Appendix C

Automated Electric Shuttle Data Collection and Analysis

Appendix C consists of a presentation from Matt Shirk of the Idaho National Laboratory (INL), which offered to include TSU's AV project in an assessment of battery endurance the agency was concurrently conducting for several US automated vehicle projects. The INL installed a meter at TSU's Central Storage facility that compiled readings when the vehicle recharged and transmitted that data to INL to be processed. This presentation provides a background to this effort, describes how the data was collected and assembled, and presents results and findings concerning energy consumption forecasts for future AV transit applications.

The research was performed under the auspices of the DOE Vehicle Technologies Office SMART Mobility research program.

Automated Electric Shuttle Data Collection & Analysis

Matt Shirk
Idaho National Laboratory

Background

- INL partnered with Automated Electric Shuttle pilots to gather real-world energy data to support DOE Vehicle Technologies Office SMART mobility research
  - Focus on energy usage of automated electric first and last mile shuttles
  - Investigate this new technology to begin to understand energy impacts due to differences in vehicle types and usage scenarios
- Data were collected in Houston TX, Ann Arbor MI, and Salt Lake City UT from EasyMile and Navya shuttles

Data Collection Methodology

- A minimal data set, outlined below, allowed characterization of energy-intensity each day when vehicle was fully charged overnight

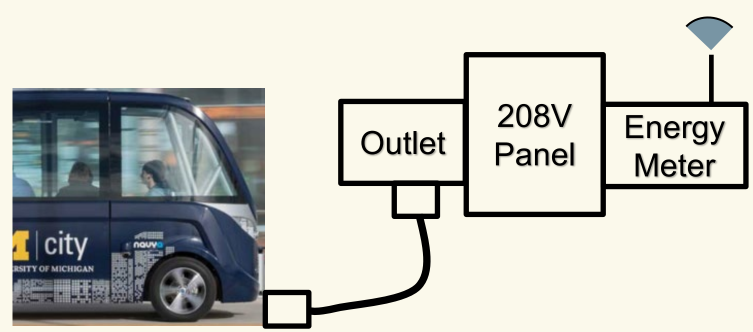
Operations Data

- Log of Odometer at start of each day
- Battery State-of-Charge at start of each day
  - Allows us be sure of a full charge

Data joined in spreadsheet or database…

Charging Energy

- AC Energy delivered to vehicle’s onboard charger from wall outlet
- No connection to vehicle networks or invasive instrumentation



Implementation of Hardware at TSU

- Meter was constantly powered by the outlet, and each charge was recorded when the vehicle was plugged in.
- A cellular modem located in the garage bay provided internet to the meter.
- Data were accessed and downloaded via a web portal.

Internet connected energy meter/datalogger

Meter connected between outlet and charge cord at TSU garage bay

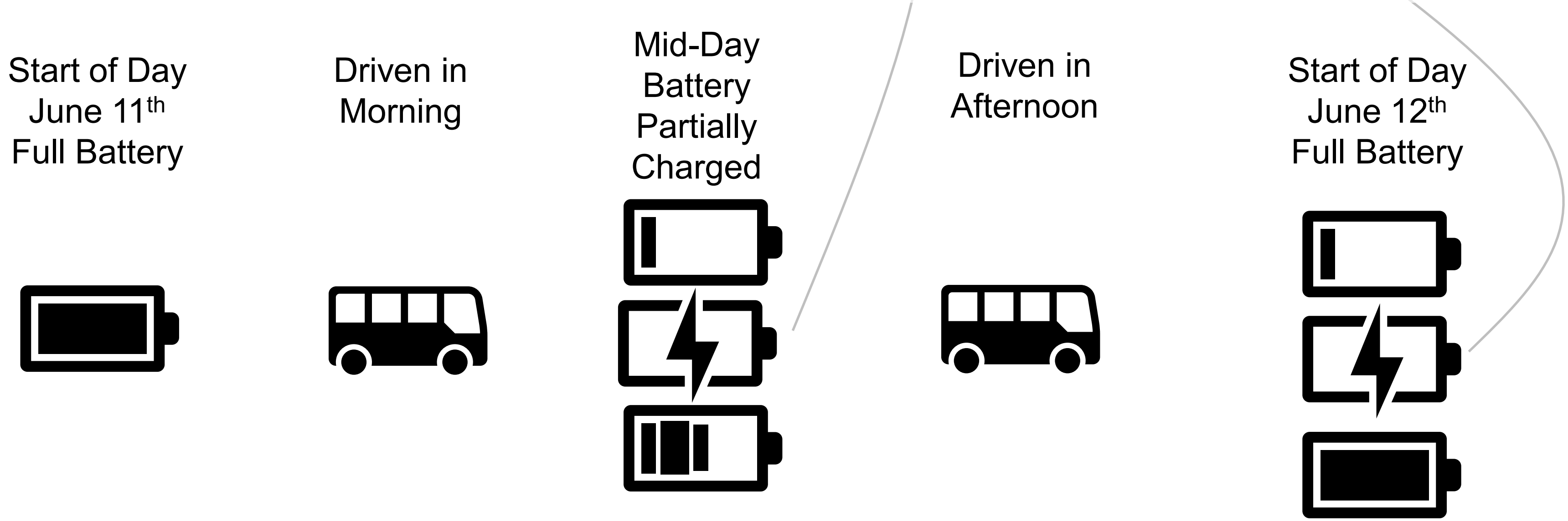
Assembly of Daily Data

Vehicle ID	Operation Date	Distance Travelled (Miles)	Recharge Energy (AC kWh)	Energy Intensity (AC Wh/Mi)	Operating Time (hr)	Average Speed (mph)
TSU	6/10/2019	30.45	36.9	1212	9.27	3.29
TSU	6/11/2019	24.86	32.6	1312	8.38	2.96
TSU	6/12/2019	26.10	32.3	1238	8.45	3.09

Operations Data			
Date	Start SOC (%)	Start Odometer (km)	End Odometer (km)
10-Jun	100	300	349
11-Jun	100	349	389
12-Jun	100	389	431

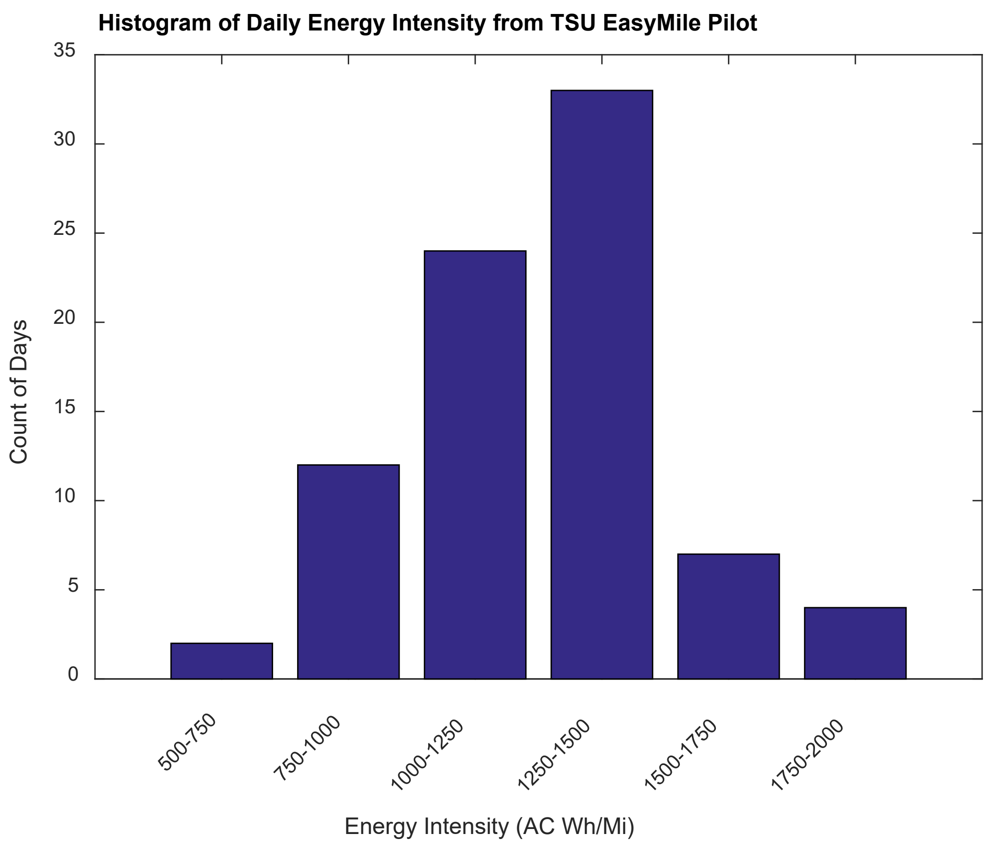
Data QA Checks:

- Battery starts day fully charged
- No jumps in Odometer records
- Battery is starts next day fully charged



Results

- Data were compiled for 89 days between June 10th and November 20th
  - 2052 miles, 2536 kWh, 1236 AC Wh/mi harmonic mean



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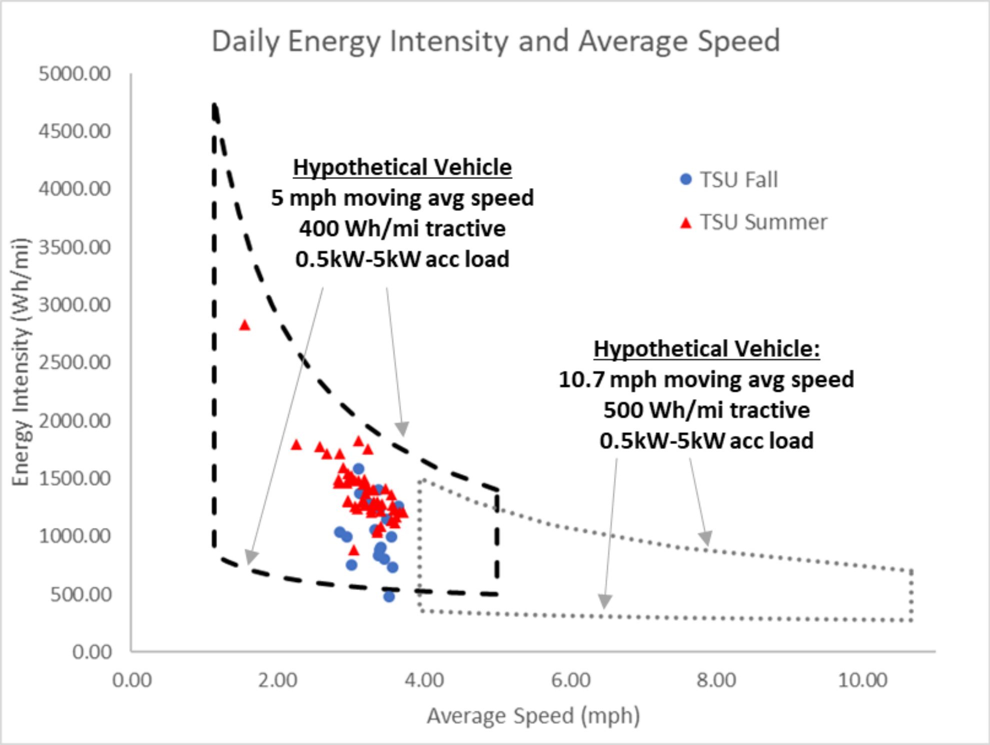
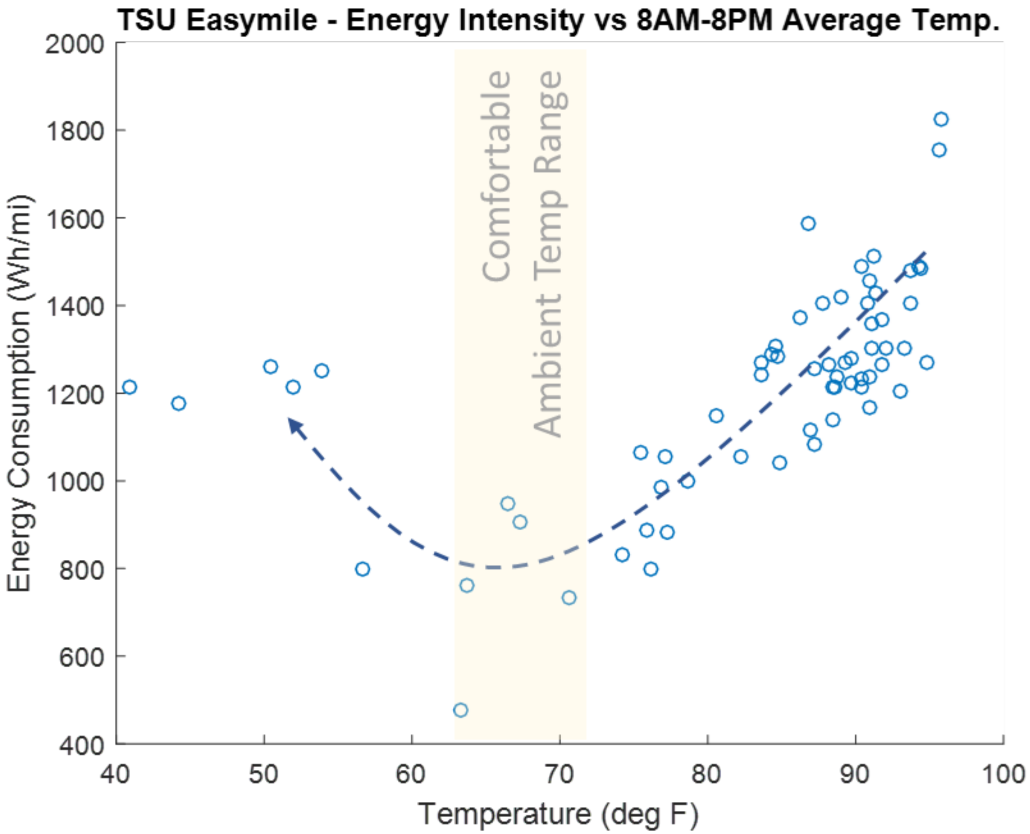
Results

- Overall average speed (operating hours including time stopped, and distance travelled) effected energy consumption due to high non-tractive loads, likely primarily air conditioning as illustrated by the seasonal impact



Results

- Adding temperature from local weather history illustrates a trend for increased energy consumption with ambient temperatures well above ideal room temperatures



Summary

- Slow moving speeds coupled with ample stops reduces overall speed to very slow speeds, where non-tractive loads will consume significant amounts of energy
- The large opening of the doors compared to the size of the vehicle and proportion of time spent with the doors open may be responsible for significant HVAC energy consumption
- Future iterations that don’t require an attendant and are used for short trips may realize an energy benefit from less climate conditioning, where the short duration of trips would have less affect on passenger comfort due to warmer or cooler interior temperatures

Thank You Houston METRO and TSU for your willingness to provide access to your project!

Supplemental EasyMile Provided Data

- EasyMile provided 1-minute averaged operations data to supplement the operations logs
- These let us look at how many hours the shuttle operated each day
- Also, it allowed confirmation of battery SOC to ensure daily start/end conditions

Time	Battery	BatteryV	InsideC	OutsideC	Odo	SpeedKPH
8/27/2019 16:39	43	49.08	26.018	35	2060	0.252
8/27/2019 16:40	43	49.04	26.008	35	2060	5.451
8/27/2019 16:41	43	49.04	25.983	35	2060	5.566
8/27/2019 16:42	43	49.02	25.783	35	2060	9.831
8/27/2019 16:43	42	49.08	24.958	35	2060	4.96
8/27/2019 16:44	42	49.03	24.825	35	2060	5.642
8/27/2019 16:45	42	49.06	24.925	35	2060	0.034
8/27/2019 16:46	42	49.01	26.033	34.733	2060	6.225
8/27/2019 16:47	41	49.06	25	34	2061	4.628
8/27/2019 16:48	41	49.04	24.592	34	2061	9.391
8/27/2019 16:49	41	49.09	23.233	33.992	2061	5.785
8/27/2019 16:50	41	49.09	23.625	33.692	2061	8.496
8/27/2019 16:51	41	49.09	23.917	33	2061	7.036
8/27/2019 16:52	40	49.08	24.283	33.225	2061	6.034
8/27/2019 16:53	40	49.06	24.483	33.975	2061	9.423
8/27/2019 16:54	40	49.06	24.258	34	2061	1.853
8/27/2019 16:55	40	49.06	24.992	34	2061	7.937
8/27/2019 16:56	40	49.07	24.15	34	2062	6.846
8/27/2019 16:57	39	49.04	23.446	34	2062	3.796

Energy Meter Details

eGauge Core Specifications

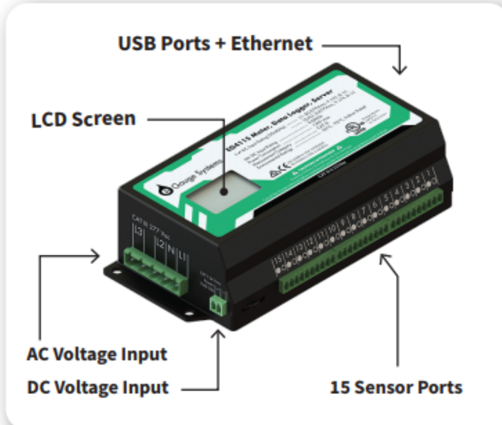
Model: EG4115

Measurement

AC Voltage: (Y: L-N, Δ: L-L)	L1: 85-277 Vrms L2: 0-277 Vrms L3: 0-277 Vrms
DC Voltage:	42 Vrms Power: 9-60 Vdc Measurement: -60-60Vdc
Current:	15 sensor ports 6900A max Sensor ports isolated from digital and high voltage
Frequency:	50 or 60 Hz
Logging Values:	V, A, W, Wh, Hz, VA VAr, THD, deg
Power Draw:	12W max, 2W typical 2 5V USB Ports @ 1A max
Accuracy:	ANSI C12.2 - 0.5% Compliant

Environment Conditions

Operating Temp:	-30° to 70°C (-22° to 158°F)
Max Altitude:	4000m (13,123ft)
Max Humidity:	80% up to 31°C
Meas. Category:	Overvoltage Category III
Location:	Open type indoor device
Pollution Degree:	2



Data Logger Capacity

Register Count:	64 (data storage points)
Granularity: *(duration/avg)*	1 hr/1 sec 1 yr/1 minute 10 yrs/15 minute Device Lifetime/1 day

Safety and Regulatory

Safety:	IEC/UL 61010-1 Ed. 3.0 B:2010
CE:	IEC 61000-6-1 Ed. 3.0 B:2016 IEC 61000-6-3 Ed. 2.1 B:2011
FCC:	FCC Title 47 CFR Part 15-Subpart B Class B ICES-003 Information Technology-Equipment Class B

^Photo of an INL owned eGauge installed at another automated shuttle charging circuit

<Source: https://www.egauge.net/eos/energy-meters/EG4115

Idaho National Laboratory

Department of Energy (DOE)
Office of Energy Efficiency and Renewable Energy (EERE)

Fiscal Year 2020 Advanced Vehicle Technologies Research Funding Opportunity Announcement

Funding Opportunity Announcement (FOA) Number: DE-FOA-0002197
FOA Type: Amendment 0001
CFDA Number: 81.086

FOA Issue Date:	01/23/2020
Amendment 0001	01/29/2020
Submission Deadline for Concept Papers:	2/21/2020
Anticipated Date of Concept Paper Notifications:	3/17/2020
Submission Deadline for Full Applications:	4/14/2020
Anticipated Date for EERE Selection Notifications:	July 2020
Anticipated Timeframe for Award Negotiations:	August 2020

- Applicants must submit a Concept Paper by 5:00pm ET on the due date listed above to be eligible to submit a Full Application.

Energy Efficient Mobility Systems	
9	Improving Transportation System Efficiency Through Better Utilization
10	Enabling Vehicle and Infrastructure Connectivity
11	Improving Mobility, Affordability, and Energy Efficiency Through Transit

https://eere-exchange.energy.gov/FileContent.aspx?FileID=925139ce-ef3a-4995-982a-c77648f52ba3