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

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

Data joined in spreadsheet or database…

[Diagram showing energy flow from outlet to 208V panel, through Energy Meter, to Internet via Wifi]
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.
## Assembly of Daily Data

<table>
<thead>
<tr>
<th>Vehicle ID</th>
<th>Operation Date</th>
<th>Distance Travelled (Miles)</th>
<th>Recharge Energy (AC kWh)</th>
<th>Energy Intensity (AC Wh/Mi)</th>
<th>Operating Time (hr)</th>
<th>Average Speed (mph)</th>
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### Operations Data

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<th>Date</th>
<th>Start SOC (%)</th>
<th>Start Odometer (km)</th>
<th>End Odometer (km)</th>
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<tr>
<td>12-Jun</td>
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### 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 10\textsuperscript{th} and November 20\textsuperscript{th}
  - 2052 miles, 2536 kWh, 1236 AC Wh/mi harmonic mean

![Histogram of Daily Energy Intensity from TSU EasyMile Pilot](Image)
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

<table>
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<th>Time</th>
<th>Battery</th>
<th>BatteryV</th>
<th>InsideC</th>
<th>OutsideC</th>
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Energy Meter Details

**eGauge Core Specifications**

**Model: EG4115**

**Measurement**

- **AC Voltage:**
  - L1: 85-277 Vrms
  - L2: 0-277 Vrms
  - L3: 0-277 Vrms

- **DC Voltage:**
  - 42 Vrms
  - Power: 9-60 Vdc
  - Measurement: -60-60 Vdc

- **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

**Data Logger Capacity**

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

**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

**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>
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

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- 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 |