Feasibility of Electric Autonomous Vehicles on Ohio State University Campus

Haley Henderson, Alex Veder, Lu Li, Miles Johnson

The Ohio State University
EEDS Capstone
Start Date: August 29, 2017
End Date: November 29, 2017

Table of Contents

I. Executive Summary

Motivated by the sustainability goals of both The Ohio State University (OSU) and the City of Columbus, this research project aims to assist OSU in finding useful and efficient ways to use electric autonomous shuttles at the OSU Columbus campus. Specifically using Local Motors' Olli electric autonomous vehicle as our vehicle of interest, we researched compatible services for the introduction of electric autonomous shuttles at Ohio State.

We researched three case studies to give us an idea of what electric autonomous shuttles are currently being used for, where they are most compatible in a campus setting, and how they are being used. We looked at examples of electric autonomous vehicle use in Michigan, London, and Las Vegas.

Our team met with potentially compatible departments at Ohio State to determine the feasibility of replacing some of their service vehicles with electric autonomous shuttles. We investigated the ways in which an electric autonomous shuttle would benefit or change the way these departments function, and cost differences between their current vehicles and Olli.

After collecting the cost data on current service vehicles, we conducted a cost analysis to compare current Ohio State fleet vehicles, to the costs of purchasing and maintaining an Olli from Local Motors. From our analysis, we found that Olli is currently not cost-effective due to high initial price relative to traditional Ohio State fleet vehicles. Olli did however, exceed OSU fleet vehicles and CABS shuttles in several categories. Olli had a cheaper cost/mile, fewer carbon emissions/mile (0.91 lbs), and lower annual maintenance costs ($600/yr).

From our discussions with departments of interest to our project, we found that electric autonomous shuttles could help alleviate transit issues, reduce labor costs, and help Ohio State reduce its overall carbon footprint. Most of the departments that we talked to were interested in the benefit of significantly reduced greenhouse gas emissions from charging the shuttle, but also the reduced labor cost of not having a driver to deliver items across campus. The transit issues that were important to Ohio State and the City of Columbus were first mile-last mile problems (the distance that a bus passenger still has to travel from their last bus stop to their destination) that many public transit systems face. The electric autonomous shuttle could help eliminate this problem by providing the extra transit needed to get around Ohio State’s many parking lots, where some stops may not exist or are not serviced frequently. The shuttle could also potentially replace current shuttle vehicles on short routes, particularly in the medical campus and Ackerman Road, where the transit service is necessary, but not used very often. Replacing this shuttle with an electric autonomous vehicle would help reduce labor costs, but also mitigate greenhouse gas emissions from this short route.

II. Introduction

The advent of electric autonomous vehicles has generated significant interest as a potential way to provide sustainable transportation services in a more effective, safe, and environmentally beneficial manner. However, research quantifying the costs and benefits of these vehicles, specifically in academic settings, is sparse. Of the 3 studies we were able to find, one, conducted at the University of Michigan, focused on passenger and road user reactions to autonomous electric vehicles (Mcity, 2017). As a pilot, two NAVYA shuttles, which can carry up to 15 passengers, were purchased to transport faculty, students, and staff. The vehicles operate on a 2-mile trial loop between the Lurie Engineering Center and the North Campus Research Complex. They run on University of Michigan roads during business hours about every ten minutes; there will be no cost to riders. During the first two years of the experiment there will be a safety conductor on board for each shuttle. Safety conductors will not only ensure passenger safety, but also observe human behavior. Hours of EAV operation and the service area size may be increased later if the technology is proved efficient as expected and consumer acceptance supports expansion. Similarly, a study conducted as a part of the Greenwich Automated Transport Environment (GATEway) project in the Smart Mobility Living Lab in London aimed to better understand how this technology can function around pedestrians and within the built environment. The GATEway study was the first of its kind that focused on external perception rather than internal (operating an EAV). Using survey data from close to 1000 individuals, this study concluded that autonomous vehicles display low risks and are welcomed by cyclists and pedestrians (Hulse, Xie, & Galea, 2017). The GATEway project has been conducting trials for automated home grocery deliveries around Greenwich, in order to better understand the commercial practicality of automated vehicles. In June of 2017, the GATEway project completed their first of many trials delivering groceries to homes in Greenwich. This study is one of the first of its kind, identifying the commercial viability of the technology as well as the public perception. Based on pending research results, autonomous vehicles may play a crucial role in reducing congestion, noise and emissions within boroughs of London (GATEway project, 2017).

The last case study our team explored takes place is Las Vegas, Nevada and utilizes the same autonomous shuttle (NAVYA) as the University of Michigan. The pilot test operates on a short 3-block route, transporting up to a dozen passengers. It is one of many future trials projected by the City of Las Vegas as they pursue the development of a downtown innovation center for autonomous technologies and green energy (Morris, 2017). Las Vegas has already invested close to $500 million in smart technologies such as connected traffic lights in the urban center in effort to further the establishment of connected autonomous vehicles.

Previous studies indicate that there may be potential benefits from the introduction of autonomous electric vehicles in the form of lowered GHG emissions, improved road safety, and reduced congestion. Building on these studies, our project examines the direct costs and benefits of adopting autonomous electric vehicles in a university setting. Working in collaboration with OSU’s Transit Lab, Center for Automotive Research (CAR), and various University departments, our team has compiled a report which highlights the potential benefits of introducing autonomous electric vehicles in Ohio State’s campus operations. Such operations include book and food delivery as well as transportation. The cost-benefit analysis we conducted indicates that electric autonomous vehicles (EAV) produce lower carbon emissions. This would allow future fleet operations for OSU to mitigate their overall footprint, which would contribute to The Ohio State's goal of reducing University fleet emissions by 25% by 2025. In addition, a more sustainable mode of transportation on campus would align the University to Smart Columbus initiatives of decarbonization and the establishment of a comprehensive transportation system.

III. Methods

Olli is an electric autonomous shuttle vehicle created by Local Motors; it uses a combination of cameras and LIDAR technology (Light Detecting and Ranging) to navigate roads and anticipate traffic or obstructions. Olli shuttles can transport up to 8 people and has a range of 32.4 miles, with a maximum speed of 25 mph. (Hugh Palmer, the VP of Project Management at Local Motors; Personal Communication). When we spoke to Hugh Palmer, he gave us more information about the current capabilities of Olli and what future models will be able to do including a further range of 100 miles, and induction charging. Once again, we decided to use this vehicle in our cost comparison because Ohio State is in the process of purchasing one for research purpose and to further the development of this technology.

To identify a scope for this project, we collaborated with the Transportation and Traffic Management depart at OSU, to see where their department saw this technology fitting in with daily functions at Ohio State. Based on feedback from these meetings, we collected data on and quantified the costs and benefits associated with switching fleet vehicles from Library services, the Book Depository, and Campus Dining Services, with Olli electric autonomous shuttles. We gathered use and cost data from Library Services, the Book Depository, University Dining Services, and University Stores and Receiving. This data included greenhouse gas emissions from vehicles, fuel and maintenance costs, purchase price, labor costs, average lifecycle, and average route distance and time spent driving on daily routes. The vehicles we used to compare to Olli were Campus Area Bus Service (CABS) shuttles, a 12-passenger minivan, and a standard minivan. We chose these vehicles to compare to Olli because of their current uses in the fleet (transporting up to 12 people, and supplies), their similar size, and their functionality comparable to Olli.

The data that we got from Ohio State was not standardized between the vehicles. Our team used Microsoft Excel to adjust this data so it could be compared accordingly for our analysis. For example, this entailed converting received data into “per mile” numbers (i.e. for cost/mile and emissions/mile). We also used Microsoft Excel to perform our cost analysis and sensitivity analysis. The cost analysis was conducted using an identified optimal route from Ohio State’s Martha Morehouse to the Medical Campus. This route was chosen because of the amount of right turns vs. left turns. The technology of Olli does not yet warrant crossing multiple lanes of traffic with a left turn. We assumed the operating time was about 2.66 hours/day based on the range of Olli. A sensitivity analysis was conducted for fuel costs, labor costs, and carbon emissions costs. We discounted the necessary values for this accordingly. Below are the additional variables we calculated to compare Olli with Ohio State fleet vehicles.

Table 1. Type of data collected and their units

Fuel Cost ($/mile)	Initial Cost ($)
Fuel Emissions (GHG, lbs CO2/mile)	Maintenance Cost ($ spent annually)
Fuel Tank/Charge time (total miles)	Lifecycle (years)
Driver Costs (hourly)	Annual Emissions (Total lbs)
Annual Savings from Avoidance of Carbon Emissions ($)	

Identifying compatible services at Ohio State University

The Book Depository at Ohio State is a high-volume storage facility for books that are not requested often, or rare books that are not kept at Thompson Library on the main Columbus campus. Daily deliveries to Thompson Library and 18th Ave Library from the Book Depository could be made more efficient by the addition of Olli EAVs. Olli can accommodate about 150 volumes of books delivered every day, while reducing the greenhouse gas emissions relative to their current cargo vehicles.

Olli could also be used at the Thompson Library to deliver books on request to the other libraries on campus as well as mail and packages to various building at OSU. (Mark Moziejko, facilities coordinator for Ohio State's library system, personal communication). The average delivery route to Thompson Library is 5 days a week and takes about 4 hours to complete, which would be compatible with a current Olli vehicle. The average cargo weight that they carry is also about 2000 lbs which is within the Olli's carrying capacity, further justifying the compatibility of the library possibly adopting this technology to deliver library materials and mail throughout Ohio State's campus.

From our case study in London, we contacted University Dining Services about how they deliver food to campus dining locations which includes cafes, dining halls, and C-Store locations. The vehicles they use include box trucks and vans that have refrigeration to keep the food fresh and safe while it is in transit. They deliver 7 days a week for about 12-15 hours a day.

Identifying Compatible Routes on Campus

Based on current autonomous technology, Local Motors suggests that Olli have a clear right of way on every road that it will be on, if it is to be used on a busy campus with many pedestrians such as the Ohio State University's Columbus Campus. This is so that people respect the vehicle and continue to follow traffic safety rules. Although Olli can detect people or objects in its path, it is not safe to assume that it is completely not prone to accidents because of its advanced technology, the pedestrians would still need to treat it with the same caution as a regular vehicle to prevent accidents. Mark McCord from Ohio State's Transit Lab suggested that a designated lane would be the most efficient way to move an autonomous vehicle on certain roads. Even though the vehicle can perform in real traffic, certain roads that often get congested may function better with an autonomous vehicle if a designated lane for the vehicle was provided.

When our group met with the Transit Lab, three routes were identified as being necessary but underutilized, where an electric autonomous shuttle could fit well. The routes currently called Ackerman Shuttle (ACK), Morehouse to Ackerman Shuttle (MA), and Morehouse to Med Center Shuttle (MM), are all necessary for transporting people from the Morehouse Tower and Pavilion to the central Medical Campus, and from the Ackerman Medical Complex to the central Medical Campus. The Transit Lab, which collects data on passenger flows on CABS buses and other traffic data, noted to our team that replacing the current CABS shuttles with an electric autonomous option could be a more efficient way of providing service to these stops. Olli has an on-demand function app that could be used by these riders when they need to be picked up, the shuttle would not need a driver to conduct it, and would also not use fossil fuels to transport people the short distance.

Annual Costs			
Cost type (per year)	Olli	OSU Fleet Vehicle	OSU CABS Shuttle
Annualized value of the purchase cost	$59,572	$4,457	$8,850
Vehicle's Lifespan (years)	5	7	7
Annual Maintenance Costs	$600	$690	$1,520
Annual Labor Cost (driving)	$15,561	$10,374	$11,252
Fuel Cost/Mile	$0.04	$0.14	$0.32
Miles/Day for Martha Morehouse-Medical Center	64.8	64.8	64.8
Annual fuel costs	$591	$2,391	$5,456
Vehicle's Range (miles)	32.4	432	284
Carbon Emissions/mile (lbs.)	0.91	1.60	2.78
Total Carbon emissions for 64.8miles/day (lbs.)	15,379	46,862	27,165
Savings from avoided carbon emissions (based on lbs)	$1,179	$(1,176)	$(3,142)
Savings from avoided carbon emissions (based on lbs)	$3,142	$1,966	$(1,966)
Total	$76,325	$17,912	$27,078

IV. Data

The chart below resembles all data collected for the previously mentioned variables for each of the three vehicles. Please see appendices 1-5 for visual comparisons.

Table 2: Summary of the costs incurred by the 3 types of vehicles included in our study

There are a few areas that need more explanation than the data provided. First, for the annualized purchase cost we used 4.16% as the discount rate, which was an industry average (Cost of Capital, 2017). We used the above-mentioned lifespans of each vehicle for the amount of time periods for calculating the annualized purchase cost. We calculated the cost of labor assuming the same # of hours per day operating 64.8 miles/business day (approximately 2.66 hours/day). Olli's steward/operator would be paid $22.50/hour (Local Motors). This wage puts Olli's labor costs at $15,600. Olli is currently required by legislation to have a steward during operation for safety purposes. However, Local Motors predicts this legislation will end in 2018; this suggests that in the near future Olli will not have any labor costs. A fleet vehicle's driver is estimated to be paid $15/hour. This wage puts the fleet vehicle's labor costs at $10,400. A CABS shuttle driver is paid $16.27/hour on average. This wage puts the shuttle's labor costs at $11,300. Using labor cost increase averages (1.7% public-OSU, 2.6% private-Olli), Olli's will increase $260/year. The fleet vehicle's cost will increase $280/year. The shuttle will have an increase of $300/year. Fuel costs for the fleet vehicle and CABS shuttle were calculated using price/gallon and miles per gallon (MPG). Olli's fuel costs were calculated using OSU's cost/kwh ($0.065), kWh in the battery (17.5), cost to fully charge once ($1.14), and cost/mile. Fuel costs can fluctuate year to year; we chose 5% as a potential yearly increase. With a 5% yearly fuel cost increase, Olli's fuel cost will increase $30/year. The fleet vehicle's fuel cost will increase by $120. The CABS shuttle's fuel cost will increase by $270/year. It is important to also note that Olli takes approximately 4-4.5 hours to charge whereas the fleet vehicle and shuttle take a few minutes. In terms of avoided carbon emissions, converting pounds emitted to dollars creates a "savings" for each vehicle compared to the other two. Choosing Olli would have a social cost savings of $1,179 compared to the fleet vehicle and $3,142 compared to the shuttle. Choosing the fleet vehicle over the shuttle would create a social cost savings of $1,966. These were calculated using a social cost value, $0.10/lb (University, S., 2016). A market value for carbon (i.e. value for carbon trading) is $0.006 (Technology, E. I., 2017). Using a market value would significantly decrease the value of avoided carbon emissions. Olli's social cost savings would reduce to $74 compared to the fleet vehicle and $197 compared to the shuttle. The fleet vehicle's social cost savings would reduce to $123 compared to the shuttle. This collected and analyzed data helped us to find valuable results.

V. Results

Based on the values in Table 2, we found that the Olli may not be feasible today, due to the exorbitantly high current initial price and shorter life span relative to the existing OSU vehicles. Currently, it also has a higher labor cost, which we expect to be driven to 0 as current legislation expires next year. However, all other costs associated with the operation and maintenance and carbon emissions are much lower than for the other OSU vehicles currently in service and would need further technological advancements for it to function comparably to current fleet vehicles and shuttles at Ohio State. The following two graphs show how great a difference Olli's initial cost is from the other vehicles and that it is the majority of Olli's annual costs.

VI. Results

After we looked at the data that we gathered about social and monetary costs of implementing one or multiple autonomous shuttles on campus, we found that the Olli may not be feasible today with its current initial price, and would need further technological advancements for it to be truly compatible with current fleet vehicles at

Ohio State. The following two graphs show how great a difference Olli's initial cost is from the other vehicles and that it is the majority of Olli's annual costs.

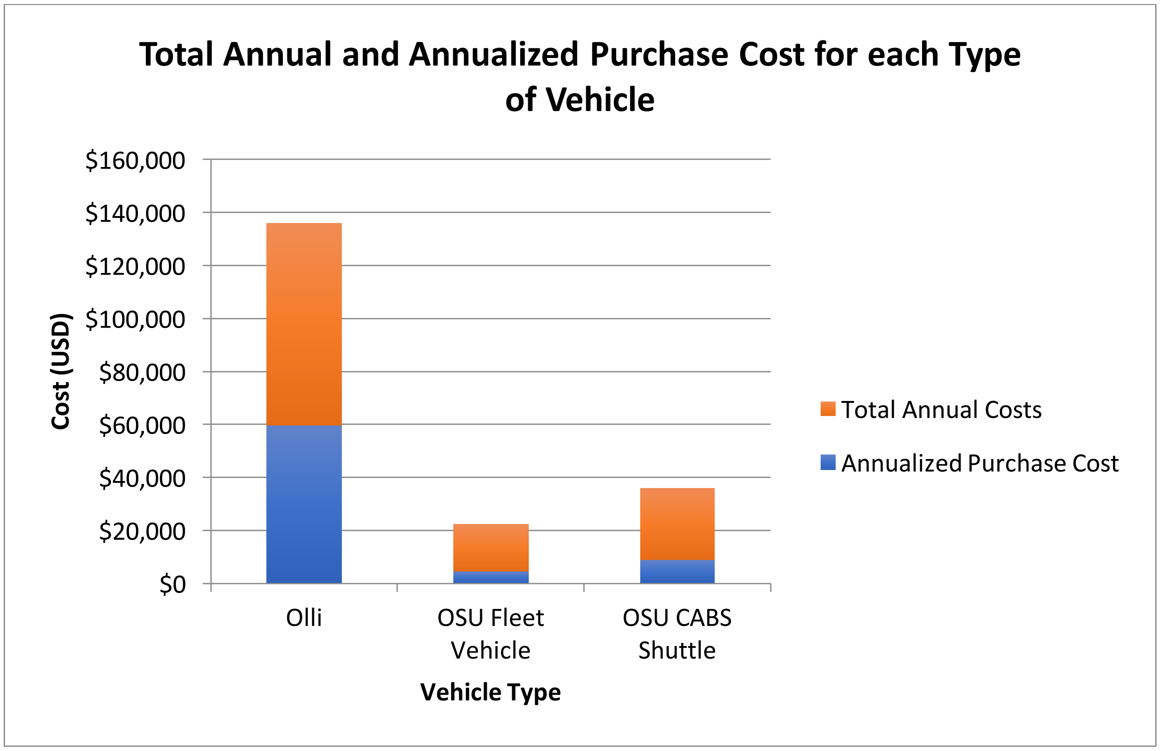


Chart 1: Visual comparison of total annual cost and annualized purchase cost for each type of vehicle

The Olli has an initial price of $275,000 ($59,500 when annualized) (Table 4), which is currently not a price that Ohio State would be willing to pay for a new service vehicle, compared to what they are already purchasing at less than $60,000 for the other two. Even though Olli has significantly lower fuel costs, greenhouse gas emissions, maintenance costs, and more avoided carbon savings over the other 2 vehicles Ohio State is currently using, Olli has a shorter lifecycle and driving range. Those two categories are important when considering investing in a vehicle that could potentially have impacts on how the university functions. For Olli to have the same annual cost to the fleet vehicle, the annualized purchase cost would need to be $1,000. Compared to the CABS shuttle, Olli's annualized purchase cost would need to be

$11,000. When looking at services OSU provides campus, the average Ohio State fleet vehicle can go 399 miles (a full tank) farther than Olli. This difference in range would be inconvenient for departments like University Dining Services or Library Services, who have to make deliveries all day. Since Olli can only go 32.4 miles/charge and takes approximately 4-4.5 hours to charge, the fleet vehicle is currently the better choice for University Dining Services or Library Services.

Our sensitivity analysis 1 showed that Olli's purchase price without labor would break even at a cost less than $144,434 (Appendix 10). With labor it needs to cost less than $75,470 to be cost effective for Ohio State to invest in (Appendix 10). In our second sensitivity analysis, we looked to see if increasing fuel prices over the next 5 years would make the Olli electric vehicle more cost effective (Appendix 11). In our analysis, assuming all other factors are constant, we found that only if fuel prices rose over $16/gallon without labor costs, then Olli would be more cost effective for Ohio State to use. The case studies also portrayed Olli and EAV technology as underdeveloped. Improvements need to be made to ensure Olli can operate on a heavily trafficked Ohio State campus. These results allowed us to make a final recommendation.

The Olli has an initial price of $275,000 ($59,500 when annualized) (Table 4), which is currently not a price that Ohio State would be willing to pay for a new service vehicle, compared to what they are already purchasing at less than $60,000 for the other two. Even though Olli has significantly less fuel costs, greenhouse gas emissions, maintenance costs, and more avoided carbon savings over the other 2 vehicles Ohio State is currently using, Olli has a shorter lifecycle and driving range. Those two categories are important when considering investing in a vehicle that could potentially have impacts on how the university functions. For Olli to have a comparable annual cost to the fleet vehicle, the annualized cost would need to $1,000. Compared to the CABS shuttle, Olli's annualized initial cost would need to be $11,000. When looking at services OSU provides campus, the average Ohio State fleet vehicle can go 399 miles (a full tank) further than Olli. This difference in range would be inconvenient for departments like University Dining Services or Library Services, who have to make deliveries all day. Since Olli can only go 32.4 miles/charge and takes approximately 4-4.5 hours to charge, the fleet vehicle is currently the better choice for University Dining Services or Library Services. Our sensitivity analysis 1 (10. Sensitivity Analysis 1) showed that the "break-even" price of Olli would need to be significantly lower (at least lower than $131,497 with no driver) to break even or cost less than $72,509 to be cost effect for Ohio State to invest in. In our second sensitivity analysis (11. Sensitivity Analysis 2), we looked to see if increasing fuel prices over the next 5 years would make the Olli electric vehicle more cost effective. In our analysis, we found that only if fuel prices rose over $16/gallon without labor costs, then Olli would be more cost effective for Ohio State to use. The case studies also portrayed Olli and EAV technology as underdeveloped. Improvements need to be made to ensure Olli can operate on a heavily trafficked Ohio State campus. These results allowed us to make a final recommendation.

VII. Recommendations

The barrier that the Book Depository immediately saw with this project was the purchase price of the Olli, which is a lot more than what they usually pay for vehicles that they purchase through a contract. The other benefit they saw with possible replacing one of their vehicles with the Olli was reduced fuel costs, they currently fill up their vehicles once a month, or once every two weeks.

Local Motors has told our group that long term goals for the company will be creating a vehicle that would be more of a cargo or truck-like vehicle that could cater to specific needs like docking into cargo bays, and holding heavier cargo. A concern that came up to our team after Kathie Serif from Campus Dining told us that deliveries are made all day, every day of the week, was that one vehicle would not be able to currently run that long to make all the deliveries in one day. Local Motors is working on new models of the Olli that will have a rage of over 100 miles, which would better fit the needs of the Ohio State Campus Dining Services in terms of the volume of products they need to move in a day. Although these problems can be solved with better technology, Serif mentioned that the main limitation to adopting a fully autonomous vehicle would be not having a driver who currently unloads all the products at the delivery locations. Adopting an autonomous vehicle would imply that a driver is obsolete and would not need to board the vehicle at all, so it would require the Campus Dining Services to figure out who would be unloading all the products at delivery locations.

When meeting with the Ohio State Transit Lab, Mark McCord identified some areas where an autonomous shuttle could be beneficial for regular transit services.

First mile- last mile was also a concern of the Transit Lab when we communicated with them. This issue is the distance a passenger still must travel from the last stop on a route to their actual destination. Ohio State University and the City of Columbus wants to try to use electric autonomous shuttles as a solution to this, mainly focused on commuter parking lots.

Olli outperforms traditional fleet vehicles and CABS shuttles in annual carbon emissions, maintenance costs, and fuel costs (6. Table 1 and 7. Table 2). The variable that it differed significantly from the other vehicles was initial purchase price, which was over $100,000 more expensive than a traditional vehicle at Ohio State. We predict that with further development in this technology, the initial cost of purchasing an electric autonomous shuttle such as Olli, or a similar vehicle, will be lower. A large decrease in initial cost would be more feasible and have a significant impact on Ohio State's carbon footprint, while saving the university money in the above-mentioned categories. We recommend that Ohio State closely monitors the progress of the electric autonomous vehicle industry. Currently Local Motors Olli is not a good choice for Ohio State without outside funding. However, maintaining oversight over the industry could provide Ohio State with the opportunity to be at the forefront of electric autonomous vehicle technology on college campuses.

Additional Considerations

The limited number of available case studies and their duration suggest that the viability of replacing traditional vehicles with EAVs to transport people or goods on university campuses has not been demonstrated using real-life, long-term data. For example, the trial runs at the University of Michigan was in Fall, 2017 and will need further long-term observations and experimental feedback moving into the future. However, OSU may benefit from these trial runs and experiences when implementing EAVs on campus.

Our project aims to find possible ways of utilizing electric automated vehicles on campus as well as determining the advantages and barriers from its implementation. Limited real-world interaction and shortened route length reflect the unreliability in dealing with complex traffic conditions. Additionally, the presence of a safety conductor on each shuttle shows that full automation cannot be guaranteed until further research has been completed. These EAV shuttles utilize a variety of sensors in effort to collect data of the outside environment through radar, LIDAR, and cameras. Although these sensors are highly sophisticated, several limitations currently exist according to Mcity. For instance, they have a short range of operation, limited accuracy in sensing the position and speed of other vehicles; in addition, the images they capture are in relatively low resolution. Poor lighting or bad weather conditions can also hinder their performance making it difficult to ensure the safety of EAVs.

For the U-M case, the primary application of the new technology is to provide another mode of transportation for people. By 2021, the U-M has set forth a goal of establishing a working system of connected and automated vehicles in Ann Arbor, taking full advantage of this emerging technology. Further research regarding the technology as well as potential opportunities is still needed in order to properly integrate a new mode of transportation. In addition, there are still a series of legal, political, regulatory, economic and safety issues that must be addressed moving into the future.

Many different components from the GATEway project provide great insight for the future application of EAVs on Ohio State’s campus. GATEway is a project that is primarily concerned with the societal implications of this innovative technology as well as the technical and legal barriers that will have to be hurdled moving forward.

Specifically looking at Ohio State, research for student, faculty, and staff perception is still greatly needed, as limited information is available for this specific topic. A few areas from this study that Ohio State could potentially learn a lot from deal with alternative services and infrastructure strategies.

As of June 2017, the GATEway project was successfully able to deliver groceries to homes in Greenwich, along a low-traffic density route. Proving that the technology can be used for services other than human transportation, Ohio State may see benefit in GATEway's finding by using this technology to update current campus operations. GATEway has established a dedicated lane within the Greenwich neighborhood that runs alongside pedestrians and cyclists. Due to the newness of this technology, EAVs are still unable to fully operate in traffic dense settings. Therefore, moving into the future, OSU may find it necessary to establish a specific EAV lane that seamlessly connects different areas on campus.

The Las Vegas case study provided a great illustration of the public and private sectors working together in order to achieve a common goal. This case study is a good example not only for Ohio State, but for the city of Columbus as we pursue the development of a smart mobility grid. The feasibility and implementation of EAVs on the campus of OSU will be much more successful when approached through a collaborative lens involving the public and private sectors. Aligning the sustainability goals of OSU and the city of Columbus will allow a comprehensive strategy to understanding the potentials of autonomous technology not only for campus, but for the greater Columbus region.

VIII. Conclusion

Looking at the research results from our cost-benefit analysis, department faculty collaborations, and case study examinations, our group concludes that Olli would not benefit Ohio State transportation services in the current environment due to several factors. Further research into the understanding of public perception is still needed not only from a user point of view, but from an interactive (road sharing) point of view as well. From an economic standpoint, the initial price of Olli is currently too high for implementation on Ohio State's campus.

As previously mentioned, another primary barrier to implementation has been the newness of this technology and lack of benchmarking information available to interested parties. Conversely, the few case studies that were included within this report are helpful in identifying where and how various institutions have had success thus far utilizing this technology. Ohio State may benefit by observing the continued research results from these studies and adapting potential ideas where applicable on campus. However, at this point in time EAVs are not cost effective for widespread adoption on campus. Compared to Ohio State's fleet vehicles and CABS Shuttles, Olli is far more effective in every category (fuel emissions, fuel costs, maintenance costs, etc.) except for the initial cost. Ohio State's current transportation vehicles will suffice until the EAV technology not only improves, but the respective price of purchasing a vehicle significantly reduces.

IX. Bibliography

a. Driverless shuttle service coming to U-M's North Campus. *Mcity.* (2017, June 21). Retrieved from https://mcity.umich.edu/driverless-shuttle-service-coming-u-ms-north-campus/

b. University Of Michigan Becomes Country's First Campus To Use Self-Driving Shuttles. (2017, July 26). Retrieved from http://www.wbur.org/hereandnow/2017/07/26/michigan-self-driving-shuttles

c. UK First: Autonomous Grocery Delivery Trials in Greenwich. (2017, June 28). Retrieved from https://gateway-project.org.uk/uk-first-autonomous-grocery-delivery-trials-in-greenwich/

d. Burgess, M. (2017, June 28). Autonomous 'milk floats' are now delivering Ocado shopping in London. Retrieved from https://www.wired.co.uk/article/autonomous-shopping-greenwich-ocado-oxbotica-trial\

e. Williams, B. (2017, June 28). Driverless vans will now deliver groceries in London. Retrieved from http://mashable.com/2017/06/28/london-self-driving-grocery-deliveries/#2fhX2wL_HPq2

f. Etherington, D. (2017, January 11). Las Vegas launches the first electric autonomous shuttle on U.S. public roads. Retrieved from https://techcrunch.com/2017/01/11/las-vegas-launches-the-first-electric-autonomous-shuttle-on-u-s-public-roads/

g. Morris, D. Z. (2017, January 14). Vegas Puts First Self-Driving Bus to Work on U.S. Public Street. Retrieved from http://fortune.com/2017/01/14/vegas-self-driving-bus/

h. Norman, A. (2017, January 12). Fully-Electric Self-Driving Shuttle Bus Being Tested On Las Vegas Roads. Retrieved from http://www.techtimes.com/articles/192359/20170112/fully-electric-self-driving-shuttle-bus-being-tested-on-las-vegas-roads.htm

i. CABS: Transportation and Traffic Management. (n.d.). Retrieved November 16, 2017, from https://ttm.osu.edu/cabs.

j. Cost of Capital by Sector (US). (n.d.). Retrieved November 16, 2017, from http://people.stern.nyu.edu/adamodar/New_Home_Page/datafile/wacc.htm.

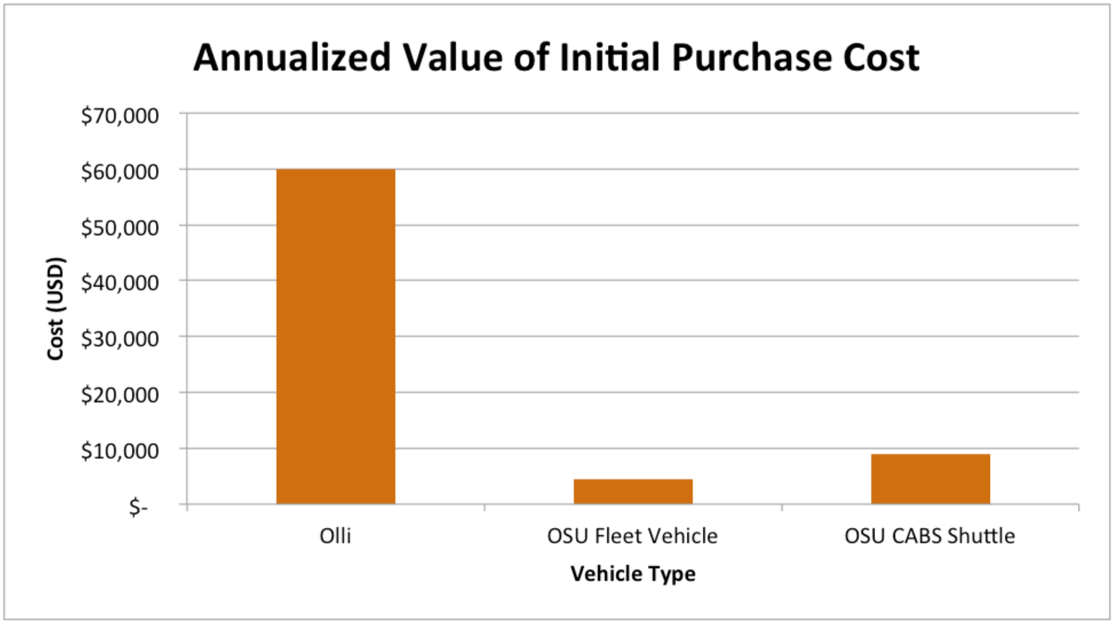
k. Wages and salaries for private industry workers increase 2.6 percent over the year ended June 2016 : The Economics Daily. (n.d.). Retrieved November 16, 2017, from https://www.bls.gov/opub/ted/2016/wages-and-salaries-for-private-industry-workers-increase-2-point-6-percent-over-the-year-ended-june-2016.htm.

l. Technology, E. I. (2017, February 10). Carbon Prices Rise In California's Cap-And-Trade Program As Legal Certainty Grows. Retrieved November 16, 2017, from https://www.forbes.com/sites/energyinnovation/2017/02/08/carbon-prices-rise-in-californias-cap-and-trade-program-as-legal-certainty-grows/#5e99c3c02355.

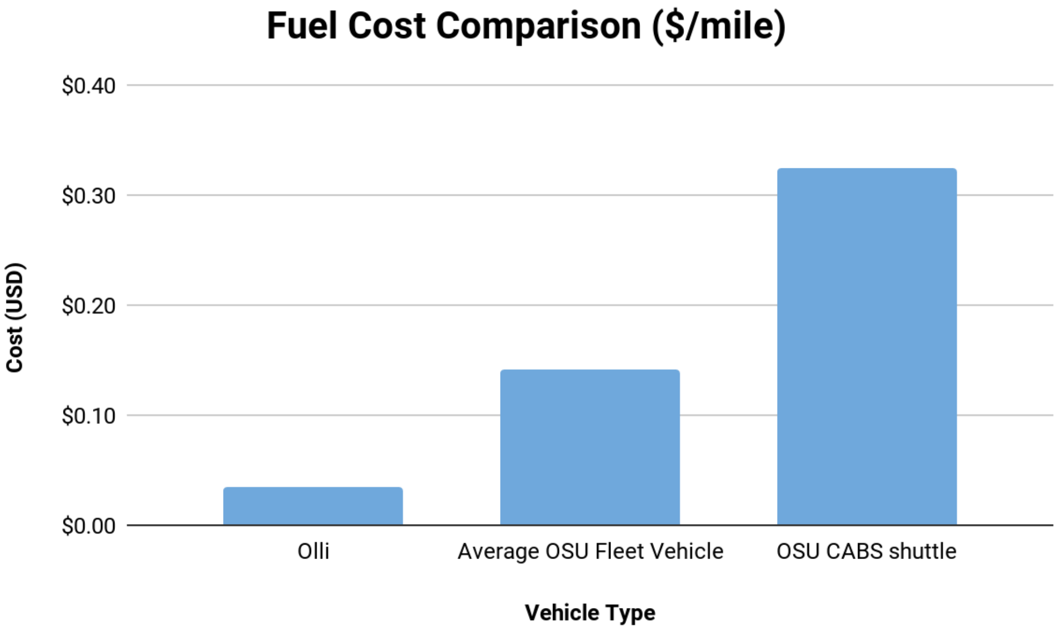
m. University, S. (2016, April 08). Estimated social cost of climate change not accurate, Stanford scientists say. Retrieved November 16, 2017, from https://news.stanford.edu/2015/01/12/emissions-social-costs-011215/.

X. Appendices

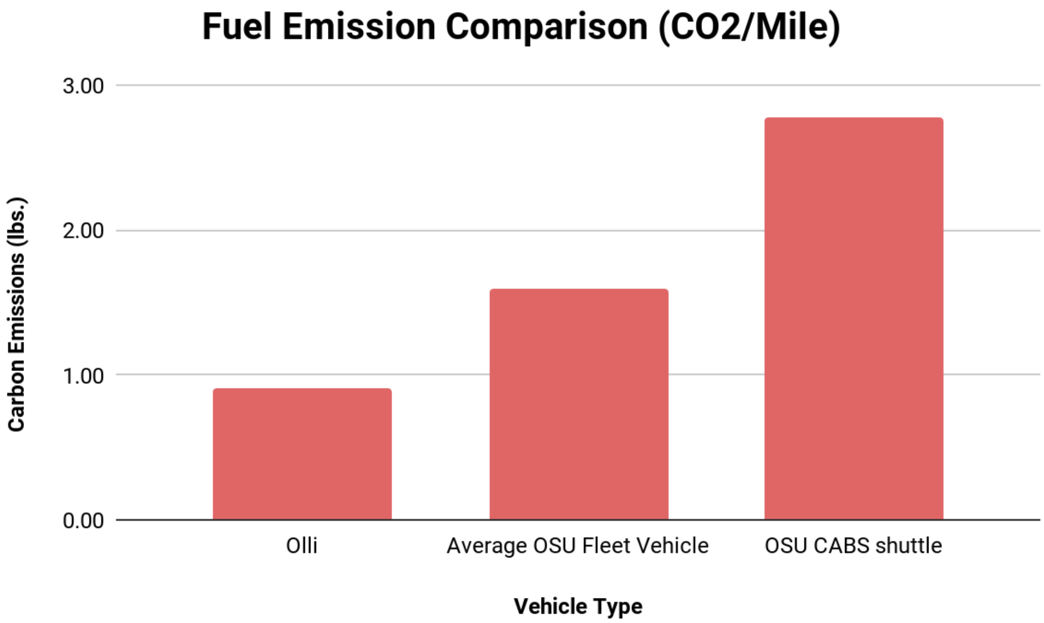
1.



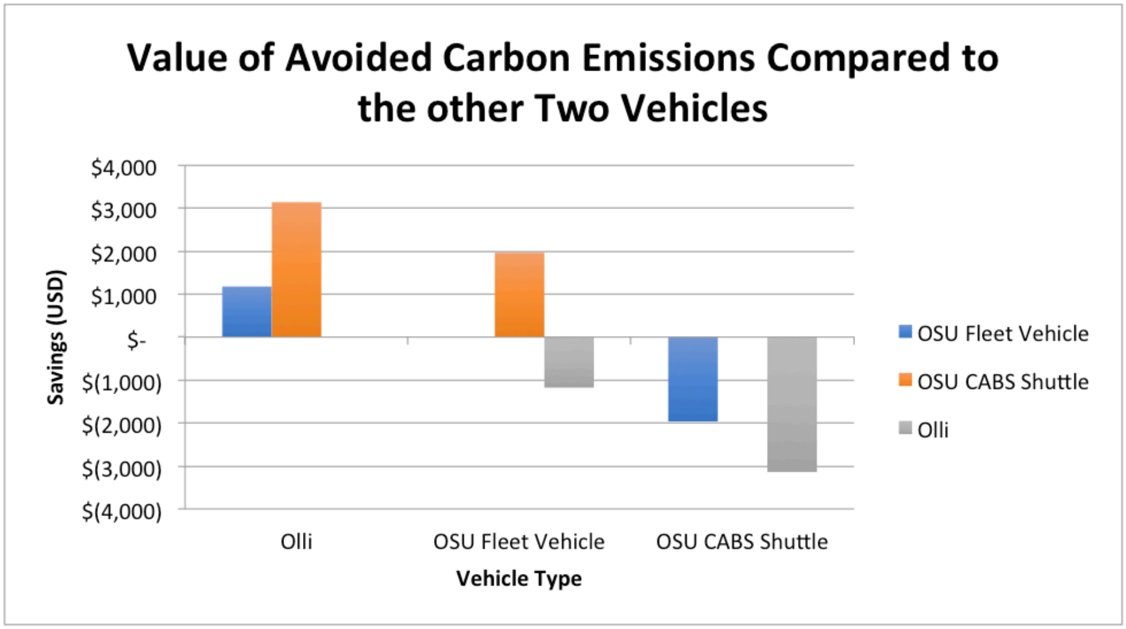
2.



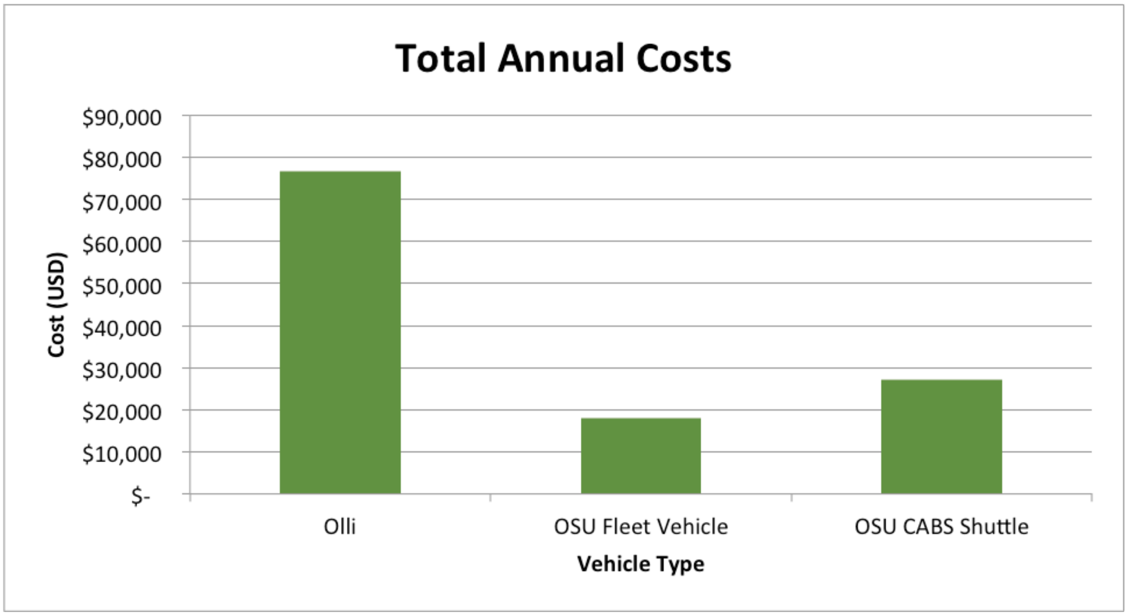
3.


Fuel Emission Comparison (CO2/Mile)
Carbon Emissions (lbs.)
3.00
2.00
1.00
0.00
Olli
Average OSU Fleet Vehicle
OSU CABS shuttle
Vehicle Type

4.


Value of Avoided Carbon Emissions Compared to the other Two Vehicles
Savings (USD)
$4,000
$3,000
$2,000
$1,000
$-
$(1,000)
$(2,000)
$(3,000)
$(4,000)
Olli
OSU Fleet Vehicle
OSU CABS Shuttle
Vehicle Type
OSU Fleet Vehicle
OSU CABS Shuttle
Olli

5.



6. **Table 1:** Basic data of Olli, Average Fleet Vehicle, and CABS shuttle

Vehicle	Price ($)	Maintenance ($/year)	Fuel cost ($/mile)	Labor cost ($/hour)	Range (miles/full tank or charge)	Life Cycle (years)
Olli	275,000	600	0.04	22.50	32.40	5
Average Fleet Vehicle	27,700	690	0.14	15.00	430.82	7
CABS shuttle	55,000	1,520	0.32	16.27	283.50	7

7. **Table 2:** Fuel CO2 Emission of three kinds of vehicles

Vehicle	CO2 Emission (lbs./mile)	Total CO2 Emission (per year)	Social Cost of Carbon ($ per year)
Olli	0.91	15,379	$1,535
Average Fleet Vehicle	1.60	26,957	$2,690
CABS shuttle	2.78	46,879	$4,678

8. **Table 3:** Initial costs and operation costs of three kinds of vehicles (Olli with labor)

Vehicle	Initial Cost ($)	Operation Cost ($ per year)				
		Maintenance	Fuel	Labor	Social Cost of Carbon	Total costs
Olli	275,000	600	592	15,561	1,535	18,287
Average Fleet Vehicle	27,700	690	2,391	10,374	2,690	16,145
CABS shuttle	55,000	1,520	5,456	11,252	4,678	22,906

9. **Table 4:** Initial costs and operation costs of three kinds of vehicles (Olli without labor)

Vehicle	Initial Cost ($)	Operation Cost ($ per year)				
		Maintenance	Fuel	Labor	Social Cost of Carbon	Total costs
Olli	275,000	600	591.50	0.00	1,534.68	2,726
Average Fleet Vehicle	27,700	690	2,391.26	10,374.00	2,690.03	16,145
CABS shuttle	55,000	1,520	5,455.54	11,252.33	4,678.07	22,906

Net Present Value Analysis

Total Costs (5 year life) of Olli, Average fleet vehicles, and CABS shuttle
Discount rate 4.16%

Situation 1: Olli with labor (including labor costs)

Year	Discount Factor	Costs ($)			Discount costs ($)		
		Olli	Average Fleet	CABS	Olli	Fleet Vehicle	CABS
0	1.0000	275,000	27,700	55,000	275,000	27,700	55,000
1	0.9601	18,287	16,145	22,906	17,557	15,500	21,991
2	0.9217	18,287	16,145	22,906	16,856	14,881	21,113
3	0.8849	18,287	16,145	22,906	16,182	14,287	20,270
4	0.8496	18,287	16,145	22,906	15,536	13,716	19,460
5	0.8156	18,287	16,145	22,906	14,916	13,169	18,683
Total Costs		366,436	108,426	169,530	356,047	99,254	156,516
Total Operation Costs		91,436	80,726	114,530	81,047	71,554	101,516
Total Savings (Using Olli)			-258,009	-196,906		-256,793	-199,530

Situation 1: Olli without labor (no labor costs)

Year	Discount Factor	Costs ($)			Discount costs ($)		
		Olli	Fleet Vehicle	CABS	Olli	Fleet Vehicle	CABS
0	1.0000	275,000	27,700	55,000	275,000	27,700	55,000
1	0.9601	2,726	16,145	22,906	2,617	15,500	21,991
2	0.9217	2,726	16,145	22,906	2,513	14,881	21,113
3	0.8849	2,726	16,145	22,906	2,412	14,287	20,270
4	0.8496	2,726	16,145	22,906	2,316	13,716	19,460
5	0.8156	2,726	16,145	22,906	2,224	13,169	18,683
Total Costs		288,631	108,426	169,530	287,082	99,254	156,516
Total Operation Costs		13,631	80,726	114,530	12,082	71,554	101,516
Total Savings (Using Olli)			-180,204	-119,101		-187,828	-130,566

Sensitivity Analysis 1: Changes Olli’s Purchasing Price

Situation 1: Olli with labor

Total savings (Olli instead of CABS)	-$199,530
Olli's price	$275,000

Olli's price	Total savings
$275,000	-$199,530
$250,000	-$174,530
$255,000	-$179,530
$245,000	-$169,530
$235,000	-$159,530
$225,000	-$149,530
$215,000	-$139,530
$205,000	-$129,530
$195,000	-$119,530
$185,000	-$109,530
$175,000	-$99,530
$165,000	-$89,530
$155,000	-$79,530
$145,000	-$69,530
$135,000	-$59,530
$125,000	-$49,530
$115,000	-$39,530
$105,000	-$29,530
$95,000	-$19,530
$85,000	-$9,530
$75,000	$470
$65,000	$10,470
$55,000	$20,470

Situation 2: Olli without labor

Total savings (Olli instead of CABS)	-$130,566
Olli's price	$275,000

Olli's price	Total savings
$275,000	-$130,566
$265,000	-$120,566
$255,000	-$110,566
$245,000	-$100,566
$235,000	-$90,566
$225,000	-$80,566
$215,000	-$70,566
$205,000	-$60,566
$195,000	-$50,566
$185,000	-$40,566
$175,000	-$30,566
$165,000	-$20,566
$155,000	-$10,566
$145,000	-$566
$135,000	$9,434
$125,000	$19,434
$115,000	$29,434
$105,000	$39,434
$95,000	$49,434
$85,000	$59,434
$75,000	$69,434
$65,000	$79,434
$55,000	$89,434