating engine speed range, from engine idle up to maximum engine speeds. The final alternator drive pulley diameter compared with the engine crankshaft pulley determines the alternator RPM. The alternator produces about 3 Amps at engine idle and up to 15 Amps at highway speeds, all while regulated at a maximum of 380 VDC.

The HVAC compressor, shown in Figure 2-4, can operate directly from 380 VDC power, which eliminates the need for a power conversion to supply the compressor from the battery and alternator. The compressor is a Sanden unit with a displacement of 33 cc/rev and a maximum speed of 8500 RPM, with a maximum power consumption of 5.2 kW. The compressor demonstrated better performance ability than the original engine accessory belt-driven compressor that it replaced. The HVAC compressor is controlled from a thermostat unit, similar to how the buses were originally equipped. The driver has a separate control unit to select the desired rear temperature set point.

Figure 2-4

Electric HVAC compressor installed in side compartment of bus



A high-voltage battery charger, provided by CurrentWays and shown in Figure 2-5, was included in the design to allow for battery charging during times when the bus is not in use. The battery charger can charge the battery in the event that the battery voltage is lower than the normal operating range for the alternator or if the battery state-of-charge is low after a service day. The charger, along with a contactor control enclosure, was installed in a side panel at the rear of the bus; the charging receptacle is located near this same side panel.

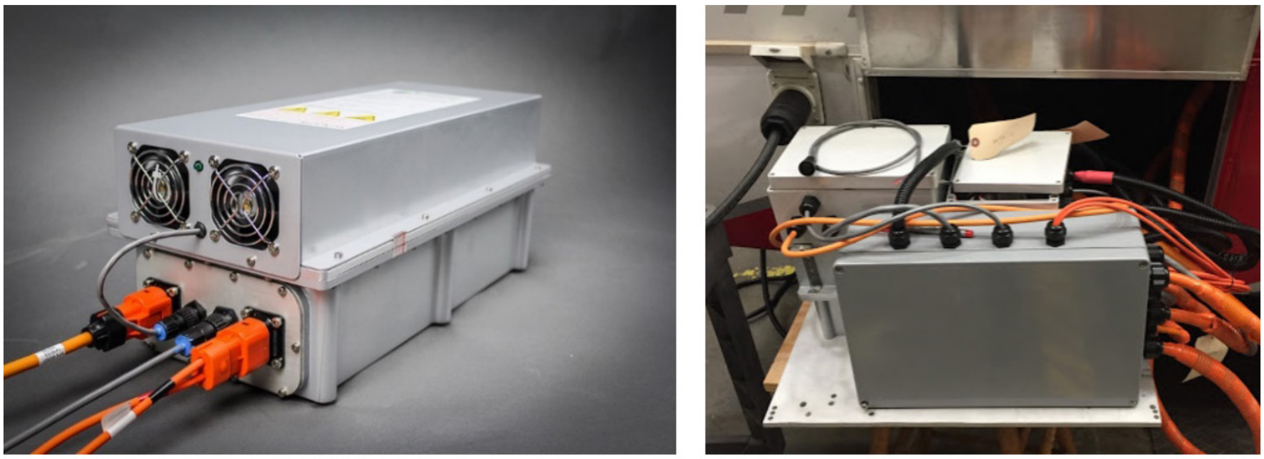


Figure 2-5

Onboard battery charger (left) and installation with contactor enclosure in side compartment at rear of bus (right)

To supply heat for the Eparc system, the same engine coolant as the existing system was used along with an auxiliary heater element added by the project team. If the coolant temperature falls below the set point during Eparc stops, the heater element is turned on. This heater element is powered directly from the 380VDC bus and heats the coolant in a reservoir at the rear of the vehicle. The coolant is circulated with a small booster pump during stops.

The Eparc system is controlled by a National Instruments CompactRIO™ system. This controller was programmed in a high-level graphical language called Labview™, also from National Instruments. The ability to program the controller using a high-level language greatly reduced the software programming time. Although this is an excellent selection for a prototype unit, the hardware cost is much higher than a custom-built controller, which is inexpensive to manufacture in volume at the expense of much higher development costs. A custom controller would be selected for a production-level Eparc system in which the higher upfront software programming cost can be spread across many production systems.

Table 2-2 summarizes the Eparc system component specification implemented during the project.

Table 2-2

Eparc System Component Specifications

High Voltage Battery	
Manufacturer	Enerdel
Model No.	PE350-394
Voltage Range	240–394 VDC
Rated Capacity	35 Ah
Rated Energy	12.3 kWh
Continuous Charge/Discharge Rating	70 A
High Voltage Alternator	
Manufacturer	C.E. Niehoff
Model No.	S942
Voltage Output (max)	380 VDC
Current Output (max)	15 A
HVAC System	
Vendor	Mobile Climate Control
Model No.	Custom build
Compressor Operating Voltage	200–432 VDC
Compressor Nominal Current	26 A
Max Rated Auxiliary Heating Power	4.5 kW
High Voltage Battery Charger	
Manufacturer	Current Ways
Model No.	BC Series, air-cooled
Input Voltage	100-240 VAC, single phase
Output Voltage	225–450 VDC
Max Output Power	3 kW

Eparc System Integration

Mounting locations for all system components were selected to not interfere with normal bus operation. The only Eparc component inside the cabin, other than the driver control interface, was the HVAC evaporator core and blower fans contained inside a similar enclosure to the evaporator that was originally in the bus. Figure 2-6 shows the Eparc system component locations within the paratransit bus.

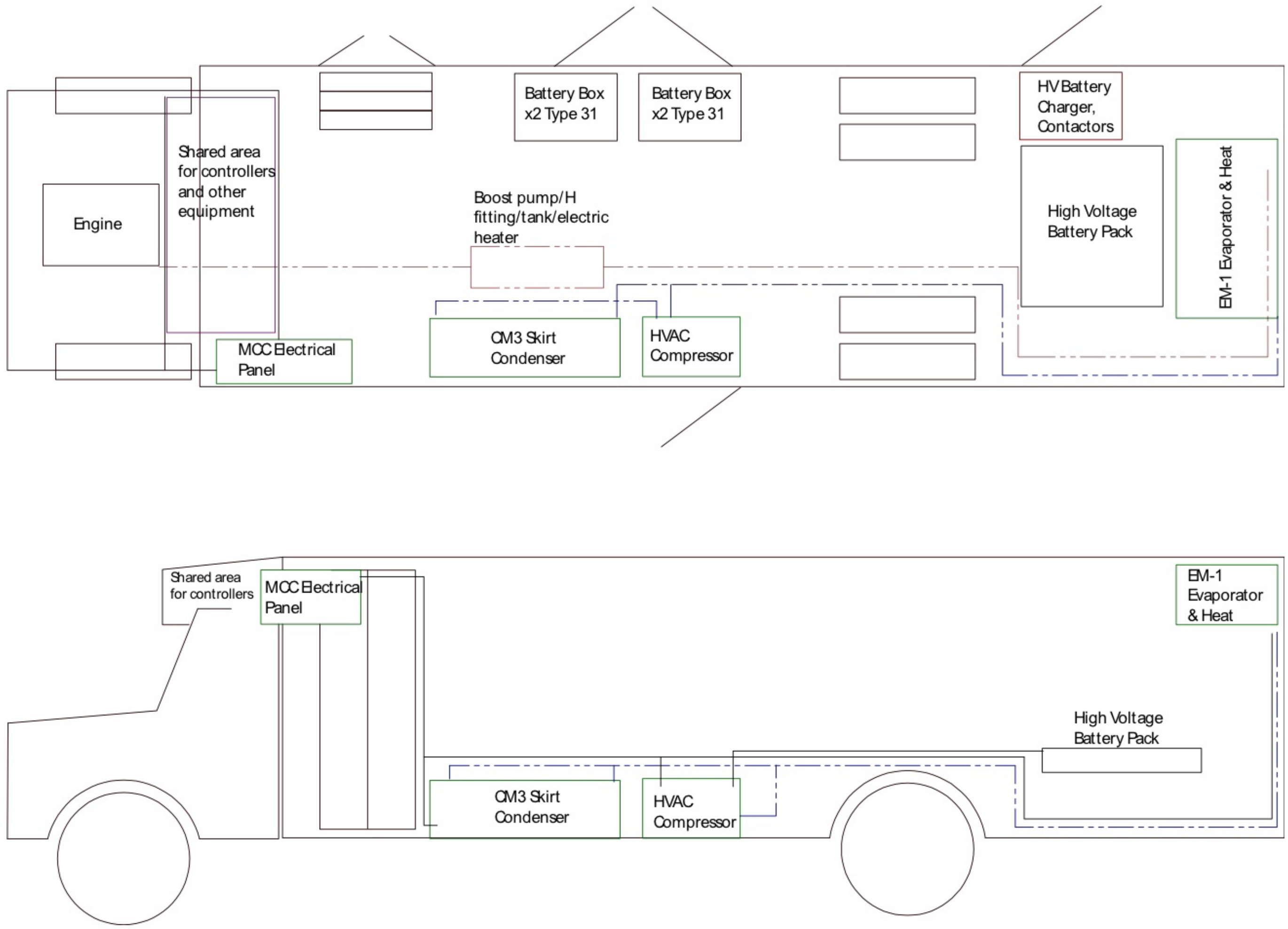


Figure 2-6

Layout of Eparc system components within paratransit bus

The former HVAC compressor was an engine belt-driven unit mounted under the hood that was removed and replaced with the new high-voltage alternator. The new HVAC compressor was mounted on the driver side of the bus in a compartment in the side skirt below the floor. The evaporator core and heater core were mounted in the passenger compartment ceiling at the rear in the original location.

There were many belt-driven accessory items originally on the bus, so the alternator installation was difficult even with the removal of the existing rear HVAC compressor. The only location the alternator would fit and still be able to take advantage of the existing drive belts was near the exhaust manifold. The mounting location required custom bracket and heat shielding fabrication. If this was a new vehicle designed to be using this alternator, a better location could have been used. This location proved to be harsh on the alternator with the local high-temperature environment, which proved to be the most significant problem in the project.

The Eparc controller was installed in a compartment over the driver's head to allow for a clean installation, as all wires were routed behind the existing interior cover panels.

The Eparc system was installed in two vehicles. The first vehicle, the prototype vehicle or "Bus #1," had the system installed by CEM to develop the assembly plan for UTA and to debug any problems with the system. The second vehicle, the demonstration vehicle or "Bus #2," was integrated by UTA under the instruction of CEM to serve as a test for the system as a retrofit to be installed by transit agencies into existing vehicles. Both were put into service at UTA after completion of the installation, with the primary distinction between the two being who performed the system integration.

Eparc System Modes of Operation

As part of the project, the team developed an owner's manual and quick reference card, shown in Figure 2-7, for UTA. The manual outlines basic troubleshooting procedures and modes of operation. Operational modes include in "Normal," "Warning to Start Engine," and "Fault." These modes are communicated to the driver through the Eparc display included on the driver dashboard. The Eparc driver interface shown in Figure 2-8 is equipped with an Eparc logo, an "Estop" switch, and a high-voltage battery state of charge (SOC) meter. The Eparc logo illuminates blue when the system is activated, and the SOC meter is backlit green when the system is operating normally. In a warning situation, such as low voltage on the Enerdel battery, the SOC meter display will turn red and send a message ("STRT") informing the driver to start the engine. In a fault condition in which the system has shut down, the meter will flash red and show a "FALT" system fault message. Figure 2-9 shows the SOC display meter states, and Table 2-3 is a summary of the modes and actions required by the driver.

Figure 2-7

Eparc quick reference card

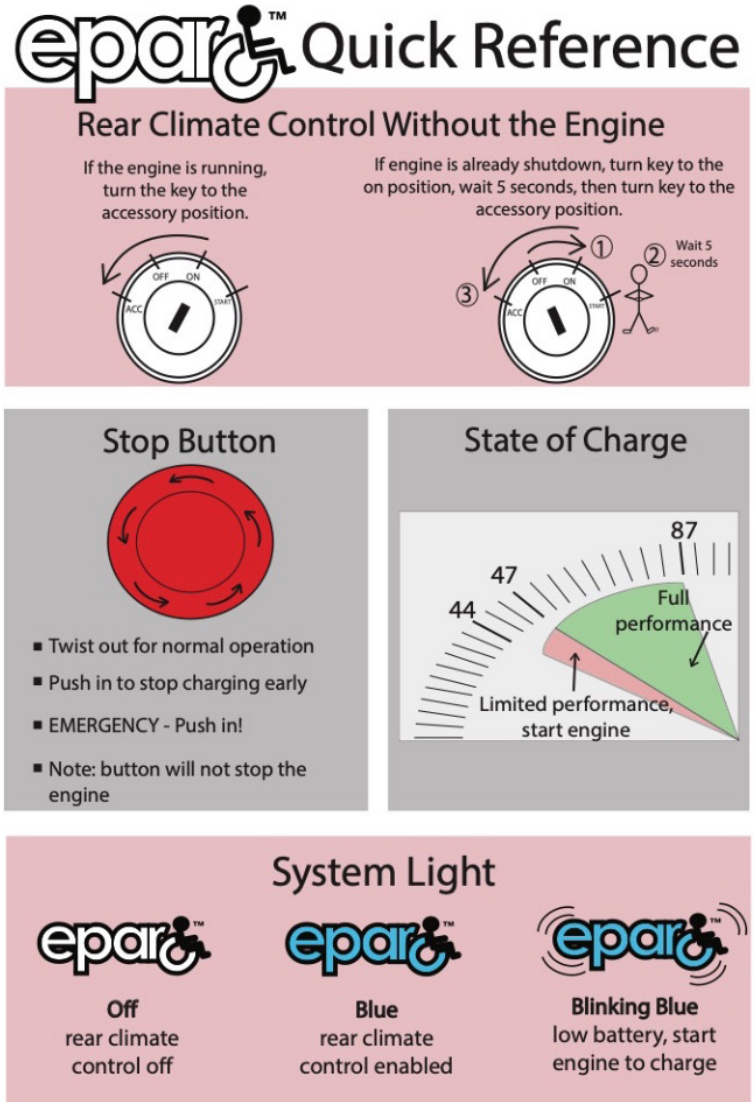


Figure 2-8

Eparc system driver display

Normal | Warning to Start Engine | Fault

Figure 2-9

Eparc system driver display modes of operation

Table 2-3

Summary of Operation Modes for Eparc System

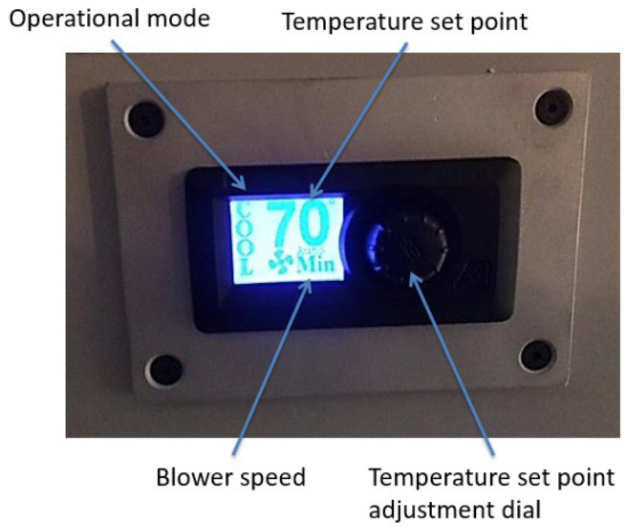
State	Eparc System Light	SOC Meter	Climate Control Power Limit	Driver Action
Normal	Solid blue	Solid green – reads between 47% and 87% SOC	None	No special action
Warning	Solid blue	Solid red – when SOC falls below 47%	Power is limited	Start engine if in ACC mode
Fault	Flashing blue	Flashing red with audible alarm – when SOC falls below 44%	Climate control disabled	Start engine if in ACC mode

In normal operation, the Eparc system is controlled by the bus operator using the key switch. When the bus comes to a stop, the driver turns the key switch to the Accessory position to engage the Eparc system and continue running the HVAC off the high-voltage battery. At the end of the stop, the driver starts the engine with the key switch and continues the route. At this point, with the engine running, the alternator is able to recharge the Eparc battery. In a next generation design, it may be preferential to implement an auto start-stop function for engaging Eparc that does not rely on the driver to manually operate the key switch.

In addition to the Eparc driver display, the new HVAC system included a display for the driver noting the operation mode, blower speed, and temperature setpoint, as shown in Figure 2-10.

Figure 2-10

Driver display for newly-installed HVAC system on paratransit bus



SECTION

3

Test & Demonstration Summary

Testing began during the integration phase of the project, beginning with component-level testing and ending with road testing. Testing was followed by the in-service demonstration. The demonstration was intended to measure any fuel economy improvements and reduction in idle time resulting from operating Eparc. Historical operational data were available to provide a baseline by which to compare the test results. Some testing was performed in a controlled environment to ensure functionality of the system before putting into operation to test for fuel savings.

Test Phase

High Voltage Alternator

C.E. Niehoff, the manufacturer of the alternator bench, tested the alternator developed specifically for this project. Full details of Niehoff's testing are proprietary, but it tested the alternator against the specification. It also tested a filter capacitor system that attenuated the voltage ripple from the alternator. The effect of the filter is shown in Figure 3-1. The attenuation of the voltage ripple is important to operating high-voltage loads such as the air conditioning compressor within their defined voltage operating range.

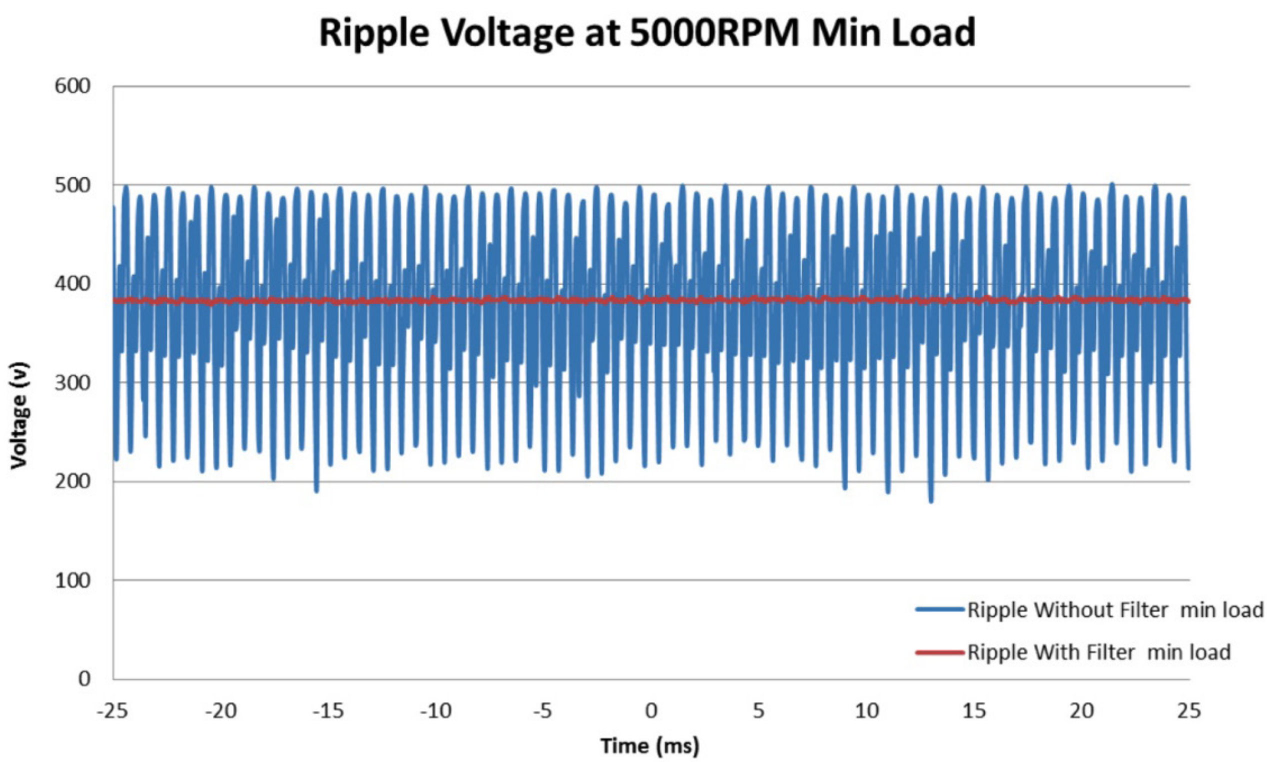


Figure 3-1

Example of ripple voltage with low-load accessory, with and without filter capacitor

Mobile Climate Control High Voltage HVAC System

MCC, the supplier of the electric HVAC system and a project partner, performed bench testing of the HVAC system components, including a high-voltage air conditioning compressor that was new to MCC. As is often the case, the system bench testing afforded opportunities to refine and debug the MCC software that controls the system. High audible noise levels at high compressor speeds were the only problem that was not resolved during the testing. High noise levels are a property of the compressor itself, and the issue was mitigated in the vehicle by adding sound insulation.

Integration and System Testing

CEM integrated the Eparc system at their facility in Austin, Texas, and, after installation of the battery hardware and controller, it tested the battery charger. The battery was charged from 317 VDC to 325 VDC, and the status of the battery was monitored throughout the event to ensure performance was as expected. Once the battery was deemed to function normally from a charger, the alternator output current and voltage were tested with a resistive load test before charging the battery. CEM found that the alternator provided the expected output and tested that the battery's CAN data output was functional and provided accurate voltage data. All components and sensors were found to function as expected and were ready for use in the Eparc system.

System Road Shakedown Testing

CEM tested the vehicle's operational readiness prior to delivery to UTA, and CTE performed an in-depth road test during the delivery of the vehicle from CEM in Austin to UTA. This journey helped to identify many issues to be addressed before deploying the vehicle into paratransit service.

CEM also traveled to UTA was in September 2017 to support the commissioning of Eparc on Bus #2 that was assembled by UTA. CEM was involved with the software installation on the controller, debugging the software, general Eparc troubleshooting, sensor calibration, and system testing and validation. The Eparc system had very few installation and checkout issues; only minor wiring connection issues were found, which were corrected during initial tests. System testing and validation followed along with road testing of the bus. All Eparc systems performed as designed, and the bus was scheduled to be put into service.

Demonstration Problems

Unfortunately, the demonstration was far from trouble-free. Shortly after delivery in August 2017, the prototype bus was removed from service because the high-voltage battery did not maintain its charge. While the bus was underway, it was supposed to recharge the high-voltage battery from the alternator, but this process intermittently failed when the Enerdel battery management system threw isolation failure faults. UTA also noticed that the bus developed a burning odor in the vicinity of the alternator.

Meanwhile, the second bus, which was integrated at UTA, had HVAC issues that were never observed in the first bus, which was integrated at CEM. Occasionally, the HVAC driver display would indicate "OFF" and would not leave this state. During this time, no heating or cooling was provided by the rear HVAC unit.

The team attempted to debug these issues remotely for about two months but failed to make satisfactory progress. In November 2017, CTE visited UTA to debug the problems directly by bringing CANbus datalogging equipment to Utah and collecting data from the bus systems while the bus was in operation, as shown in Figure 3-2. From these data, CEM was able to diagnose the HVAC issue with the second bus as a wiring error. UTA fixed this problem under the direction of CEM.

Figure 3-2

CANbus datalogging at UTA

During the same trip, CTE also conducted an endurance road test of the second bus with the assistance of UTA to determine if the second bus would also suffer from intermittent isolation failure faults. CTE depleted the battery by operating the heater in Eparc mode until the battery reached its minimum capacity of 47%. The operator drove the bus at highway speeds for around 40 minutes to exercise the alternator as it recharged the battery. The ambient temperature was 55–60° F with blustery wind. A graph of the voltage and ground resistance (the source of isolation failure faults) during this road test is shown in Figure 3-3.

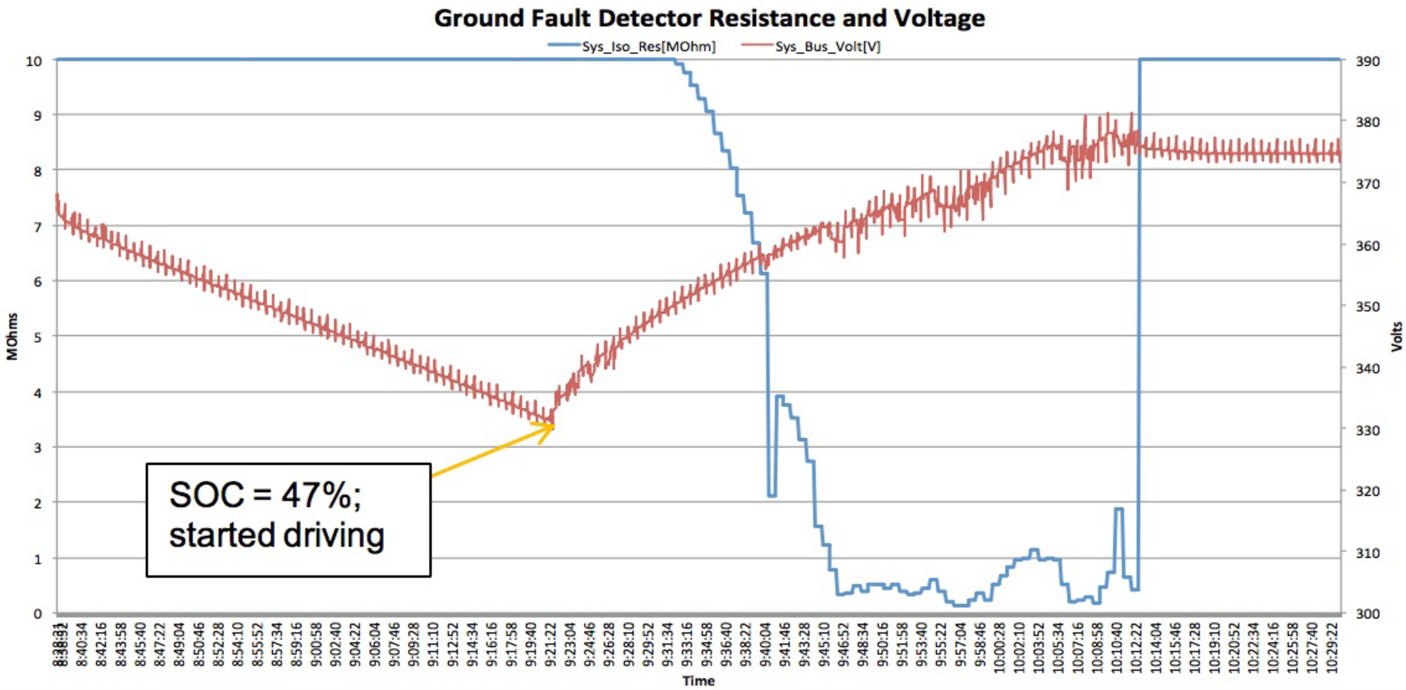


Figure 3-3

Ground fault detector resistance and voltage

CTE determined that the alternator in the second bus was showing the same symptoms as the alternator in Bus #1. While testing, the Bus #2 ground fault detector came close to faulting (the resistance dropped to as low as 0.132 MOhms). In summer weather, CTE suspected that the ground fault would have been thrown. The alternator produced the same smell that was produced by the alternator on the other bus.

The results of this testing called into question the ability of the alternator to provide the required service without overheating, especially since it is located the near the engine's exhaust manifold.

C. E. Niehoff agreed to redesign and rebuild the alternators. Unfortunately, this was a time-consuming process—even removing the alternators from the buses required almost a week. Niehoff also needed time to design, build, and test the new version of the alternators. Once this was completed, the alternators had to be shipped back to Salt Lake City and installed once again. Niehoff's design change also forced some rewiring of the vehicle, but it believed that the redesigned alternators would avoid the problems experienced with the original alternators.

Unfortunately, when the vehicles were returned to service, the problems began to recur. Without sufficient time for another alternator redesign, the team decided to disconnect the alternators and charge the batteries from the shore chargers at the UTA bus depot. This mode of operation allowed the vehicles to get some run time, but not nearly as much as with the alternators installed.

In June 2019, the team began monitoring charging issues on both buses that would prevent the vehicles from being sent into service. CTE and CEM assisted UTA in attempts to debug the issue remotely, but the issues persisted through July. In August 2019, CEM made a trip to UTA to diagnose and debug the charging issue. The Eparc controller was in an operational state; however, the controller was waiting for sequence events to occur. It was determined that the control output command was not getting to the field devices. A faulty relay circuit and a blown fuse in the relay circuit were found and replaced. Testing showed that the bus was charging from shore power after the repairs. After completing the repairs on Bus #2, the team started looking at Bus #1.

Bus #1 was also examined, as it had a reported intermittent shore power charging issue. The Eparc controller was timing out on the startup sequence and going to the shutdown state caused by systems not responding to the controller. After reviewing the wiring from the controller to the external systems, CEM determined there was an issue with the connections to a high-voltage contactor. The wiring issue was corrected, and the Eparc system was tested and working correctly.

In December 2019, CEM again tried to correct the shore power intermittent charging issue on Bus #1. With the project nearing its end, the team was hopeful that the issue could be corrected so the vehicle could accumulate a few more miles in service to provide more data for evaluation. The Eparc controller was functional but not completing the startup sequence using shore power. The team looked into the circuits and wiring leaving the controller, and a faulty relay-printed circuit board was determined to be the cause of the intermittent charging issue. A replacement relay board was not available to replace the faulty board at the time, and there was not adequate time remaining in the project to replace the relay board and accumulate additional miles.

Although the alternator problems caused the most serious challenges for the project, other problems also slowed progress. The buses were already past their useful life when the project began, and they had maintenance issues with transmissions and other components unrelated to the project. The project also lost time related to information technology upgrades required for the buses that were deployed across the entire UTA paratransit fleet.

The system developed coolant boil-over issues during its first winter, suggesting that the heating element may have been oversized. The team redesigned and replumbed the buses to avoid this problem.

The timeline of challenges observed during the project are shown in Figure 3-4, with green months representing both vehicles in operation, orange representing one or more vehicles experiencing issues inhibiting service, and red representing months without any in-service operation from either vehicle.

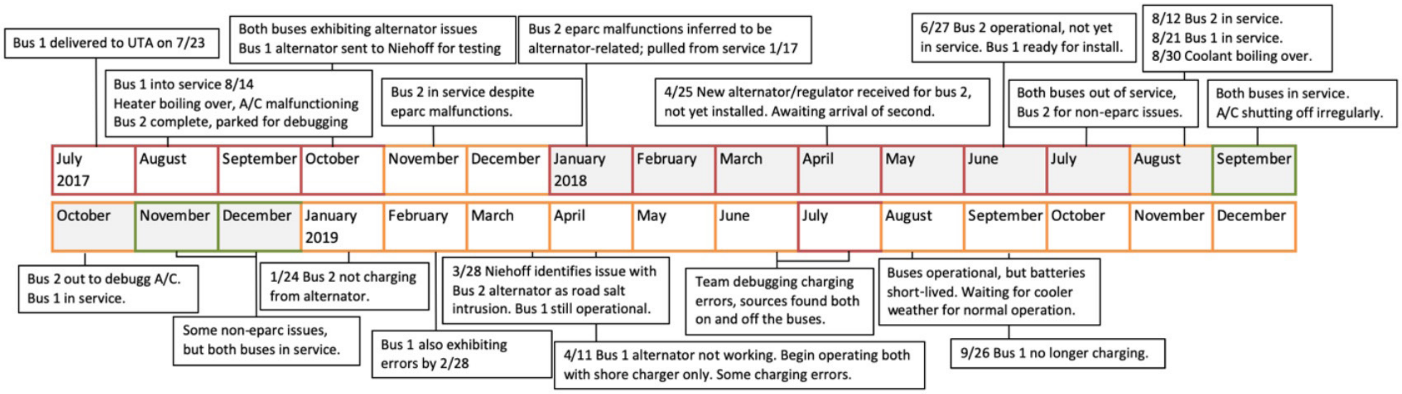


Figure 3-4

Vehicle operations timeline

Demonstration Results

CTE solicited feedback from a bus operator of the Eparc-equipped buses and the maintenance personnel charged with maintaining them. There was no noticeable difference in the climate control of the system for passengers—the vehicle cooled or heated, in hot or cold weather, as well as or better than other paratransit vehicles in the fleet. However, there were complaints about the balance of the system between the front and back that left the front of the vehicle receiving too little air conditioning. This was an expected result of the design, as the driver's air conditioning compressor was still driven by the engine and thus did not run when the engine were shut down. This result reinforced to the project team that a future iteration of the design should electrify both air conditioning compressors.

A suggestion from the bus operator to add an audible noise to the bus while it was in Eparc mode came was unexpected. The operator said that visually-impaired passengers relied on bus engine noise and felt uneasy when it was missing; this problem could be easily rectified with a noisemaker on a future iteration.

A suggestion to hide the Eparc indicators from view of passengers also was unexpected. The driver reasoned that some passengers might become distressed if the battery state of charge got low, even when there was no cause for alarm. The visual change could cause unease for more sensitive passengers, although in this situation, the driver can simply restart the bus to recharge the battery. This suggestion could also be rolled into a future design.

The driver also suggested other minor improvements to the user interface that could be rolled in a future design.

Despite the problems that kept the buses mostly off the road, UTA maintenance staff remained positive about the concept and were particularly complimentary of the MCC HVAC system that, in their opinion, performed much better than the system it replaced. This was because the MCC system was able to both heat and cool the vehicle, which was useful on days when seasons are beginning to change causing cold mornings and hot afternoons, whereas other paratransit fleet vehicles only offered one or the other. The MCC system was a bright spot in the project, operating almost entirely trouble-free. (The earlier wiring issue that caused HVAC issues was outside the HVAC system.)

Quantitatively, the Eparc system did not demonstrate the fuel use improvements that were expected. Savings were marginal at best, with some months of collected data demonstrating worse efficiency than before the system was put into place. Because the system was unreliable, the team was not able to capture enough data to determine the reason the fuel economy did not improve or if it did not. The team still believes that a reliable operating system would save fuel, but the data do not demonstrate this result.

The results of the fuel use data collection are shown in Figure 3-5 and Figure 3-6, with the former distinguishing between the first and second years of the analysis and the latter showing the average post-implementation fuel economy.

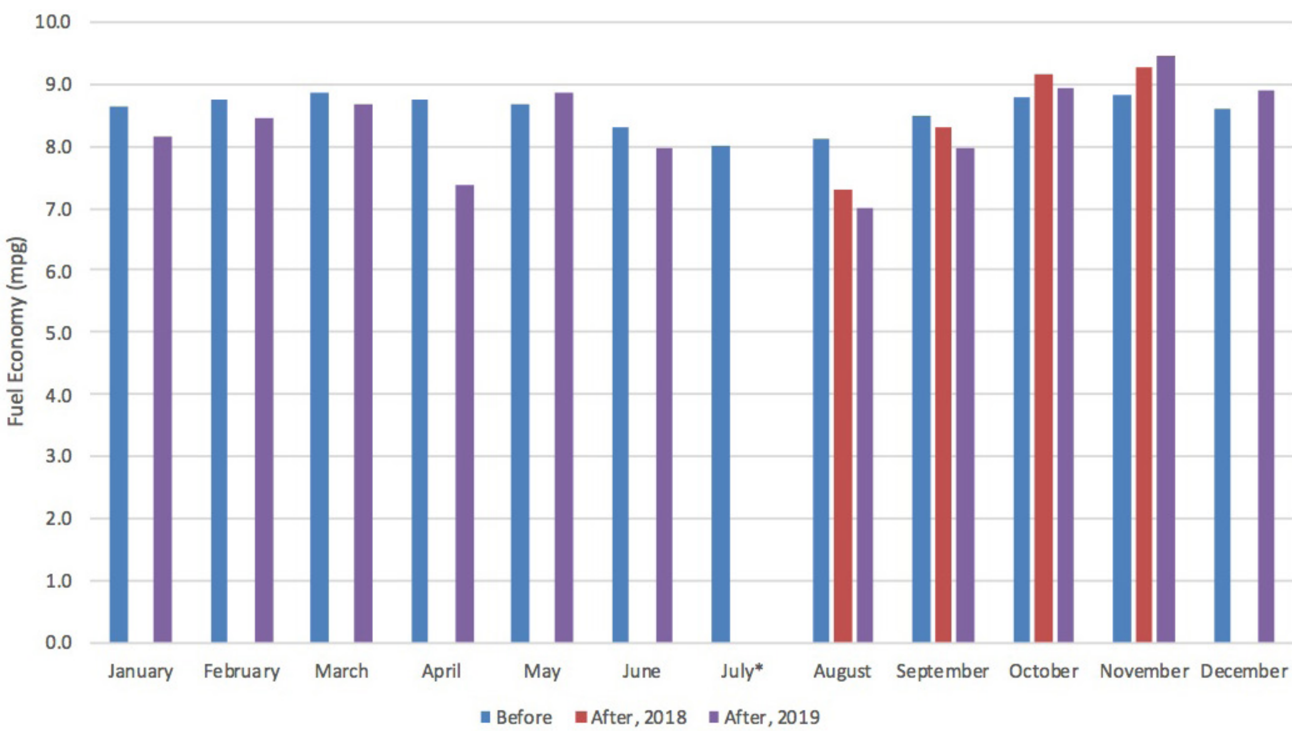


Figure 3-5

Fuel economy before and after Eparc by first and second years

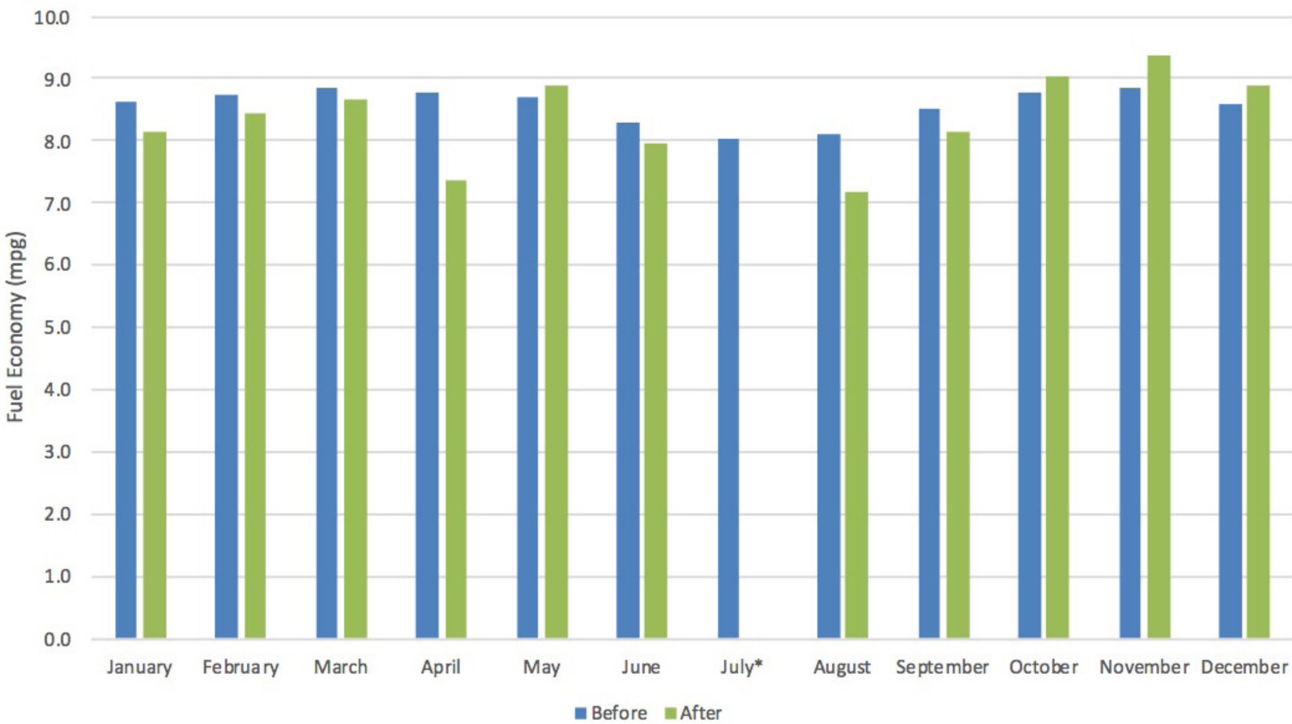


Figure 3-6

Average fuel economy before and after Eparc

No data were collected in July 2019 due to complications involving the use of the shore charger. Fuel economy differences observed ranged from 0.9 mpg improvement in August to 0.6 mpg worse in November. However, whereas improvements were inconsistent for fuel economy, the primary benefit of reducing idle time during paratransit operations was realized. Idle time elimination reduced engine run time by approximately 19%, which helps to reduce exposure to harmful fumes for UTA's paratransit riders and operators. From July 2017 to December 2019, the Eparc system was shown to save 231 hours of engine idle time from Bus #1 out of 955 hours of service and 253 hours of engine idle time from Bus #2 out of 1588 hours of service.

SECTION

4

Market Potential and Readiness

The Eparc system demonstration on two paratransit buses with UTA provided insight into the challenges and benefits of deploying similar technology on a large scale. Although run-time was severely limited due primarily to problems with the alternators, the system was received positively by UTA drivers and passengers when it was operational.

Beyond UTA, TWA gauged interest in Europe where conversations pointed to large commercial interest in the progression of this technology. In a meeting with International Association of Public Transport (UITP) representatives at their headquarters in July 2013, UITP expressed interest in the results of this project with the thought of using the technology in the European market. European countries have differing regulations regarding the transport of persons with disabilities, fuel costs are higher in Europe, and there is much more attention placed on carbon emissions than in the U.S. These differences may make the product more interesting for European customers than for those in the U.S.

The project team expects continued interest in this technology in the U.S. based on continued development and cost reductions. Preliminary analysis indicates that the commercial version of this system will approach a cost-neutral basis at today's energy prices, especially when reduced costs of maintenance are factored in. The non-monetary benefits of the operation of the vehicles will also be significant, with major reductions in noise and air pollution as well as positive improvements in safety and general quality of life for the vehicle's operators and passengers.

Although this demonstration did not show fuel economy improvements, the project team still believes that idle reduction technology has the potential to save fuel. There appear to be potential savings of up to 10% in fuel and emissions based on operational periods in which the bus was in heavy and reliable use.

A more promising benefit than fuel savings appears to be the reduction in engine idle time over the life of the vehicle, which will reduce wear on the engine, lead to reduced maintenance and greater reliability, and increase the life of the vehicle. During 6,000 hours of service on one of the buses, the Eparc system was able to eliminate 1,000 hours of idle time. Although it is difficult to draw firm conclusions on monetary savings and life extension results from this short demonstration, engine idling is known to be stressful on the engine, so idle time reductions are expected to lead to cost savings in both of these ways.

The project team and UTA feel the technology and the Eparc concept have great potential for commercial success. There are aspects of the design that could be more industrialized from the prototype vehicles for a future commercial system, including a more robust industrial controller, production-level contactors, and control relay systems. These are relatively minor changes that are anticipated when moving from a prototype system to a commercial system. A more drastic consideration for a potential commercial system might include operating the system at a lower voltage to open up the design to a larger selection of alternators and HVAC compressors, thus potentially solving the problems seen during this project with the developmental high-voltage alternator. In addition, a future commercial system might even consider the use of standard lead acid batteries at a lower voltage.

There also appears to be the potential to downsize the battery energy capacity. The SOC of the battery pack rarely dropped below 70% during regular operations while the alternator was properly functioning, suggesting that the capacity and, therefore, much of both the weight and the cost of the system may have the potential to be reduced in a redesigned version of the system. Figure 4-1 shows the trend in battery capacity during a day of heavy HVAC use; the charge is held steady due to regular recharging from the alternator.

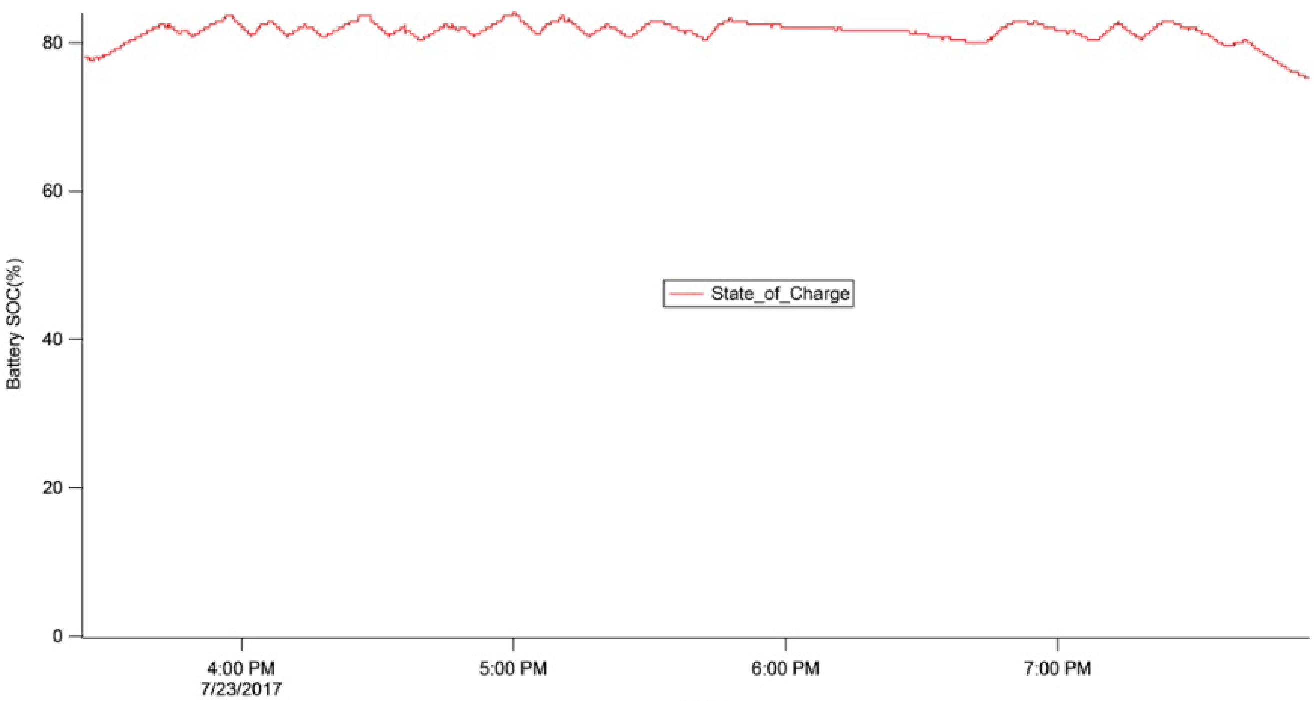


Figure 4-1

SOC change during operation for day of high HVAC use

SECTION

5

Independent Evaluation Findings

Dr. Xiaoyue Liu, Associate Professor of Civil & Environmental Engineering at UoU, provided an independent evaluation as part of the project to determine the overall effectiveness of this research and demonstration project and the validity of its results. He evaluated the collected data regarding fuel use and idling time on both test vehicles and approved the evaluation methodology chosen by the project team. The full report can be found in Appendix B, and a summary of primary findings are as follows.

UoU agreed with the approach of using the vehicles in service to estimate real-world savings that could be realized by implementing the Eparc system. Although both vehicles ran into service delays caused by malfunctions both of the Eparc and other unrelated components of the vehicles, UoU's review of the data collected helped to determine that the in-service demonstration results could serve to provide meaningful data on the effectiveness of the system. This form of testing also resulted in feedback on the system's performance from vehicle operators who were able to use the system in service with customers. This combination of feedback helped to evaluate the effectiveness of the system as a whole.

UoU evaluated operating days and miles, fuel economy, and idle time reduction. The fuel economy results are in strong agreement with those found by the project team, which is to say that there were marginal fuel economy savings as a result of the Eparc system and that further testing of the system would help to add confidence in the results due to the small data sample. These results and additional operational information from UTA helped to inform UoU's analysis of potential financial savings due to idling reductions through the Eparc system. This estimate determined that the payback horizon for the system is expected to be around 11.7 years, accounting for savings in production when the system is ready for mass production.

UoU's assessment of overall team effectiveness was positive, stating that the team successfully worked under deadlines and within the given budget. Assessment of the system indicates that it shows potential and that an additional project to further refine the problem areas present in the current design could result in a product that can lead to cost savings for transit agencies from cost reductions in paratransit operations.

SECTION

6

Conclusions and Future Steps

This project helped to contribute valuable information towards the development of a system for eliminating idling from paratransit vehicle operations. Although the results of this experiment did not demonstrate a significant reduction in fuel consumption, engine time was reduced by an impressive 19%. Idling is loud, expensive, and increases maintenance costs.

The project also demonstrated that the system can be successfully retrofitted by a transit agency. Although the project did not try this, there is no reason why the system cannot be included as original equipment on new buses as well.

Unfortunately, the placement of the alternator near the exhaust manifold allowed for the intrusion of road salt and debris and also exposed the alternator to heat, which may have led to the failure of alternator. Since attempts to rectify this situation failed, the demonstration was greatly delayed, shortened, and made to rely on recharging via shore power, a mode of operation for which the system was not originally intended. This mode of operation did not allow the vehicle to operate all day.

APPENDIX

A

Project Work Plan

UTA Paratransit Bus Electrification Project
Revised Project Description
April 13, 2015

The proposed project has been modified from the original proposal to take advantage of less costly off-the-shelf component parts, while demonstrating the most cost effective and simplest means to achieve the project's original goals. It will improve the emissions and efficiencies of two paratransit buses through the electrification of HVAC (heating, ventilation, and air conditioning) systems utilizing a purposed built auxiliary power unit (APU). The APU will include a high-voltage alternator and electrical energy storage system using state-of-the-art batteries. Additional upgrades to the vehicle will include a high-voltage electric refrigerant compressor for the HVAC system.

Studies and demonstrations have shown that electrifying belt-driven accessories on transit buses can improve overall fuel economy. For example, the BAE Hybrid Drive System uses an electric air conditioner, an electrified auxiliary power unit, as well as air compressors, power steering pumps and cooling fans driven by electric motors. Adding motors to previous belt-driven pumps, fans, and compressors is beneficial since it enables the devices to be decoupled from the engine, thus reducing parasitic load and allowing for variable operation independent of engine speed. Through their electrifications of accessories, the BAE HybridDrive claims a fuel economy improvement of 10-20% compared to mechanically driven accessories.[1]

Of the existing mechanically driven accessories, air conditioner loads represent one of the greatest opportunities for increasing fuel economy and efficiency.[2] This is especially true in paratransit applications where the buses typically idle 20-25% of their duty cycle with long dwell times for passenger loading and unloading. During this time, the engine will typically run for the sole purpose of keeping the cabin cool. By electrifying the air conditioner and using an advanced high-voltage alternator and energy storage system coupled to a high-voltage HVAC compressor, the project team will allow paratransit operators to greatly reduce engine run time during passenger stops and realize significant fuel, emissions, and maintenance savings.

The project team will couple the electric air conditioning system to an advanced APU using currently available and off-the-shelf commercial components. While at passenger stops, the vehicle's engine will remain off while the battery energy storage systems powers the HVAC system and other auxiliary loads, such as wheelchair ramps and lights. The battery system will be capable of cooling or heating the cabin for over 30 minutes without additional recharge from the high-voltage alternator. When the vehicle resumes driving or the engine is turned on, the belt-driven alternator will begin recharging the batteries. The high-voltage, belt-driven alternator is designed to couple to existing engines with a power output of 5 kW up to a nominal 300 VDC, allowing complete recharging of the batteries within approximately 15 minutes.

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[1] http://www.hybridrive.com/pdfs/HybriDrive%C2%AE%20Electrified%20Accessories%20brochure.pdf
[2] http://www.cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=1196

The proposed vehicle retrofit is expected to result in operational efficiency improvements and emissions reductions for paratransit operators. The electrified HVAC system will eliminate idling at passenger stops, thus resulting in 10-15% savings in fuel and emissions. In addition, the paratransit operators will save on maintenance costs since engine run time will be cut by 20-25% with the proposed anti-idling technology.

The objective of the proposed project is to develop an electrified HVAC system with a high-voltage APU, which can be implemented and retrofitted onto existing paratransit buses through the use of aftermarket components. The goals of the R&D program include:

1. Define design criteria for a mild-hybrid paratransit bus through the use of detail vehicle and route models, as well as input from the team's transit agency.
2. Design and fabricate an aftermarket paratransit bus with a high-voltage alternator, an electrified air conditioning and heating system, and improved vehicle fuel economy.
3. Test and evaluate two paratransit buses through detailed power systems tests by a third-party evaluator.
4. Demonstrate the enhanced efficiency of the paratransit bus through in-service operation, with daily data collection and assessment by a third party evaluator.

The project team will include the following team members:

Project Partner	Roles/Responsibilities
Center for Transportation and the Environment (CTE)	1. Project Management 2. APU Purchase
University of Texas at Austin-Center for Electromechanics (CEM)	1. Develop requirements definition 2. Power systems modeling and duty cycle analysis 3. Development of control system and integration of the first prototype vehicle APU and control system 4. Assist UTA with retrofit of 2nd vehicle 5. 3rd party evaluator of prototype vehicle's power system prior to delivery to UTA
Utah Transit Authority (UTA)	1. Refurbish vehicles with new engines, HV alternators, electric A/C compressors, and electric water heaters 2. Retrofit 2nd vehicle with APU and control system, with assistance from CEM. 3. Operate demonstration vehicles
TransWorld Associates (TWA)	Project Consultant in design and fabrication of vehicle, including re-powering and refurbishment of base vehicle and hybrid retrofit.
University of Utah (UoU)	Data collection and performance assessment as a 3rd party evaluator

APPENDIX

B

Independent Evaluation Report

Independent Evaluation Findings (Full Report)

FTA Bus Efficiency Enhancement Research and Demonstration

"Utah Transit Authority's (UTA) Paratransit Vehicle Electrification"

Third-Party Evaluation Report

December 27, 2019

Submitted by:

University of Utah
Xiaoyue Cathy Liu, Ph.D., P.E. – Associate Professor
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Submitted to:

The Center for Transportation and the Environment

Project Description and Approach

Under the FTA Bus Efficiency Enhancement Research and Demonstration program, the Center for Transportation and the Environment (CTE) and project partners Utah Transit Authority (UTA), Mobile Climate Control (MCC), the University of Texas at Austin Center for Electromechanics (CEM), and Transworld Associates (TWA), developed and demonstrated a hybrid paratransit shuttle bus system with electrified accessories – Electric Paratransit Anti-idling and Rider Comfort (Eparc). This project aims to demonstrate savings in fuel consumption associated with the operation of paratransit vehicles that idle for extended periods of time while loading and unloading passengers with disabilities. In addition to fuel savings and associated reductions in criteria and greenhouse gas emissions, this project is also expected to reduce operating and maintenance costs, reduce brake wear, and improve the environmental quality of local communities by eliminating engine exhaust in local neighborhoods during passenger loading and unloading. The Eparc system enabled the electrification of paratransit bus accessories and heating, ventilation, and air conditioning (HVAC) using a high voltage battery and alternator system. The cabin HVAC is powered by the high voltage battery. During normal driving operation, the engine will charge the battery through the alternator. When the engine is turned off for passenger loading and unloading, the high voltage battery will continue to power the cabin HVAC rather than utilizing a belt-driven HVAC system. The driver's A/C compressor remains belt-driven. Such a solution allows for a cost-effective and easy means of electrifying existing HVAC onboard uses and reduces the energy requirements on the APU and hybrid charging system.

During the project, fuel economy and idling cost savings were estimated. A before-and-after analysis upon Eparc installation was conducted on two paratransit buses. This report, completed by the University of Utah, documents the findings as the third-party evaluation of the outcomes of the Eparc project under the FTA Bus Efficiency Enhancement Research and Demonstration program.

Fuel Economy Analysis

Operating Frequency

Two paratransit buses (#8228 and #8240) in the State of Utah were chosen to test the performance of implementing the Eparc system. The testing period spanned from August 2018 to November 2019. Figure 1 shows their respective service frequency in each month. In total, bus #8228 was operated 132 days, and bus #8240 was operated 97 days throughout the entire testing period. The two buses operated more frequently during the winter time than other seasons. In June and July, only bus #8240 was in service, and only for one day.

In conjunction with the operating frequency records, mileage data was recorded. Figure 2 shows a boxplot of the mileage distribution (mileage per day) across different months. On average, #8228 runs approximately 182 daily miles, and #8240 runs around 175 daily miles. From the boxplot, it is observed that the average mileage in summer is lower than the average mileage in other seasons.

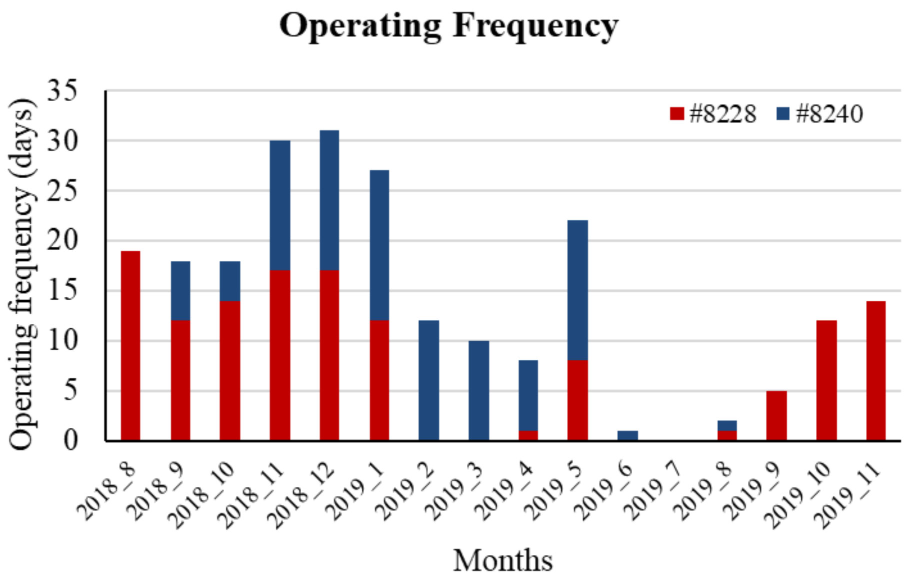

Figure B-1. Running frequency records for buses equipped with Eparc

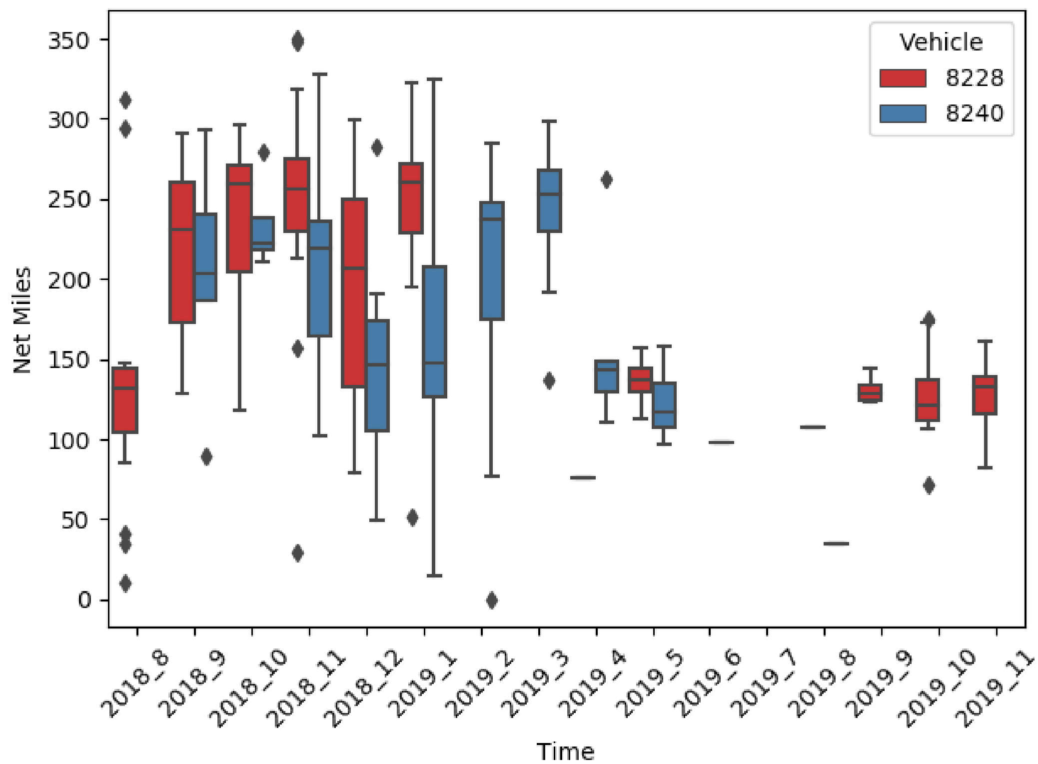

Figure B-2. Boxplot of daily mileage distribution across different months

Fuel Economy

Average mile per gallon (MPG) by each month from Aug, 2018 to Nov, 2019 was calculated to examine fuel economy. In Figure 3, red bars represent the average fuel economy for buses equipped with the Eparc; in comparison, blue bars represent the four years' historical MPG records before the installation of Eparc. The historical data contains records of 52 buses with time spanning from the July, 2009 to July, 2013. Since neither bus (#8228 and #8240) was in service in July, there are no MPG records for that month. In Figure 3, it is found that after deploying the Eparc system on the paratransit buses, average fuel consumption rate is higher than the historical average in winter time (Oct, Nov, and Dec), yet the Eparc system does not show significant effectiveness in fuel economy in other seasons. This might be contributable to a variety of reasons, such as in-house testing, calibration and alternator malfunction.

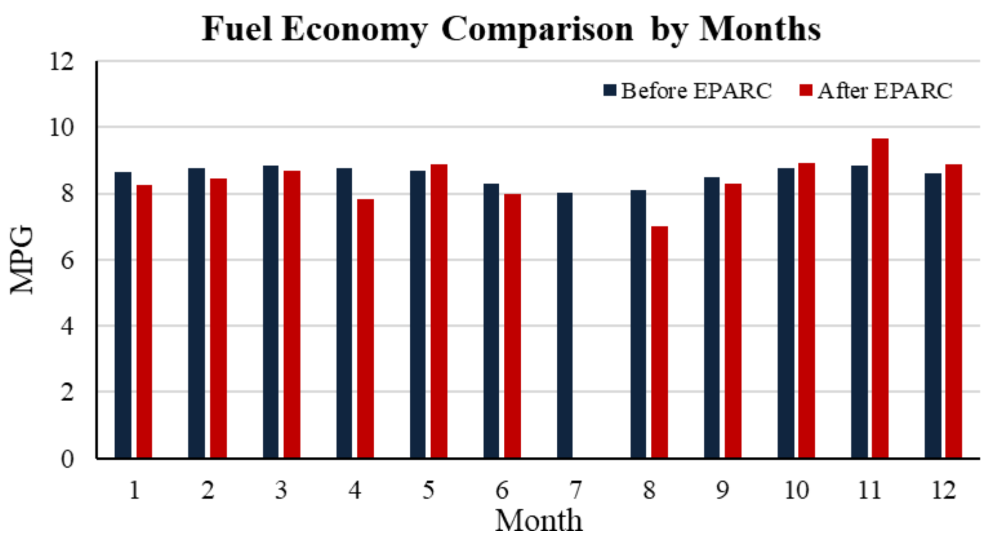

Figure B-3. Fuel economy comparison of Eparc-equipped buses to UTA historical fleet data

Moreover, fuel economy for individual Eparc-equipped buses (#8228 and #8240) by each month is calculated and shown in Figure 4. Note that Bus #8228 was not operated in Feb, Mar, Jun and July in 2018, and #8240 was not in service in July 2018. In general, #8228 outperforms the historical average MPG for most months; whereas #8240 shows relatively lower MPG than the historical values for most months. It should be noted that MPG for #8228 in Apr and #8240 in Aug are extremely low (2.12 and 3.40). This may be due to the in-house testing of the buses.

Fuel economy is further examined by comparing the average MPG before and after the installation of Eparc for #8228 and #8240, respectively. Figure 5(a) shows the annual average MPG for bus #8228. Historical data from 2009 to 2013 reveals that average MPG fluctuates across years. After the installation of the Eparc, average MPG is relatively higher than that of historical years. Figure 5(b) shows the annual average MPG for bus #8240. It should be noted that the MPG is slightly lower than the MPG in historical years.

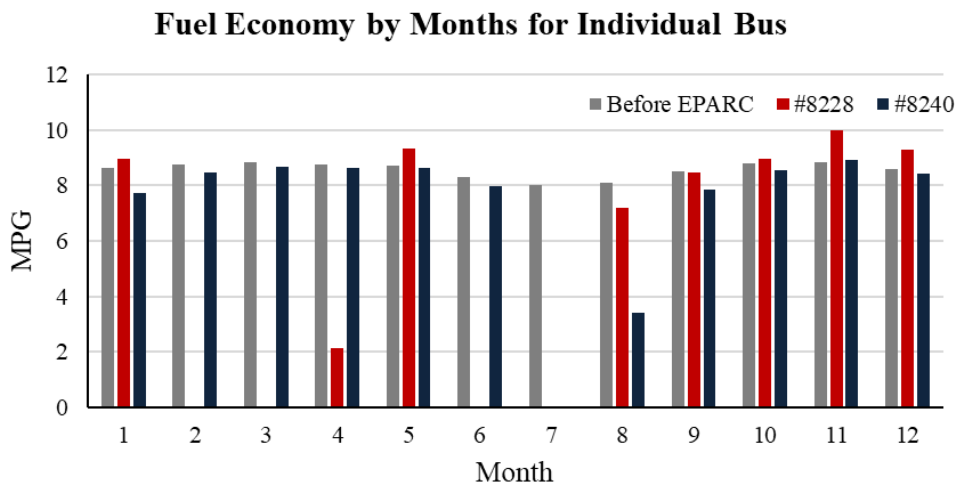

Figure B-4. Fuel economy comparison of Eparc-equipped buses (individual) to UTA historical fleet data

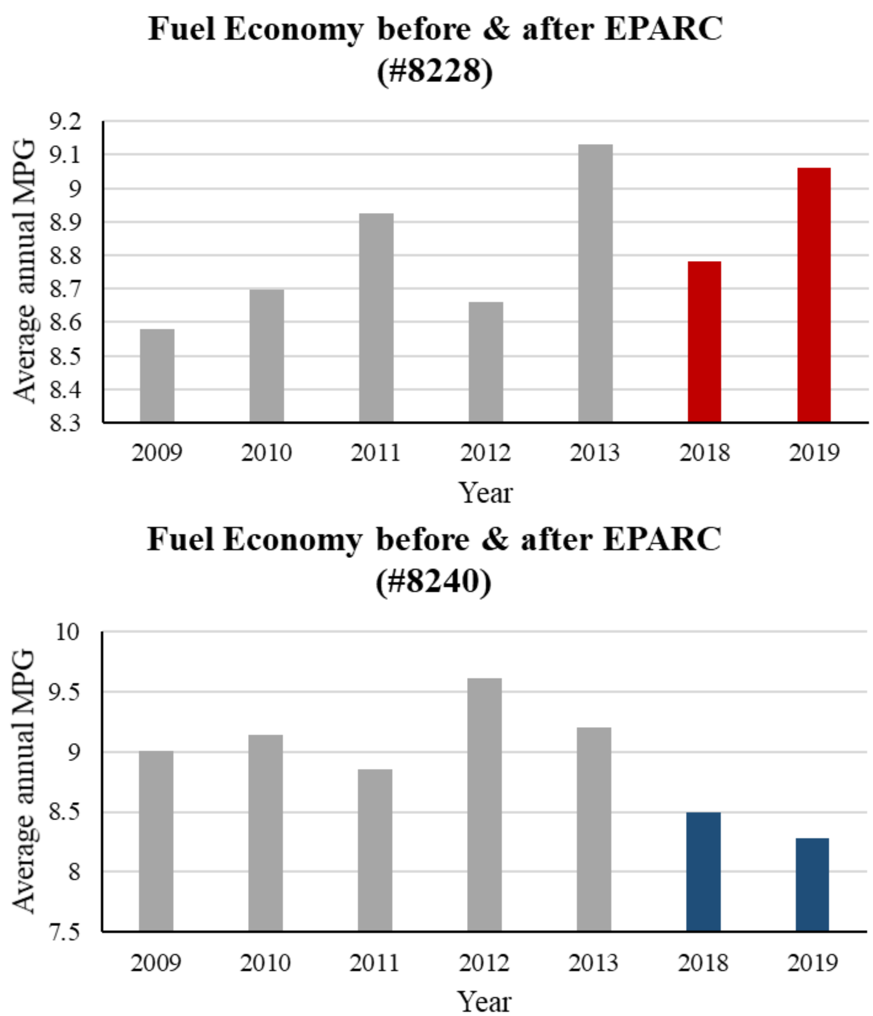

Figure B-5. Fuel economy comparison of Eparc equipped buses before and after the installation of the Eparc

Idling Cost Saving Analysis

Researchers at Argonne National Laboratory have produced a series of tools to help businesses analyze idling time in order to identify the most cost-effective approaches to improve their idling profile [1]. To this end, one of the sketch planning tools is to enable fleet managers and vehicle owners to calculate potential savings from reducing their vehicle idling time via idling reduction (IR) devices. The University of Utah utilized this sketch planning tool to estimate the idling cost savings as a result of Eparc implementation. The tool first estimates the total costs during the idling state, and then determine the costs by IR devices to derive annual savings and possible payback time of replacing with IR devices. The following description details how each indicator used in the tool is determined, as well as the analysis results.

Fuel Consumption Cost during Idling State

In order to estimate fuel consumption cost when idling, idling time needs to be determined. We used the GPS trajectory data for one of the retrofitted buses to derive the value.

The GPS data log contains location, speed, time stamp, road grade, and distance information for a trip every 2 seconds. Considering the GPS signal may bounce around when the bus is idling, GPS points of which the speed is lower than 1 kmph are identified as idling state. It should be noted that an idling state can be caused by braking for reasons other than passenger stops (e.g., waiting at signalized intersections). To separate the aforementioned situations, only consecutive low-speed GPS points (at least two) are selected to be counted towards total idling time. The result shows that the total idling time is 35 minutes (0.58 h) for one paratransit bus in a day. Subsequently, the running days for one bus in a year is calculated by averaging four years' historical running records from July 2009 to July 2013 of 52 paratransit buses. It is shown that a paratransit bus ran 217 days on average per year. As a result, the estimated annual idling time for one bus is 126 hours.

In the next step, the fuel consumption rate at idling state and fuel cost are required for calculation. The UTA paratransit buses are powered by 6.0 L diesel engines with automatic transmissions, and their fuel consumption rate resembles the rate of delivery trucks as a result of their powering similarity. It is estimated that idling fuel consumption rate for a delivery truck is 1.1 gal/h with load. The average diesel fuel cost in the State of Utah in 2019 is $3.4/gal. Thus, the total fuel cost for one bus during idling state is:

$$126\ h/year * 1.1\ gal/h * \$3.4/gal = \$471.24/year \quad (1)$$

Meanwhile, the historical data of 52 paratransit buses indicates that the average fuel economy is 8.87 mi/gal. The corresponding annual mileage of idling (idling is like putting miles on your engine) is calculated as:

$$126\ h/year * 1.1\ gal/h * 8.87\ mi/gal = 1{,}229.4\ mi/year \quad (2)$$

Oil Change Cost

The oil change cost is $150 each time, and the average mileage between oil changes is approximately 10,662 miles. As a result, the annual preventative maintenance cost is:

$$\$150/(10662\ mi) * 1229.4\ mi/year = \$17.3/year \quad (3)$$

Engine Overhaul Cost

The estimated engine overhaul is $10,000 on average, and the estimated mileage between overhauls is 100,000 miles [2]. The annual overhaul cost is calculated as:

$$\$10000/(100000\ mi) * 1229.4\ mi/year = \$122.94/year \quad (4)$$

Based on the aforementioned estimates, the total avoidable idling costs for one paratransit bus becomes:

$$\$471.24/year + \$17.3/year + \$122.94/year = \$611.48/year \quad (5)$$

Cost from Eparc System

The Eparc system consists of an energy high voltage battery, engine-driven high voltage alternator in addition to a high voltage HVAC compressor and auxiliary heater element. The high voltage battery is usually charged overnight when the bus is not utilized, and it can fulfill the whole day's capacity during passenger stops. In the State of Utah, the electricity cost changes by facilities and by regions. It also varies with different purposes (e.g. commercial, residential, and industrial usage) from 5.6 ¢/kWh to 9.5 ¢/kWh [3]. For simplicity, we assume the average electricity cost is 7.0 ¢/kWh. The battery capacity is 12 kWh. This implies that the charging cost is approximately $0.84 for a daily operation (0.58 h). Correspondingly, the annual electricity cost for the Eparc system is $182.

Idling Cost Saving Analysis

By shutting off the engine and utilizing the Eparc system to operate HVAC during passenger loading/unloading, each paratransit bus could save approximately $427 each year through idling reduction. The Eparc system prototype for the experiment cost about $30K. Yet future projection of the cost will be reduced to around $5K. As a result, the payback time is estimated at 11.7 years. Figure 6 shows the interface of the sketch planning tool along with the customized result for this project.

Overall Project Effectiveness

The project team, their execution of tasks, and their ability to complete the project timely and on budget appeared to be very effective. Although the Eparc system does not demonstrate significant fuel reduction on the two tested buses, it is estimated to be capable of reducing overall idling cost, which directly links to a reduction of maintenance cost. The results from the work show great promise in cost savings for traditional engine-powered paratransit buses. The effectiveness of the team leads to the interests from the UTA to continue being involved in developing this technology of a second generation of electrification and other commercialized vendors to get the prototype onto the market. The most notable outcome and value from this FTA-funded project, beyond technical success and demonstration of the technology, was the improvement of the HVAC as the team made progress towards moving it to the electrified system.

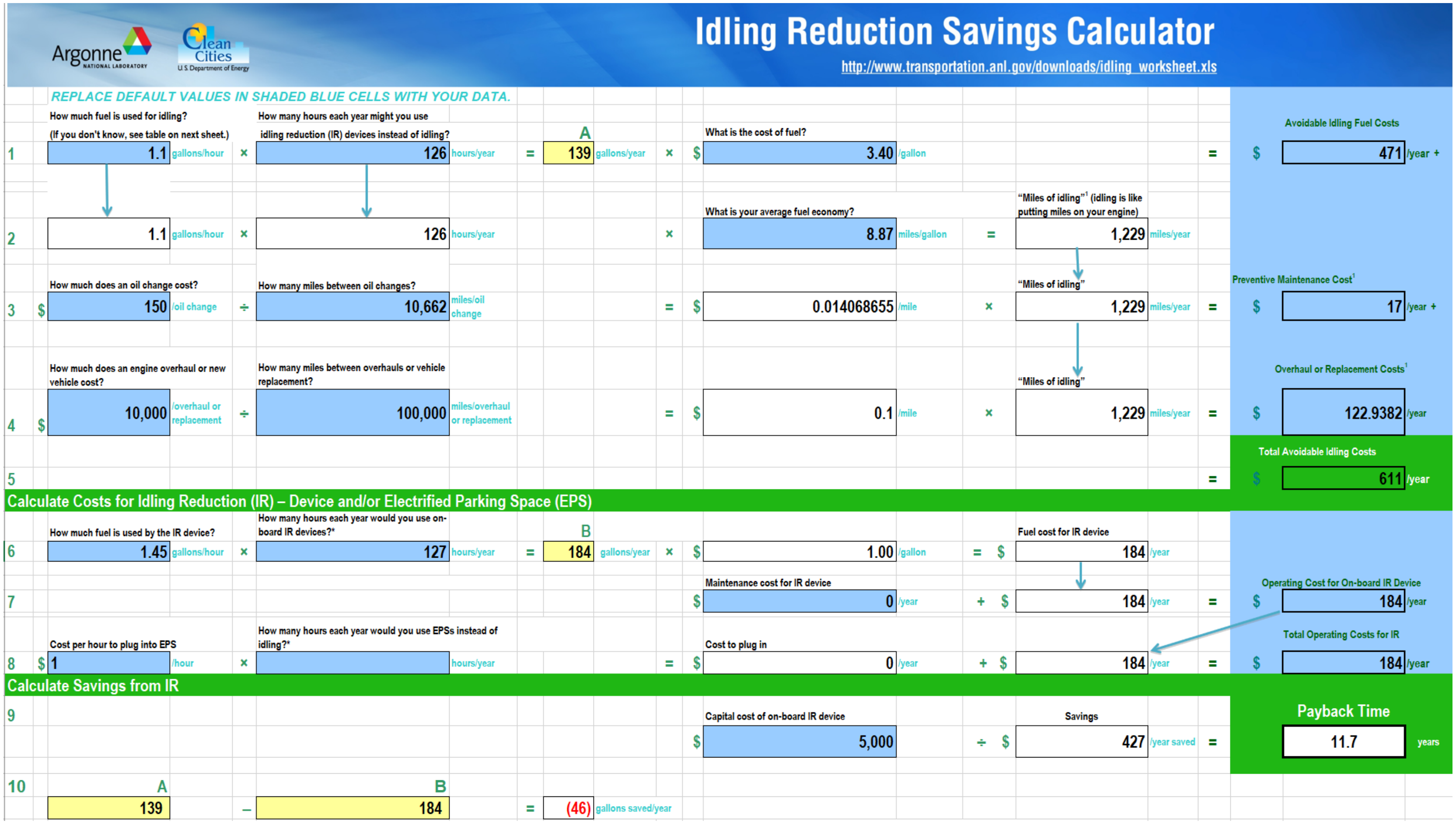

Figure B-6. Analysis results from Argonne National Laboratory sketch planning tool

References

[1] Argonne National Laboratory, Idle Reduction Research, retrieved from https://www.anl.gov/es/idle-reduction-research

[2] Teledyne Continental Motors Time Between Overhaul Periods, November 1998.

[3] Utah Electricity Rates, retrieved from https://www.electricitylocal.com/states/utah/

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