Development of an Autonomous Platooning Campus Vehicle System

(Technical Paper)

The Environmental Impact of Lithium-Ion Batteries

(STS Paper)

A Thesis Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

Cameron Chiaramonte

Fall, 2021

Technical Project Team Members

Patrick Dunnington

Gilchrist Johnson

Nicholas Sofinski

Alex Wilson

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

ADVISORS

Joshua Earle, Department of Engineering and Society

Tomonari Furukawa, Department of Mechanical and Aerospace Engineering

The Potential Impact of Autonomous Vehicles

In recent years, the electric vehicle industry has rapidly grown in parallel to defining evidence of climate change. The broad impression advertised to the public is that of a movement away from gas powered vehicles is a massive step in the right direction (Jose et al., 2021). However, the goal of this research is to develop an understanding of whether electric vehicles truly have less of an impact on the environment. More specifically, this project will focus on the creation and disposal of lithium-ion batteries, a critical component in powering an electric vehicle. Millions of electric cars are being produced each year branded with environmental friendliness, allowing for disastrous effects if their claims prove to be untrue (Bartlett, 2022). Alongside the exploration of this topic, a closely partnered technical project will be underway. With the intention of developing a fully autonomous campus transportation system, the technical project will span both the fall and spring semesters as shown in the Gantt chart below. For both the technical and STS projects, the fall will consist mainly of planning and research. In preparation to develop a comprehensive thesis portfolio in the spring, extensive analysis of journal articles and research papers will be performed.

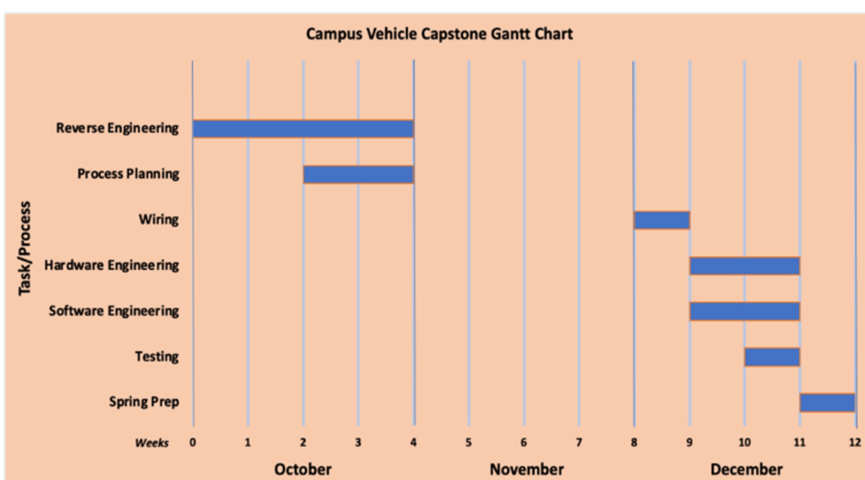

Figure 1: Campus Vehicles Technical Project Gantt Chart

Developing an Autonomous Golf Cart Platooning System

In 2014, the Society of Automotive Engineers definitively outlined the six levels of driving automation, and it has since become an industry standard (SAE International). Level zero indicates a complete lack of automation and a requirement of full human control of the vehicle. On the other hand, level five implies a fully autonomous vehicle. The levels increase progressively with technologies such as cruise control at level 1 and lane keeping at level 3. It is important to note that there are no existing level 5 cars known to the general public (Baca, 2022). This technical capstone project is under the advisory of Professor Tomonari Furukawa and the Mechanical and Aerospace Engineering department at the University of Virginia. The engineering team consists of Patrick Dunnington, Alex Wilson, Gilchrist Johnson, Nicholas Sofinski, and Cameron Chiaramonte. In addition, the project is sponsored and funded by Club Car, a golf cart distributor and manufacturer (Club Car). The entirety of the research and development of this technical project will be conducted in the Virginia Cooperative Autonomous Robotics (VICTOR) Lab located in the Observatory Mountain Engineering Research Facility.

This technical project is centered around advancing transportation around grounds at UVa. There are a number of issues with the current options of transportation that were verified by the technical team through a customer needs assessment and survey. By nature, Charlottesville has large hills and elevation changes that scatter throughout the university. Although it may be the easiest form of transportation to most, walking can be an obstacle to those with disabilities or injuries. The university provides a phenomenal bus system that is free of charge to students. However, this bus is limited to certain routes and times. Thus, not only are students restricted by the fixed bus stops but are also likely to have to walk an extended distance to their intended destination. The fastest and most flexible transportation mode could arguably be a personally owned vehicle; however, it also comes with the largest drawbacks. Most students are financially and geographically restricted from bringing a vehicle to school. In addition, it can be difficult to find a parking spot that is both convenient and open.

After analyzing the shortcomings and inconvenience of existing transportation modes at the university, the campus vehicles capstone team decided to work towards developing a level 4 autonomous golf cart platooning system. This system will advance campus transportation and drastically increase the accessibility for any students that may have a disability or injury. The platoon will consist of three golf carts that can follow an additional, manually driven leader cart that navigates through campus to pick up and drop off any passengers.

The Club Car project has been in development over a number of years and through multiple universities. There has not yet been a team that has successfully completed the goal of a level 4 autonomous system. Thus, our immediate focus will be on reviewing the efforts of past teams and understanding what worked and what did not. Past teams have tried to streamline efficiency or make advanced adjustments to the carts in their efforts towards completion; however, our goal this year simply is to end with a functioning system.

Last year's team successfully transformed the leader cart to be drive-by-wire, essentially meaning it can be controlled with a video game controller. The first steps will be copying the advancements made on the leader cart to the next follower cart to have a base off which to work then improvements towards a level 4 autonomous system can begin. The leader cart will use a LiDAR sensor to map its immediate terrain. A number of different programs will interpret this data and send messages to each control system and indicate how much the cart should brake, accelerate, or turn. The programs will be written through the Robot Operating System (ROS) along with all other software implemented to control the system. In addition, each cart will be fixed with an onboard computer and touch screen monitor to have a live view of the data being processed during testing. Steering will be controlled through a Nexteer Electric Power Steering Column that comes with built in capabilities such as lane keeping and park assist (Nexteer). Braking is controlled simply and mechanically via a pulley system and a DC motor. Because there is no engine, acceleration does not need mechanical controls and throttle can be communicated entirely through the software with the help of an Arduino processing chip. What past teams have been unable to make strides on is figuring out how to have the other carts accurately follow the leader cart. Our team plans to mount cameras on the follower carts with each preceding cart having an AR tag that can be identified by the cameras as a point of reference (Kakashaniya). ROS will allow the system to maintain a view of the AR tag on the cart immediately in front of it and program a safe following distance. In addition, the AR tag system coupled with ROS will allow for a delay in control instruction to each follower cart in line to allow for accurate operation mimicking.

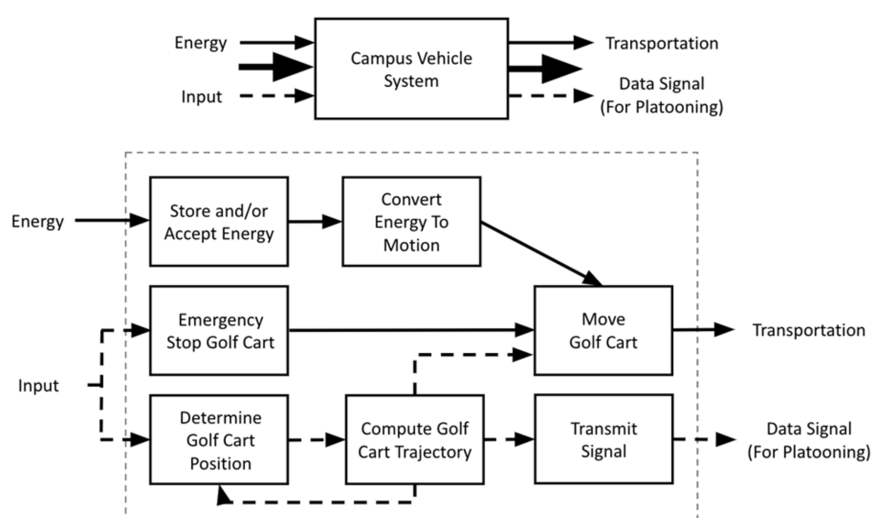

Figure 2: Functional Composition of Technical Design

The Environmental Impact of Lithium-Ion Batteries in Electric and Autonomous Vehicles

Due to the need for large scale production, and therefore disposal, of lithium-ion batteries to fuel the autonomous vehicle industry, when all things are considered are electric cars truly better for the environment? As production of electric vehicles continues to grow each year there is an entire industry being created around supplying lithium-ion batteries to car manufacturing companies (Wang et al., 2017). Because these are still budding technologies, their impact on a large scale is unknown. In addition, their advertising as solutions to climate change result in much of the public turning a blind eye to any hidden environmental effects. The methods of mining and disposal along with the countless number of heavy machinery necessary for these processes are certainly negatively impacting the environment (Jose et al., 2021). The question is whether or not the net effects are lesser than that of the manufacturing of and emissions from gas powered vehicles.

There is a lot of gray area in defining relevant social groups in regard to the overarching research questions listed. Climate change and environmental impacts from autonomous vehicles can be considered to affect every human living on the planet. However, this would certainly be outside the scope of this paper. The relevant social groups in regard to this research are autonomous vehicle manufacturers such as Tesla, Lithium-ion battery production companies along with those that work directly inside of the mines, persons living near and around said mines, and autonomous vehicle users. As stated, although the scale of the potential effects of pollution from lithium-batteries is massive, it has been dialed down to those that could be more directly and promptly affected for the purpose of this paper.

The research questions described above will be explored using a number of different methods and frameworks. The two main methods will be synthesizing previous literature and unpacking the stories that we tell ourselves. Due to the fact that this has not been a widely studied subject, it would be far more difficult to identify leading researchers in the field with which to speak. In addition, with such a new industry that is surrounded by controversy, all of the spoken opinions would have to be adjusted according to bias. Thus, reading previous literature will be a primary source of largely analyzed data sets from published authors. Secondly, unpacking the stories we tell ourselves will allow for an understanding of the perspective that is being pushed by media outlets and public policy. There has been a plethora of funding recently granted towards the electric vehicle industry getting a vote of confidence from powerful people such as the president of the United States (FHWA, 2022). Understanding the protagonists and antagonists in these stories and their competitors will lead to a clear vision of where the true impact of the industry lies. In addition, the frameworks that will be used to analyze the research will be Actor-Network Theory (ANT) and the Social Construction of Technology (SCOT).

The SCOT framework was briefly touched on above in describing the relevant social groups. SCOT is a theory that looks to understand how society and technology are intertwined and depend on each other to function (Bijker, 2002). The main concept to examine is the effect of the automobile industry on society. Not only will I examine the ways in which society has become dependent on vehicles, but also how American society has, in turn, shaped cars themselves (Kline, Pinch, 1996).

On the other hand, ANT is a framework that examines societal relationships and simply identifies the actors as human or nonhuman (Cresswell et al., 2010). These frameworks will be effective for two reasons. Firstly, because of the nature of the given technology and its direct connection to human need and their relationships connected through it. Secondly, autonomous vehicles will soon teeter the line of what form of an actor it can be defined as. Thus, these frameworks not only assist, but further the investigation of the research questions.

Significant Texts

To supplement the analysis of the environmental impact of autonomous vehicles as a result of lithium-ion batteries, a number of influential texts will be cited. The foundational text that inspired my interest in this topic is a book titled *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming* by Naomi Oreskes and Erik Conway. The title is self-explanatory, but the text delves into the political agendas of this small group of scientists that worked to prevent certain regulatory bills put forth by the government (Oreskes & Conway, 2010). Some of the topics these scientists hid facts on were highly significant at the time and included subjects along the lines of the ozone layer, the consequences of secondhand smoke, and acid rain. What was more significant is that these scientists did not specialize in any of the subjects they were studying, but simply used their powerful connections to sway regulations (Oreskes & Conway, 2010). Although this text does not concern electric vehicles or lithium-ion batteries, its exposure of the amount of truth that can be hidden about climate change was instrumental in selecting the overarching research question for this paper.

Moreover, a number of different case studies and scientific articles will be used to reinforce any of the analysis made in this research paper. The primary case study focuses on the carbon footprint of the aforementioned lithium-ion battery industry (Wang et al., 2017). At the early stages of the booming industry, two case studies were conducted in China to assess the overall carbon footprint and define a life cycle for the given technology. This is one of the first papers to perform an analysis on the topic and will be an important resource during the research conducted for this paper.

In addition, another life cycle assessment was conducted and centered around the recycling of spent lithium-ion batteries (Sambamurthy et al., 2021). This scientific article will be an invaluable resource in the coming research along with another paper focused directly on the consequences of lithium mining (Kaunda, 2020). Kaunda's paper uses clear data to support the arguments made throughout the text. This paper does a great job of detailing the process of lithium mining and explains exactly what chemicals and methods are necessary to extract raw lithium from mines. The Sambamurthy paper focused on lithium-ion battery recycling conducts actual experiments with dead cell phone batteries to examine any toxic waste produced from the used lithium. Unpacking all of the above texts will allow for a thorough start to the exploration of the research questions.

References

About Us. Club Car. (n.d.). Retrieved December 2, 2022, from https://www.clubcar.com/en-us/our-company/about-us

Baca, M. C. (2022, September 14). *Where are the autonomous cars?* Semiconductor Engineering. Retrieved December 2, 2022, from https://semiengineering.com/where-are-the-autonomous-cars/#:~:text=Advanced%20driver%20assistance%20systems%20(ADAS,situations%2C%20do%20not%20yet%20exist.

Bartlett, J. S., & Preston, B. (n.d.). *Automakers are adding electric vehicles to lineups*. Consumer Reports. Retrieved December 2, 2022, from https://www.consumerreports.org/hybrids-evs/why-electric-cars-may-soon-flood-the-us-market-a9006292675/

Biden-Harris Administration announces approval of First 35 state plans to build out EV charging infrastructure across 53,000 miles of Highways. Biden-Harris Administration Announces Approval of First 35 State Plans to Build Out EV Charging Infrastructure Across 53,000 Miles of Highways | FHWA. (n.d.). Retrieved December 2, 2022, from https://highways.dot.gov/newsroom/biden-harris-administration-announces-approval-first-35-state-plans-build-out-ev-charging

Bijker, W. E. (2001). Technology, social construction of. *International Encyclopedia of the Social & Behavioral Sciences*, 15522–15527. https://doi.org/10.1016/b0-08-043076-7/03169-7

Conway, E. M., & Oreskes, N. (2014). *Merchants of doubt*. Bloomsbury Publishing.

Cresswell, K. M., Worth, A., & Sheikh, A. (2010). Actor-network theory and its role in understanding the implementation of information technology developments in Healthcare. *BMC Medical Informatics and Decision Making*, *10*(1). https://doi.org/10.1186/1472-6947-10-67

Electric Power Steering & Steer-by-wire. Nexteer. (2022, August 24). Retrieved December 2, 2022, from https://www.nexteer.com/electric-power-steering/

Jose, P. S., Jose, P. S., Wessley, G. J., & Rajalakshmy, P. (2021). Environmental impact of electric vehicles. *E-Mobility*, 31–42. https://doi.org/10.1007/978-3-030-85424-9_2

Kakashaniya, H. (n.d.). *Harshkakashaniya/AR-tag-detection: AR tag detection*. GitHub. Retrieved December 2, 2022, from https://github.com/harshkakashaniya/AR-tag-detection

Kaunda, R. B. (2020). Potential environmental impacts of lithium mining. *Journal of Energy & Natural Resources Law*, *38*(3), 237–244. https://doi.org/10.1080/02646811.2020.1754596

Kline, R., & Pinch, T. (1996). Users as agents of technological change: The Social Construction of the automobile in the rural United States. *Technology and Culture*, *37*(4), 763. https://doi.org/10.2307/3107097

Sambamurthy, S., Raghuvanshi, S., & Sangwan, K. S. (2021). Environmental impact of recycling spent lithium-ion batteries. *Procedia CIRP*, *98*, 631–636. https://doi.org/10.1016/j.procir.2021.01.166

Society of Automotive Engineers. (n.d.). *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles*. SAE International. Retrieved December 2, 2022, from https://www.sae.org/standards/content/j3016_202104/

Wang, C., Chen, B., Yu, Y., Wang, Y., & Zhang, W. (2017). Carbon footprint analysis of lithium ion secondary battery industry: Two case studies from China. *Journal of Cleaner Production*, *163*, 241–251. https://doi.org/10.1016/j.jclepro.2016.02.057