ROCK-SLIDE: DESIGNING A MECHATRONIC CLIMBING VOLUME

ASSESSING ELECTRIC VEHICLE MANUFACTURER DECISION MAKING FOR SUSTAINABLILITY

A Thesis Prospectus
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Bachelor of Science in Mechanical Engineering

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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.

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INTRODUCTION

This paper will outline the two projects to be completed by the author in accordance with the University of Virginia's capstone requirements for graduating students within the School of Engineering and Applied Science. These two projects include a technical report which will detail a technical issue within the author's chosen academic discipline and a thesis which will investigate a socio-technical issue chosen by the author. In the following paper, a preliminary design analysis of a novel technology to be utilized within indoor climbing gyms will be offered along with a detailed examination of the potential role of electric vehicles within the pursuit of increased global sustainability.

Technical Background

In the last few years, the sport of rock climbing has taken off in terms of popularity. Rock climbing managed to break into the public consciousness in 2018 following the critically acclaimed documentary *Free Solo* and continued that momentum by making its debut as an Olympic sport in 2020 Tokyo Olympics. While the origin of the sport lies in mountaineering techniques developed during the 20th century, indoor climbing has become increasingly popular. The Climbing Business Journal reported that in 2021 there were 591 active climbing gyms in the United States (2022). The number of climbing gyms in the US has more than doubled in the last decade with 53 gyms opening in 2021 marking an 8.2% annual growth rate. While outdoor climbing may be intimidating, indoor gyms offer an accessible entry point to beginners. Climbing gyms provide a safer experience with padded mats allowing for cushioned falls and a lower barrier of entry by allowing customers to rent shoes and equipment. As indoor climbing continues to grow it has evolved into a separate entity from outdoor rock climbing. Eden and Barratt make this distinction arguing that different skill sets are developed climbing on indoor

walls than those learned at an outdoor climbing area (2010). Eden and Barratt also note that outdoor climbing requires considerably more equipment along with the skill to employ it safely. As indoor climbing further deviates from traditional mountaineering, an opportunity has been identified to develop a novel technology that provides fun, challenging boulder problems within indoor gyms which do not resemble boulders found in nature.

TECHNICAL TOPIC

Due to the lack of equipment necessary to engage in bouldering, it is often seen as the most accessible form of rock climbing. Indoor bouldering routes are set on walls of typically four to six meters in height using colored holds as seen in Figure 1.

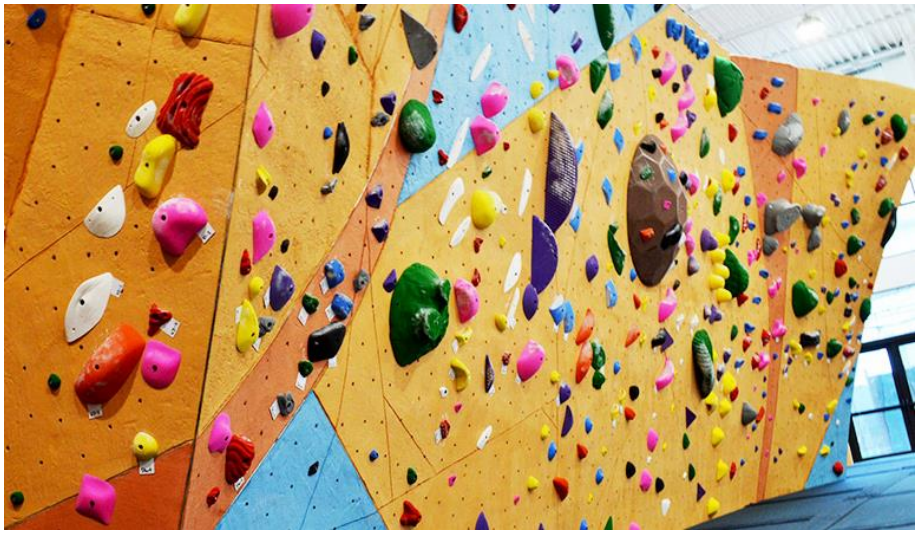

Figure 1. The Slaughter Climbing Center's Bouldering Wall (UVA IM-Rec, 2021).

Carter describes rock climbing as a lifestyle sport where social norms and self-governance play a large role within the sport's community (2019). At any given gym or crag climbers can be observed exchanging 'beta' (specific information about finishing a route) using a myriad of other jargon followed by jubilation when a friend finally completes the project they had been working on (Kozak, 1988). As a final deliverable the team plans to design, build, and implement a new

indoor climbing device which will facilitate social interaction amongst climbers and engage users in a novel manner.

The Tension Board is an existing training board which promotes the social aspect of climbing that this team plans to target. All Tension Boards possess the same holds, allowing for routes be replicated anywhere another tension board exists. A phone application facilitates the social features of the technology, cataloging routes that have been created by climbers worldwide and encouraging climbers to engage in route setting. Figure 2 shows a Tension Board which possesses LEDs, allowing for routes to easily be loaded from the phone app and seen on the board.

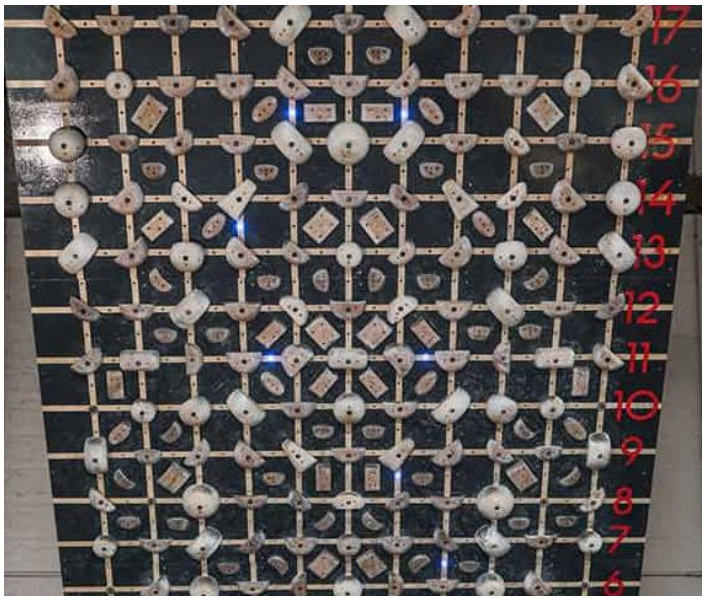

Figure 2. A Tension Board with LEDs showing the Current Route (Tension Climbing, 2022)

Several training boards like the Tension Board already exist. Due to existing competition and the logistical constraints of the project the team has decided to pursue a new climbing technology which could be implemented using a mechanized volume. A volume is a wall fixture used in indoor rock climbing that acts as a modification of the wall it is placed on. Volumes are not

considered holds but rather features of the wall and therefore is usable by climbers on any route which happens to pass over the volume.

Figure 3. A Climber Performing a Heel Hook onto a Volume (Dimension Volumes, 2022)

The team plans to design a volume which would allow for a hold attached to the volume to move after the volume is placed on the wall. This feature would allow for dynamic route setting where the difficulty of a climb could be adjusted on the fly. One of the goals for this project is also for the design to be able to move while supporting a climber's weight with the intention of creating gamified climbing where timing becomes a consideration.

Following several design iterations, the team has loosely identified a design for the final product. A DC brush motor will be used to power a lead screw on which a carriage travels holding the movable climbing hold. The volume will encase the inner mechanisms and allow for attaching the product to the wall as shown in Figure 4.

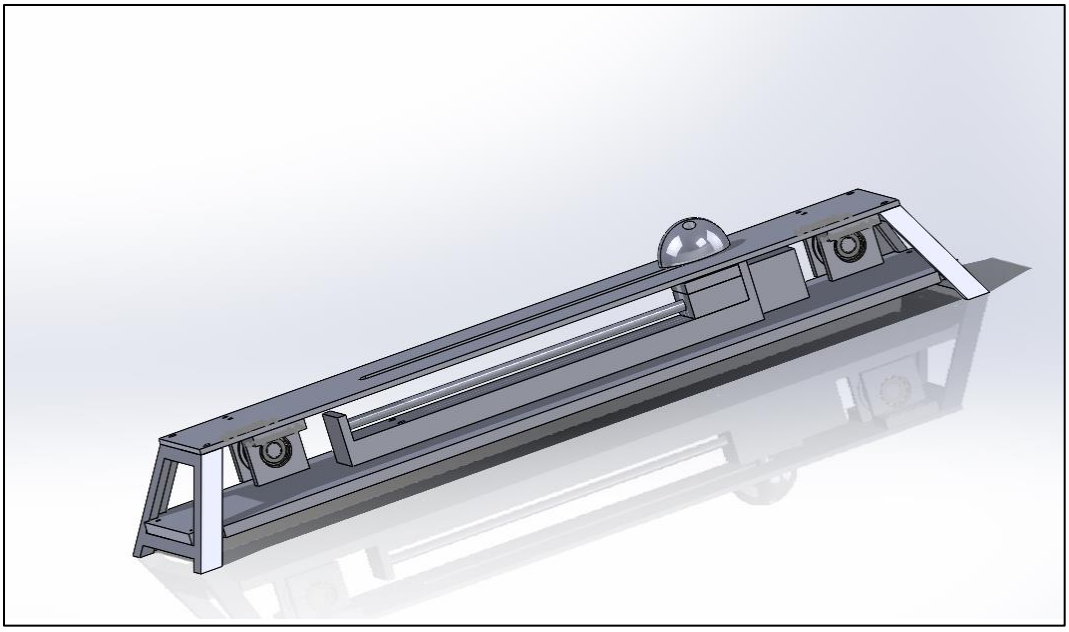

Figure 4. A Photo Showing a CAD Model of the Team's (Gross, 2022)

The hold which will move can be seen on the top face of the volume. The motor turning the lead screw is planned to be powered with a high voltage battery pack and controlled using a Propellor 2 microcontroller. In this model the side faces are open but in the final product each side is planned to be enclosed with wood. The top and back faces of the volume are expected to be wood reinforced with aluminum sheet metal. Major design considerations moving forward are the loading torque which the motor will be able to output to the lead screw and the shear forces which will need to be endured by the mounting bolts. Due to the nature of the design, safety is a major concern. Preventing users from inserting their fingers into the guide slot is planned to be achieved using a belt system. Extensive loading analysis of the volume will be performed using finite element analysis methods before the final design is implemented.

Socio-Technical Background

The world is facing a climate crisis. Over the last four decades average global temperatures have increased at a rate of 0.32° F per decade. Additionally, nine of the ten warmest years on

record happened within the last ten years (NOAA National Centers for Environmental Information, 2021). The transportation sector is one of the largest contributors to climate change and a major point of focus for improving global sustainability. According to a report by the International Energy Administration the transportation sector generated 7.7 billion tons of carbon dioxide emissions in 2021 with road vehicles accounting for 76% of that figure (2022). The adoption of electric vehicles is seen as critical in reducing the carbon emissions of the transportation sector and greenhouse gas (GHG) emissions as a whole ((Reichmuth,2020).

Most life-cycle greenhouse gas (LCGHG) emissions for light vehicles occurs during the operation phase of the product's life (Ambrose et al, 2020). For internal combustion engine vehicles (ICEVs) and hybrid electric vehicles (HEVs) this accounts for the GHGs generated at the tailpipe during operation. For electric vehicles (including HEVs and battery electric vehicles (BEVS)) operational GHG generation is produced upstream at electrical plants. The production of battery cells is the second largest source of LCGHG production for EVs, accounting for up to 31% of a vehicles LCGHG emissions (Ambrose et al, 2020). Lithium-ion batteries (LIB) provide several advantages over other energy storage technologies and are commonly used in electric vehicle applications (Miyamoto et al, 2000) but present sustainability concerns that threaten EVs as a long-term replacement to ICEVs. For electric vehicle manufacturers to ensure long-term sustainability within the transportation sector the design of employed battery technologies must fulfill basic sustainability criteria.

STS TOPIC

Lithium-ion batteries posses higher energy density than nearly all other currently usable battery technologies and are utilized by nearly all commercial electric vehicle manufacturers (Goldman et al, 2019). Many different compounds are used as the cathode of LIBs, but the first

successful batteries produced for EVs utilized cobalt and it is still widely used. Nickel-Magnesium-Cobalt (NMC) cathodes were the most produced cathodes in 2018, accounting for 41% of the global market share (Pillot, 2019). Nickel-Cobalt-Aluminum (NCA) cathodes are also popular for their capacity retention capabilities. Cathodes which do not use cobalt exist with Lithium-Iron-Phosphate (LMP) cathodes chief among them. At this point in time LMP cathodes cannot match NMC or NCA cathodes in terms of energy density though their lower cost has made them desirable in some applications.

The continued use of LIBs with cobalt cathodes raises concerns about whether EVs are the beacons of sustainability that manufacturers would have you believe they are. Lithium and cobalt are both defined as critical materials by the United States government (DOI, 2018). Critical materials are very important to the nation but have highly vulnerable supply chains. Over 50% of all lithium and cobalt are mined in one country, Chile, and the Democratic Republic of the Congo (DRC) respectively (U.S. Geological Survey, 2022). Due to this recycling is seen as important in ensuring the long-term supply of lithium and cobalt in the United States (Ambrose and O'Dea, 2021). Beyond potential supply shortages, cobalt mining within the DCR has ethical concerns that threaten the sustainability of LIBs. Large scale mining operations have caused conflicts between foreign investors and the local communities with the DCR (Prause, 2020) and artisanal and small-scale mining (ASM) operations frequently exploit workers, violate child labor laws and place women situations with dangerous power-dynamics (Sovacool, 2021). The nature of cobalt mining has caused some EV manufacturers to explore different battery technologies however LIB with NMC and NCA cathodes are the top performing batteries currently in use are highly unlikely to be abandoned soon. The importance of mineral mining and

refinement to the Congolese economy also generates pressure to continue current, destructive mining practices.

The proposed socio-technical thesis will analyze the manufacture of EV batteries using a sustainability assessment framework. The design, manufacture, and implementation of LIBs for electric vehicles is vital to promoting global sustainability in the transportation sector. Gibson proposes eight criteria with which to assess sustainability related decision making which focus on the interconnected nature of sustainability design (2005). The basic criteria are socio-ecological system integrity, livelihood sufficiency and opportunity, intergenerational equity, intergenerational equity, resource maintenance and efficiency, socio-ecological civility, precaution and adaptation, and immediate and long-term integration. These criteria will guide the analysis of decision-making surrounding lithium-ion batteries within the upcoming thesis. Gibson's framework will require specifying the general criteria which have been listed into the context of electric vehicle manufacturers making decisions about the employed forms of battery technology.

RESEARCH QUESTION AND METHODS

The proposed thesis research will attempt to answer the question, are electric vehicle manufacturers making design choices about their energy systems which further the sustainability of their products? For electric vehicles to play their foreseen role in reducing greenhouse gas emissions their overall design and manufacture must be sustainable. If a bottleneck exists within the production of electric vehicles the divorce of the transportation industry from fossil fuels will be hindered. Combatting climate change will require changes to be made at many levels and cleaner electricity generation must go hand in hand with a reduced reliance on gasoline. Electric

vehicle manufacturers claim they will be ready to aid this transition, but empirical proof is needed.

The proposed research will include collecting statements from electric vehicle manufacturers concerning their design philosophies regarding batteries. I plan to contact representatives at major car manufacturers that produce or plan to produce electric vehicles such as Tesla, Volkswagen, and Nissan. The interviews will center on the battery technology employed in their cars with the intent of evaluating their design choices using Gibson's criteria for assessing sustainable decision-making. Gibson's basic criteria will be specified beforehand to achieve this. An example of a specific topic which will be explored include where the company sources it LIB components.

The interview data will be aggregated and sorted so that the choices of different design manufacturers can be compared to another. One goal of the interviews will be to collect at least one response tied to each specific criteria generated from the Gibson framework. An analysis will then be done hoping to compare manufacturers who only produce EVs, those who produce some EVs and those who plan to implement them in the future.

CONCLUSION

The upcoming thesis and capstone work will attempt to address two issues: How can indoor climbing be improved in a fun, social way and are electric vehicle manufacturers making decisions which further the sustainability of the transportation sector? The technical project seeks to solve the defined problem through the development of a climbing volume with the ability to move climbing holds. When complete the technical project will provide an interesting new experience for indoor boulderers. The STS thesis will address the issue using social science methods, focusing on collecting testimony from industry representatives. Ensuring sustainability

within electric vehicle design is paramount to the pursuit of sustainability of the transportation sector. Internal combustion engines are a large source of greenhouse gas emissions which must be reduced in order to combat climate change. As their replacement, EVs must be designed to be sustainable in all aspects. When complete the proposed STS thesis will determine whether electric vehicle manufacturers are actively making design decisions regarding lithium-ion batteries which further the pursuit of sustainable transportation

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