Design and Manufacturing of a Commuter Human-Powered Vehicle in Conjunction with the 2021 ASME Human-Powered Vehicle Challenge

(Technical Paper)

Understanding and Changing the American Opinion of Human-Powered Commuter Vehicles

(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

Commented [SF1]: Insert your full name

Skyler Moon

Fall, 2020

Technical Project Team Members

Ryder Sadler

Trevor Marchhart

Lauren Weis

Riley Roe

Joe Flynn

Kavi Patel

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

Signature ____ Date __________

Skyler Moon

Approved ____ Date __________

Natasha Smith, Department of Mechanical and Aerospace Engineering

Approved ____ Date __________

Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

Introduction: Carbon Dioxide and the American Commute

Beginning in the middle of the twentieth century, American working-class culture began to favor living far away from one's business. The creation of new housing developments, which came to be known as the suburbs, drew families increasingly far from the cities, where the breadwinner of the family was likely to be employed (Frost, 2001). However, the increased distance between home and work for many Americans led to an increased need for commuter vehicles, a role which the automobile was more than able to rapidly fill (*City and Suburb*, 2017, n.p.).

As cars have become more and more ubiquitous, the default commuter vehicle for a vast majority of working people has become the single-occupant combustion vehicle (SOCV), usually in the form of a car where the driver rides alone (U.S. Census Bureau, 2011). Although the independence and convenience of an SOCV is alluring for many commuters, it has been detrimental to the environment; an average individual commuter releases about 30 pounds of carbon dioxide per day for a round trip commute, or nearly four tons per year (Stanford Transportation, 2019, n.p.). Without any alternative commuter vehicles, pumping that much carbon dioxide into the atmosphere daily will accelerate climate change beyond any hope. Fortunately, there has been increased interest in the use of human-powered vehicles (HPV's) as a potential replacement for SOCV's (Rodriguez et al., 2011, n.p.). European towns and cities already have a steady HPV-commuting population, but few smaller towns in America have even begun to consider replacing SOCV's (Rodriguez et al., 2011, n.p.). My team is working to design and fabricate an efficient HPV that could theoretically replace SOCV's in order to mitigate the carbon emissions problem inherent in their use. In order to understand how HPV adoption might be best executed, I am studying both American commuter patterns and the American perception of current HPV's.

Technical Topic: Designing and Fabricating an Efficient Human-Powered Vehicle

Although human-powered vehicles show promise as replacements for single-occupant combustion vehicles, current HPV's are insufficient in many of the utilitarian aspects required of a commuter vehicle. The most widely used HPV, the bicycle, generally lacks storage space. Any cargo needed at the commuter's job must be directly carried by the commuter, regardless of size and weight. With an SOCV, the commuter has an abundance of comfort and storage capacity, including the vehicle's trunk and all of the uninhabited seats. Bicycles, although far more efficient than walking, are still not the most efficient HPV due to their higher aerodynamic drag and suboptimal biomechanical drive (Sawyer & Brindos, 1988, n.p.). Previous HPV designs have attempted to reduce both of those effects by using a recumbent bicycle design and building an aerodynamic shell called a fairing around the frame of the vehicle (Sawyer & Brindos, 1988). These aerodynamic designs, although they greatly improve the efficiency and speed of the vehicle, still miss out on comfort and storage space, both of which an SOCV readily provides. With these prior designs in mind, my team has set out to design and fabricate our own HPV that meets the requirements of a commuter vehicle.

Our preliminary design specifications were based on the requirements for entrance in the 2020 American Society of Mechanical Engineers Human-Powered Vehicles Competition, which include stability at low speeds, maximum braking distance, roll cage strength, and maximum turning radius, among others (*HPVC_2021_Rules_9-23-2020.Pdf.Pdf*, n.d.). These competition specifications are summarized in Table 1 below.

Competition Parameter	Parameter Value	Team's Design Specification
Braking Distance	6 meters from ≥25 kmh	5 meters from 25 kmh
Stability	Travels straight 30 meters at 5-8 kmh	Same as competition requirements
Rollover Protection	<5.1 cm of deflection from top load of 5340N, <3.8 cm of deflection from side load of 2670 N	<4 cm deflection for top load case, <3 cm for side load case
Turning Radius	8 meters	Same as competition requirements
Weight	N/A	< 150 lbs.
Size	Fits tallest and shortest riders with >2" clearance between helmet and roll cage	Fits riders between 66" and 77"

Table 1. The American Society of Mechanical Engineers has outlined some design specifications that teams must meet for the competition. In order to make our vehicle more competitive, my team has refined our own, more stringent, requirements.

Because the values for these requirements were given by the governing authority for the competition, they were interpreted to be the minimum capabilities the vehicle needed to achieve in order to be a viable replacement for SOCV's. In order to produce a competitive vehicle, my team decided to make our own design specifications more rigorous than those given by the competition. Based on the competition requirements and prior teams' research, a tadpole trike-style vehicle with two front wheels and one rear wheel seemed to be the most successful at exceeding the competition requirements (Pierre, 2020, n.p.). A three-dimensional computer model of my team's preliminary frame design is shown below in Figure 1.

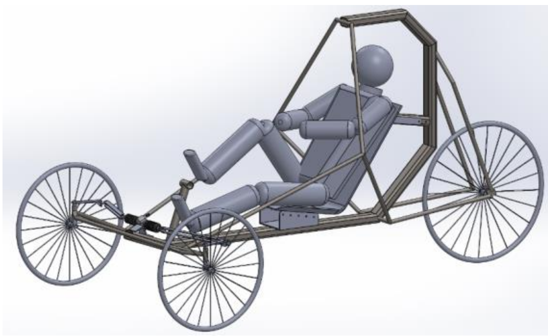

Figure 1. My team has designed an initial frame model using 3D modeling software. This model will serve as the basis for future design choices and allows for design optimization before physically building the vehicle.

With the general shape of the frame chosen, my team set about designing the rest of the vehicle's subsystems. In order to create a sturdy, light roll cage, the frame will be built off of a curved central spine; this allows for a high degree of strength while minimizing the number of large members used in construction. The frame will be made from steel for ease in manufacturing and strength, although using steel does make the design heavier than other materials like aluminum. The center spine also allows for a large gap between the back of the driver's seat and the frame, which can be used for the storage space necessary in a commuter vehicle. The three-wheeled tadpole trike design also creates a very stable vehicle, even when traveling at low speeds, and enables rear wheel drive, which is more efficient than front wheel drive on similar vehicles (Pierre, 2020, n.p.). However, steering with two front wheels is a challenge because the two different wheels need to spin at different rates to avoid skidding. This is a problem solved by the use of Ackerman steering geometry, which angles the wheels in such a way that the outer wheel turns less sharply than the inner wheel when the vehicle is turning (Pierre, 2020, n.p.). In order to increase the efficiency of our vehicle, my team is incorporating a fairing, or an aerodynamically shaped shell, into our design. This fairing will be composed of carbon fiber, allowing it to be custom-shaped and very light.

The advantages of my team's HPV design over SOCV's in terms of carbon emissions are apparent; none of the carbon dioxide emitted during combustion is emitted during the operation of an HPV, removing 30 pounds of carbon dioxide per vehicle per day (Stanford Transportation, 2019, n.p.). However, there are still many technical considerations that our design needs to meet before it can be considered a viable replacement for SOCV's. One such area for improvement is the vehicle's weight: even with the lighter frame design, our vehicle is still rather heavy. A good deal of frame optimization needs to be done before the fabrication process can start.

STS Topic: Understanding American Commuting Patterns and Perception of HPV's

Americans have traditionally neglected human-powered vehicles as commuter vehicle options, and instead favored single-occupant combustion vehicles. A great deal of this neglect is due to the concerns with practicality; since 2001, the average American commute has taken at least 25 minutes by car (U.S. Census Bureau, 2011, n.p.). The length of the American commute began to increase dramatically with the creation, and subsequent filling, of new suburban areas in the 1950's (Frost, 2001, n.p.). The development of these suburbs outside of the city of Chicago is a prime example of how commute duration is a function of not only the increased distance of commutes but also the number of vehicles on the road (Frost, 2001, n.p.). As the working population moved away from the city, new roads had to be built in order to get new commuters into the city, and these roads quickly filled with commuter vehicles, almost all of them SOCV's

(Frost, 2001, n.p.). If the sheer distance was not enough to rapidly increase commute durations, the increased traffic absolutely was. The new, long commutes demanded a comfortable commuter vehicle, and SOCV's were the vehicle of choice (Frost, 2001, n.p.). At the typically slower speeds of HPV's, that same commute from the suburbs to the city would take much longer. Also, regular bike rides 20 miles in length or longer require a significantly higher amount of cardiovascular endurance than driving a car. Because HPV designs that offer increased efficiency, such as the recumbent bicycle with a fairing, were not thoroughly explored until the 1980's, the early suburban commuters would have been stuck with traditional bicycles (Sawyer & Brindos, 1988, n.p.).

Another major factor that has greatly hindered American adoption of HPV's as commuter vehicles is the American perception of HPV's. Americans have traditionally thought of HPV's as either recreational or exercise equipment (Rodriguez et al., 2011, n.p.). This means that most people rarely even consider using HPV's to get to work. Figure 3 below can help to illuminate why the American perception of HPV's generally does not include commuter vehicles; only about five percent of reported bicycle usage is commute-related (Alan M. Voorhees Transportation Center, 2011, n.p.).

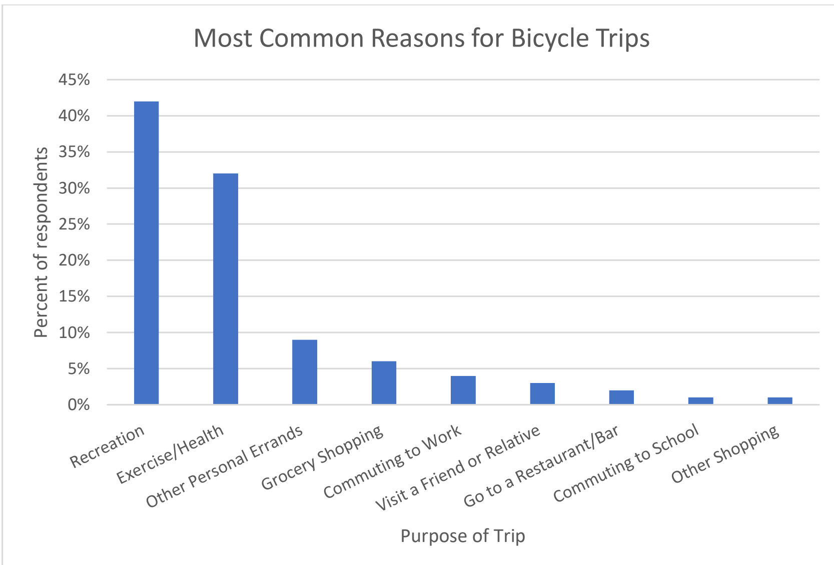

Figure 3. There is a large difference between the proportion of Americans that view HPV's as recreational or exercise equipment and the proportion of Americans that view them as utilitarian commuter vehicles. The former includes roughly 75%, the latter only five percent. (Alan M. Voorhees Transportation Center, 2011, n.p.*)*

Even among people who have considered HPV's over SOCV's as commuter vehicles, attitudes vary with respect to a number of variables (Heinen et al., 2011, n.p.). According to Heinen's 2011 study, people are more likely to use HPV's if they are more aware of the environmental impact of their cycling.

Many European cities, such as Delft and Zwolle in the Netherlands, have had great success promoting the use of human-powered vehicles as urban transportation (Heinen et al., 2011, n.p.). The people in these cities and towns seem to have a much more utilitarian attitude regarding the purpose of HPV's. These cases show that having a large part (~20%) of the commuter fleet composed of HPV's is in fact possible (Heinen et al., 2011, n.p.). Other studies have shown that the motivation for choosing to bike to work can be very personal and vary wildly, from gained fitness and weight loss to simply enjoying the scenery along the commute (Rodriguez et al., 2011, n.p.). The personal reasons listed in Rodriguez's study also imply that it may be possible to reframe current American opinions about HPV usage to favor usage as commuter vehicles by highlighting the ability to get all of the same personal benefits of recreational HPV usage during a commute.

Considering the perceptions of HPV usage is important because attitudes toward a technology can be the difference between adoption and abandonment. This has been seen before in the context of Aramis, the failed public transportation system detailed in *Aramis, or the Love of Technology* by Bruno Latour. The Aramis system was a proposed system of railcars designed to transport people around the city of Paris (Latour, 1996, n.p.). Technologically, the system was quite sound, but public opinion of it centered around a perceived lack of safety (Latour, 1996, n.p.). The lack of favorable opinion eventually drove this system to abandonment (Latour, 1996, n.p.). While the concerns around HPV use, such as efficiency, comfort, and storage space, are not exactly the same as the concerns surrounding Aramis, the fact that adoption of a transportation system can hinge on public opinion highlights the need for consideration of public opinion throughout the system design process.

Conclusion: Potential Deliverables and Problem Resolution

At the conclusion of the capstone project, my team hopes to have a fully realized and fabricated human-powered vehicle design capable of providing a replacement for single-occupant combustion vehicles in urban environments. This design should be able to meet or exceed all of the design requirements summarized in Table 1. In lieu of the official competition, my team is developing driving tests to assess our vehicle's capabilities. I also hope to finish the research project with a deeper understanding of the societal and cultural roadblocks that have previously hindered American adoption of HPV's as commuter vehicles, and how to potentially reframe American opinions about HPV's to encourage more use. With the successful completion of both of these deliverables, my team and I hope to be able to put forward an efficient human-powered vehicle suitable for urban commutes.

References

Alan M. Voorhees Transportation Center. (2011). *BICYCLE ACTIVITY AND ATTITUDES SURVEY* [Survey]. Rutgers University.

Arcadia. (2018, May 18). *Bike to work? Check out your carbon footprint.* https://blog.arcadia.com/biking-to-work-does-it-really-make-a-difference/

City and Suburb. (2017, February 28). National Museum of American History. https://americanhistory.si.edu/america-on-the-move/city-and-suburb

editors, the M. E. N. (1981, September). *Human Powered Vehicles—Green Transportation*. Mother Earth News. https://www.motherearthnews.com/green-transportation/human-powered-vehicles-zmaz81sozraw

Frost, L. (2001). *The History of American Cities and Suburbs: An Outsider's View. Journal of Urban History*, *27*(3), 362–376. https://doi.org/10.1177/009614420102700307

Guest Column: It's Time to Build Resilient Streets for Somerville. (2020, September 22). *StreetsblogMASS*. https://mass.streetsblog.org/2020/09/22/guest-column-its-time-to-build-resilient-streets-for-somerville/

Heinen, E., Maat, K., & Wee, B. van. (2011). The role of attitudes toward characteristics of bicycle commuting on the choice to cycle to work over various distances. *Transportation Research Part D: Transport and Environment*, *16*(2), 102–109. https://doi.org/10.1016/j.trd.2010.08.010

HPVC_2021_Rules_9-23-2020.pdf.pdf. (n.d.). Retrieved October 15, 2020, from https://efests.asme.org/getattachment/Competitions/Human-Powered-Vehicle-Challenge-(HPVC)/HPVC_2021_Rules_9-23-2020.pdf.aspx?lang=en-US

Latour, B. (1996). *Aramis, or the love of technology* (C. Porter, Trans.). Harvard University Press.

McKenzie, B. (n.d.). *Who Drives to Work? Commuting by Automobile in the United States: 2013*. The United States Census Bureau. Retrieved October 8, 2020, from https://www.census.gov/library/publications/2015/acs/acs-32.html

Pierre, J. (2020). *The Smithinator: Recumbent Vehicle Design and Entry for the 2020 ASME Human-Powered Vehicle Challenge* [Technical Design Report]. University of Virginia School of Engineering and Applied Science.

Rodriguez, C., Carswell, J. W., Smalley, M., & Johnson, B. J. (2011). *A Case Study of American Bicycle Culture: How Cycling to Work Works in a Small Town in Kansas*.

Sawyer, K., & Brindos, R. (1988). *Recumbent Bicycle* (United States Patent Office Patent No. 4,773,663).

Stanford Transportation. (2019). *Commute Cost & Carbon Emissions Calculator: Results*. https://transportation-forms.stanford.edu/cost/calculator_results.php

U.S. Census Bureau. (2011). *A Look at Commuting Patterns in the United States from the American Community Survey*. 13.