Connected, Electric Autonomous Vehicles
Presentation on the Linden Deployment
SPEAKERS

ALYSSA CHENault
City of Columbus
Communications Project Manager
anchenault@columbus.gov

JEFF KUPKO, P.E., PTOE
Michael Baker International
CEAV Project Manager, City of Columbus
jeffrey.kupko@mbakerintl.com

LAUREN ISAAC
EasyMile
Director of Business Initiatives
lauren.isaac@easymile.com

LEVENT GUVCNC
The Ohio State University
Professor
guvenc.1@osu.edu
PURPOSE OF THIS WEBINAR
• Share concept development activities from Smart Columbus with stakeholders

WEBINAR CONTENT
• Smart Columbus program overview
• Route Overview
• EasyMile Overview
• NHTSA and Importation
• Test Plan
• OSU Simulation
• Launch
• Challenges and Lessons Learned
• Stay Connected
• Stakeholder Q&A

WEBINAR PROTOCOL
• All participant lines have been muted during the webinar in order to reduce background noise
• Questions are welcome via chatbox during the Q&A Section
• The webinar recording and presentation materials will be posted on the Smart Columbus website
$40 MILLION
78 APPLIED • COLUMBUS WON

VISION:
To empower our residents to live their best lives through responsive, innovative and safe mobility solutions.

MISSION:
To demonstrate how an intelligent transportation system and equitable access to transportation can have positive impacts on everyday challenges faced by cities.

OUTCOMES:

SMART CITY CHALLENGE

THE CITY OF COLUMBUS
ANDREW J. GINThER, MAYOR

U.S. Department of Transportation
USDOT PORTFOLIO - TECHNOLOGIES

Connected Vehicle Environment
• 100+ roadside units
• 1,500-1,800 on-board units
• 1,240 light duty vehicles
  o 430 transit vehicles
  o 110 emergency vehicles
  o 12 freight vehicles

Connected Electric Autonomous Vehicles
• Scioto Mile Deployment (May Mobility)
  o December 2018-September 2019
  o 6 vehicles
• Linden Deployment (EasyMile)
  o January 2020-January 2021
  o 2 vehicles (3rd coming soon)

Smart Mobility Hubs
• 6 locations to facilitate first-mile/last-mile connections
• Anchored by an interactive kiosk
Operating System
- Big data and complex data exchange
- Analytics and visualization
- Data aggregation, fusion and consumption
- Replicable and scalable

Multimodal Trip Planning App
- Publicly available app (Pivot)
- Backed by Common Payment System

Prenatal Trip Assistance
- Research study to improve transportation for moms-to-be
- Up to 500 participants

Mobility Assistance
- Research study with app for turn-by-turn navigation
- Increase independence
- Up to 30 participants

Event Parking Management
- Publicly available app (ParkColumbus)
- Probability of on-street parking
- Reserve private lot/garage spaces
LINDEN DEPLOYMENT
ROUTE OVERVIEW
• Connect the community to services with FMLM connections
• Grow COTA ridership
• Establish a common data exchange interface
• Establish a set of procurement guidelines
• Develop a set of AV operational testing and evaluation guidelines to benchmark AVs
• Develop a methodology for evaluating operational safety
• Validate and ensure equitable and accessible options
• Summarize lessons learned
STAKEHOLDER MEETINGS

• Multiple meetings held to identify and refine routes
• Provide input into RFI
• Reconvene to review RFI responses
• Final input on route and scoring
## RANKING CRITERIA

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Smart Mobility Hub</td>
<td>The route provides a connection to a proposed Smart Mobility Hub as part of the Smart Columbus initiative.</td>
</tr>
<tr>
<td>Food and Service Access</td>
<td>The route connects to food and services needed within a community. The list includes grocery store, bank, pharmacy, and food bank/pantry.</td>
</tr>
<tr>
<td>Ladders of Opportunity</td>
<td>The route connects residents with job or opportunity centers for enhanced placement access. The list includes an Opportunity Center and Ohio Means Jobs.</td>
</tr>
<tr>
<td>COTA</td>
<td>The route connects to a COTA stop and acts as a FMLM connection to expand the reach of a traveler.</td>
</tr>
<tr>
<td>Alignment Considerations</td>
<td>The route serves more as a missing link than a duplicate of an existing COTA route.</td>
</tr>
<tr>
<td>Safety and Accessibility</td>
<td>The route has lighting and sidewalks in the vicinity of anticipated stops.</td>
</tr>
<tr>
<td>Prenatal Support</td>
<td>The route connects pregnant women with services that can aid in a healthy pregnancy.</td>
</tr>
<tr>
<td>Neighborhood</td>
<td>The route connects to an opportunity neighborhood for increased mobility.</td>
</tr>
<tr>
<td>Storage</td>
<td>The route provides a nearby facility for storage and charging of vehicles.</td>
</tr>
<tr>
<td>Route navigation</td>
<td>The technology at the time of deployment will allow the route to be traveled.</td>
</tr>
<tr>
<td>Recs and Parks</td>
<td>The route connects to a City recreation center or park.</td>
</tr>
</tbody>
</table>
ROUTE OVERVIEW

• Access to two Smart Mobility Hubs
  o Linden Transit Center
  o St. Stephens

• Access to services

• FMLM connection

• Fills transit gap

• Linden LEAP
EASYMILE OVERVIEW
Founded in June 2014

Current headcount 230 employees

Headquartered in Toulouse (France), with offices in Denver (USA), Berlin (Germany), Singapore, and Adelaïde (Australia)

Privately funded by founders, with Alstom, Continental and Bpifrance as strategic investors
Overview Video

EasyMile EZ10 Video P Fabre 2018
EZ10 AUTONOMOUS SHUTTLE

Autonomous and electric shuttle

Accessibility ramp

Up to 12 people (8 seated, 4 standing)

Pre-mapped network of roads

Up to 16h autonomy - 8 hours with extended use of heating/AC

Other vehicles’ maximum speed

EZ10 maximum operating speed
While a typical deployment process can take 3-4 months from contract signing to operations, the Columbus project took closer to 8 months.
NHTSA FMVSS EXEMPTION AND IMPORTATION
Federal Regulation Process

- Federal approval is required since the EZ10 is not compliant with FMVSS (Federal Motor Vehicle Safety Standards).

- EasyMile is required to get a federal exemption from NHTSA (National Highway Traffic Safety Administration) via Box 7 to import and operate the EZ10.

- This process typically takes 45-60 days; however, this project’s route is extra complex and required many months and discussions to obtain approvals.

- NHTSA approval was received in December 2019 and is valid for 6 months with the opportunity for extension.
There are three state approvals required for public road operations in Ohio:
EZ10 autonomous vehicle enabling smart mobility in urban, suburban or private areas. Designed to bridge the gap between hubs and to enable new mobility for public and private sites, it is the most deployed driverless shuttle in the world.

Deployments in 27 countries

>250

120 Shuttles worldwide
TEST PLAN
TEST PLAN

• Thoroughly vet the vehicles’ capabilities

• Broken into phases
  o Factory Acceptance Testing
  o Preliminary Acceptance Testing
  o Final Acceptance Testing

• 52 different tests and 115 total tests over three phases
TEST PLAN – FEATURES NOT TESTED

- Stress tests
- Network security
- Roadway support infrastructure
- Lane changes
- Roadside units
- Onboard units
- Unit and component testing
FACTORY ACCEPTANCE TESTING

FAT6: Factory Audit
Ensure the factory where the vehicles were manufactured meets the City’s expectations.

FAT10: Signalized Intersection
Demonstrate how a signalized intersection would be navigated.

FAT25: Deploy Ramp
Demonstrate that vehicles can deploy a wheelchair accessible ramp.
FACTORY ACCEPTANCE TESTING
PRELIMINARY ACCEPTANCE TESTING

PAT3: Movement Alert
   Ensure the vehicles have an indicator to alert passengers when the vehicle will begin moving following a stop.

PAT5: Manual Override
   Ensure a manual override is possible.

PAT21: Moving Obstacles
   Demonstrate detecting and responding to moving obstacles (a pedestrian, scooter, bike, ball, car).
PRELIMINARY ACCEPTANCE TESTING

PAT37: Facility Check
Show that the vehicles are provided with a safe and secure location for overnight storage, charging, and routine maintenance.

PAT38: Charging
Demonstrate the vehicles taking on a charge from each charging port.
PRELIMINARY ACCEPTANCE TESTING
PRELIMINARY ACCEPTANCE TESTING
FINAL ACCEPTANCE TESTING

FiAT11: Car Following in Stop and Go Traffic
Demonstrate car following in stop and go traffic conditions.

FiAT14: Traffic Circle
Demonstrate entering and emerging from a stop-controlled traffic circle.

FiAT31: Weather
Demonstrate operating in rain, fog and light snow conditions not deemed a weather emergency (when conditions are available).
FINAL ACCEPTANCE TESTING
FINAL ACCEPTANCE TESTING

- Allow emergency responders time to get hands-on with the vehicle and ask questions
- Hold an emergency responder tabletop exercise with scenarios
The Ohio State University Automated Driving Lab

SIMULATION ENVIRONMENT AND STUDY
MOTIVATION

- Linden Residential Area AV shuttle route simulation environment
- Soft AV shuttle operation in the planned route before deployment
- Check for feasibility, difficult operating
- Propose mitigation methods
- Safety Management Plan
- Educational tool
SETUP

Simulation

PC with Graphic Card

Hardware
SIMULATION ENVIRONMENT CONSTRUCTION

**Map**
- OpenStreetMap

**Model Generation**
- Load road network into Unity

**Simulation**
- Generate 3D model of the environment

Get online map data from OpenStreetMap
LINDEN RESIDENTIAL AREA MAP
• Other traffic actors such as cars, pedestrians and bicyclists navigate using map annotations.
• Map annotations includes lanes, intersections, stop lines, etc.
• Pedestrian paths such as junctions and crosswalks are also annotated.
TRAFFIC CIRCLE MAP NAVIGATION

Traffic Circle annotation

Traffic Circle example simulation snapshot
OTHER TRAFFIC MAP NAVIGATION

Three-way intersection annotation

Three-way intersection example simulation snapshot
• Blue lines represent lanes that other vehicles should follow

• Magenta lines represent stop lines or stop signs

• Stop lines can be configured to yield to other specific lanes
OTHER TRAFFIC MAP NAVIGATION

• Can simulate real life situations such as crashes, unpredicted car behaviors, etc.

• Other traffic can also run by stop lines and traffic lights
The simulator provides AV sensor emulation for different virtual sensors:

- Point cloud emulation is generated on surfaces of 3D models for LIDAR sensor
- Synthetic camera provides rendered pixels with RGB, depth information and segmentation ground-truth data
- GPS is enabled with respect to the map position in global coordinates
- IMU data is provided
A 3D point cloud was generated within the simulator for emulating 3D Lidar sensors.
Camera Demo in Simulation

RGB camera images, depth camera images and ground truth for segmentation are provided in the simulator.
In ROS-based AV testing, the following functions are tested for pre-deployment simulation:

• High definition 3D point cloud mapping
• Map matching based AV localization
• Path following along the autonomous shuttle route
• Emergency braking in testing scene
3D POINT CLOUD MAPPING
MAP MATCHING BASED LOCALIZATION

Used virtual LIDAR sensor data to localize the vehicle
The soft AV shuttle follows the route in Linden using AV functions.
The soft AV shuttle applies an emergency brake when a collision risk is determined.
Autonomous Shuttle in Linden

A simulation demo
• The AV shuttle path following performance along the shuttle route depends on speed
• The route finish time was impacted by different traffic conditions
• Real vehicles and pedestrians (as well as bicyclists and scooters) may have unexpected and sudden collision threat generating maneuvers
SIMULATION FINDINGS: SIGNIFICANT EVENTS AND TRAFFIC SCENARIOS

- Handling a traffic circle with stop-controlled entry
  - Non-AV traffic may not obey the rules of traffic properly
- AV sensors may have difficulty in picking up all other traffic including vulnerable road users at non-signalized intersection or traffic circles
- Stopped vehicles or other objects on the road stalled the AV
- Weather conditions may impact performance and safe operation
ITEMS OF CONCERN FED INTO THE SAFETY MANAGEMENT PLAN

- Response to sudden appearance of pedestrian, bicyclist or scooter
- Emergency braking response
- Inclement weather condition operation
AV SIMULATION WORK BENEFITING OSU CURRICULUM

• Linden Residential Area AV route building and simulation is being incorporated into ECE 5553 Autonomy in Vehicles lectures
• One homework assignment and final project of ECE 5553
• Simulation work and AViL testing to be incorporated into ME 8322 Vehicle System Dynamics and Control
OUTREACH & ENGAGEMENT
LAUNCH PLANNING AND COORDINATION

- Audience Identification
  - Grassroots
  - Grasstips
- Project timeline with key milestones
  - Planning
  - Development
  - Testing
  - Deployment
LAUNCH PLANNING AND COORDINATION

- Route selection press release (Feb. 2019)
- Outreach & engagement (Feb. 2019-current)
  - Updates at Area Commissions and community meetings
  - Group presentations
  - Tabling at area events
  - Newsletter updates
  - Social media
  - One-page info sheet
- Vendor selection press release (May 2019)
LAUNCH PLANNING AND COORDINATION

- Joint community meeting with other city departments (June 2019)
- Contract with trusted organization (Sept. 2019)
  - Inform messaging
  - Distribute information
  - Hold an information session
  - Recruit people
- Community input on naming (Oct.-Nov. 2019)
- Mailer (Jan. 2020)
LAUNCH PLANNING AND COORDINATION

- Local hiring event (Jan. 2020)
- Ambassador Training (Jan. 2020)
- Door-to-door outreach (Jan. 2020)
LAUNCH PLANNING AND COORDINATION

- Website (Jan. 2020)
  - Service changes

- Partner previews (Feb. 2020)

- Press conference (Feb. 2020)

- Community launch event (Feb. 2020)
LAUNCH PLANNING AND COORDINATION

- Rider and driver tips (Feb.-April 2020)
- Encouraging surveying (Feb. 2020-end of pilot)
- Programming to support ridership (Feb. 2020-end of pilot)

Tabling at area events
CHALLENGES
Accommodating NHTSA feedback

- School and daycare inventory
- Parking counts
- Committing to signage
Developing a thorough Test Plan

- Vet the system
- Incorporate VRUs for public validation
- Ensure procurement requirements are met
- Closed course and open road
CHALLENGES

Roadway geometry

• Western driveway grade differential at St. Stephens

• Required a resubmission to NHTSA of route

• Longer distance on 18th Avenue
LESSONS LEARNED
LESSONS LEARNED

Timeline

• If route is complex allow additional time
• Compresses deployment time following approval
• Risk of having route not approved
“I guess one thing we’ve learned from this pilot is that forestry is a vital department to keep autonomous shuttles operable. It’s good to be needed.”

- Assistant Director, Rec and Parks
LESSONS LEARNED

Closed course approval

• Allows for vehicles to be imported
• Able to do testing, wrapping and training
• Aids in retaining deployment schedule
LESIONS LEARNED

Data

- First Ohio deployment strengthened procurement language on data
- Identified datasets, method of transmission, and frequency
- Meets performance measurement goals

<table>
<thead>
<tr>
<th>Data Category</th>
<th>Example Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle route and schedule (GTFS)</td>
<td>Wheelchair ramp deployments</td>
</tr>
<tr>
<td>Real-time vehicle location information (AVL, GTFS Realtime)</td>
<td>Sensor and other telemetry data (Under NDA)</td>
</tr>
<tr>
<td>Trip updates and service alerts</td>
<td>Navigation variances (Under NDA)</td>
</tr>
<tr>
<td>Ridership (stop-level boardings and alightings)</td>
<td>Probe data (nRTK-enabled or similar) (Under NDA)</td>
</tr>
<tr>
<td>Actual stop arrival and departure times</td>
<td>Mechanical data (vehicle condition)</td>
</tr>
<tr>
<td>Vehicles miles traveled</td>
<td>Disengagements/interventions by the operator</td>
</tr>
<tr>
<td>Vehicle hours traveled</td>
<td>Any other logged events</td>
</tr>
<tr>
<td>Number of route-trips served</td>
<td>Conditions driven in (weather, congestion, etc.)</td>
</tr>
<tr>
<td>Duration of each trip</td>
<td>Incident reports</td>
</tr>
<tr>
<td>Battery usage</td>
<td>SPaT, MAP, and BSM</td>
</tr>
<tr>
<td>Average vehicle speeds</td>
<td></td>
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</tbody>
</table>
HOW TO STAY CONNECTED

SMART COLUMBUS INQUIRIES:
Alyssa Chenault,
Communications Project Manager
anchenault@columbus.gov

Linden LEAP Documents:
https://smart.columbus.gov/projects/self-driving-shuttles

Upcoming Smart Columbus Webinars:

<table>
<thead>
<tr>
<th>Title</th>
<th>Date</th>
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<tbody>
<tr>
<td>System Architecture and Standards Plan</td>
<td>3/3/20</td>
</tr>
<tr>
<td>CVE Test Plan; Installation, Recruiting and Development Update.</td>
<td>3/24/20</td>
</tr>
<tr>
<td>Draft Human Use Approval Summary</td>
<td>4/2/20</td>
</tr>
<tr>
<td>SMH Launch and Test Results</td>
<td>4/14/20</td>
</tr>
<tr>
<td>MMTPA/CPS - CPS Test Results + Presentation of Combined MVP + Lessons Learned</td>
<td>4/22/20</td>
</tr>
</tbody>
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Webinar recording and materials will be available at ite.org and smart.columbus.gov
QUESTIONS?
SIGN UP FOR OUR E-NEWSLETTER
Contact: SmartColumbus@columbus.gov
Smart.Columbus.gov
@SmartCbus
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