Designing and Manufacturing a Human Powered Vehicle Achieving a Low Life Cycle Carbon Footprint

(Technical Paper)

Robotic Welding: Shifting the Relationships Between Robotic and Human Welders in Manufacturing

(STS Paper)

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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:

According to the United States Environmental Protection Agency (EPA), as of 2017, the transportation economic sector was the leading contributor of greenhouse gas emissions, being responsible for 29% of emissions. Further, 96.5% of the greenhouse gas emissions from the transportation sector were carbon dioxide, totalling an emission of 1,800.57 million metric tons (EPA, n.d., n.p.). Although the government and private business sector push to be environmentally friendly through transportation, carbon dioxide emissions during the life cycle, specifically manufacturing, are increasing without strict regulation.

Battery powered cars emit less carbon dioxide than gas powered vehicles during operation; however, the manufacturing of their lithium-ion batteries increases the life cycle emissions. A study conducted by the International Council on Clean Transportation found that between 56 and 494 kilograms of carbon dioxide per kilowatt-hour capacity of these batteries are emitted during the production of the electric vehicle (Hall, 2018, p. 2). Additionally, a study conducted by Argonne National Laboratory found that 920 megajoules of energy and 62 kilograms of carbon dioxide are released during the welding phase of a 1532 kilogram vehicle (Sullivan, 2010, p. 18). Therefore, carbon dioxide emissions during production need to decrease to ensure a low or zero carbon footprint is achieved.

As an attempt to create a sustainable, operational, and efficient transportation vehicle, the technical project aims to create a human powered vehicle for the American Society of Mechanical Engineers (ASME) Human Powered Vehicle Competition (HPVC), which will achieve a low life cycle carbon dioxide footprint. Each production process will be methodically approximated for the carbon dioxide emissions, and the power supplied to the vehicle will be sourced from pedaling. The STS research will analyze the shift in the relationships between robotic and human welders as a result of implementing welding automation. As human jobs are displaced in industry by robots, an understanding of the relationships between humans and robots will be critical in analyzing the consequences of automation in manufacturing.

Technical Topic: Designing and Manufacturing a Human Powered Vehicle Achieving a Low life cycle Carbon Footprint

On average, a gas powered vehicle emits approximately 4.6 metric tons of carbon dioxide a year (EPA, n.d., n.p.). Conversely, during operation the power source of a human powered vehicle emits essentially zero greenhouse gas emissions. Seven basic principles that define the goals of human powered vehicles from the *Built Environment* journal are, "reducing the need to travel, reducing absolute levels of urban car use and road freight, promoting energy efficient modes, reducing noise and vehicle emissions, encouraging efficient use of vehicle stock, improving the safety of pedestrians and all road users, and improving the attractiveness of cities for residents, workers, shoppers and visitors" (Cox, 2008, p. 142). To achieve these sustainability goals, various methods are used to report emissions and ensure consumer well-being. In 2009, Sustainable Value Research Ltd conducted a study to discover sustainability performance among automobile manufacturers. In their study, they analyzed reporting methods of emissions produced during manufacturing, which resulted in noticing reporting deficiencies of missing data, methods of consolidation, data extrapolation, and data correction (Hahn, 2009, p. 19). Due to the inaccuracies with the reported data, it becomes difficult to calculate sustainability. As an attempt to better measure sustainability for companies, organizations like the Carbon Fund were established.

The Carbon Fund is an organization that calculates carbon footprints for individuals, vehicles, and businesses. It aims at bringing attention to reducing the carbon footprint in various sectors. To calculate a carbon footprint, carbon emissions for the life cycle of a product must be reported to the Carbon Fund. In past ASME HPVCs for innovation, universities reported their carbon footprint for each production step for their vehicle. For example, as shown in Figure 1, the University of Pittsburgh estimated their life cycle carbon dioxide emissions by quantifying the energy used to mine their raw materials, produce their vehicle material from the raw material, and energy used during the assembly process (Stucky, 2017, p. 22). Other competitions featured in the ASME HPVC are speed and endurance races, which test which vehicles are the fastest and most durable. Therefore, quality materials, testing, and manufacturing processes must be used to perform well in each competition.

Raw Material Extraction			
Process	**MJ/tonne of Ore**	**kgCO2**	**Ref.**
Drilling	1.99		[US D.O.I.]
Blasting	3.37		
Loading	7.34		
Haulage	59.15		
Miscellaneous	7.54		
Total	79.39	3,088,141	

Material Refining			
Process	**MJ/tonne**	**kgCO2**	**Ref.**
Theoretical Minimum Energy	8620	4,632,212	[DOE]

Manufacturing & Assembly		
MJ/day	**kgCO2**	**Ref.**
125.5	108	[Inside Energy]

Recycle Production and Processing		
MJ/tonne	**kgCO2**	**Ref.**
1600	19.02	[DOE]

Figure 1: The University of Pittsburgh's 2017 Design Report table for approximating carbon dioxide emissions for raw material extraction, material refining, manufacturing and assembly, and recycle production and processing for their human powered vehicle. The calculations used to measure the amount of carbon dioxide emissions included multiplying the weight of material or time of energy usage to the amount of carbon dioxide created for that process (Stucky, 2017, p. 23).

For the 2020 ASME HPVC, my 14-member capstone group will design and manufacture a human powered vehicle powered by pedaling. Our vehicle will encompass qualities that are used to achieve strength, aerodynamics, consumer-friendliness, speed, durability, and a low carbon footprint. To ensure the vehicle achieves strength and aerodynamic qualities, finite element analysis (FEA) and computational fluid dynamics (CFD) testing will take place to provide numerical data, such as the drag coefficient, to compare our project specifications with the requirements of the ASME handbook. Additionally, to focus our efforts on demand, a market research survey was conducted to discover user values, such as comfort, speed, sustainability, cost, and safety. Further, to achieve top travelling speeds and durability, analysis of gear ratios, biomechanics, and frame design will occur. To ensure a low carbon footprint is achieved, coordination with the Carbon Fund will occur regularly to calculate updated emissions.

Focusing on the carbon footprint, various processes will be monitored to approximate the most accurate carbon emissions. The primary factors contributing to the carbon footprint of our human powered vehicle are mining of raw materials, production of used material from raw material, energy and flux used during welding, electricity used during assembly, and shipping of materials and pre-manufactured parts. We will use the weight of each part to approximate the carbon dioxide emissions for its life cycle. Additionally, when available we will use recycled bicycle parts for features on our vehicle. A study on recycled materials in construction found that by recycling ferrous and nonferrous metals, there are carbon dioxide emissions savings of 2.374 and 14.67 tons per ton of waste, respectively (Kucukvar, 2014, 504). Therefore, we believe that using recycled parts for our design, specifically metals, will decrease our carbon footprint because of eliminating the mining and production processes. An additional method we plan to research is sustainable welding because this will be a primary production method used for our vehicle, specifically the steel frame. The Tulsa Welding School explains welding techniques, such as vacuum soldering, friction welding, and diffusive welding that use hydrogen, friction, and pressure and heat, respectively, that eliminate the need of flux (Nguyen, 2015). Therefore, to further reduce the carbon footprint by eliminating welding flux, these techniques will be implemented.

STS Topic: Robotic Welding: Shifting the Relationships Between Robotic and Human Welders in Manufacturing

To implement more sustainability in industry, advanced technologies, such as cobots, collaborative robots that work alongside other robots and humans, and 3D printers, are being implemented by various manufacturing companies (Koenig, 2019). A study done to compare manual and robotic welding in small and medium manufacturing companies found that robotic welding decreased the arc time by 50.4 seconds, increased the power source efficiency by 0.3%, and increased the annual parts production by 162,560 parts (Epping, 2018, p. 11). Regarding the improvements in these welding features, energy and carbon dioxide emissions are saved. Additionally, as shown in Figure 2, TRUMPF, a German industrial machine manufacturer, conducted a study comparing the emissions of manual metal arc welding, laser arc-hybrid welding, and gas metal arc welding, both standard and modified versions. When comparing the life cycle assessment for each type of welding practice, it was found that the laser arc-hybrid welding emitted the least amount of phosphate, sulfur dioxide, ethene, and carbon dioxide as shown in Figure 2 (Kaliudis, 2017). Likewise, both comparison studies highlight how robotic welding is more environmentally friendly and efficient than the alternative of manual welding.

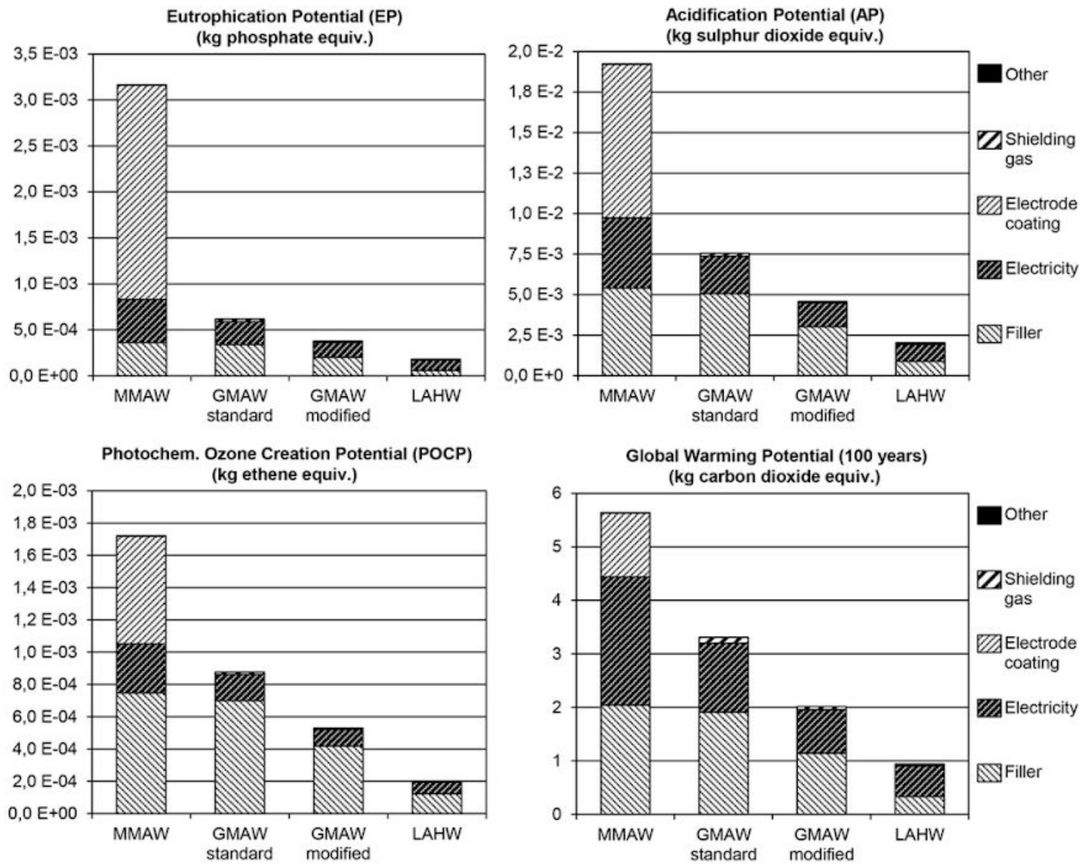

Figure 2: The graphical results of emissions for phosphate, sulphur dioxide, ethene, and carbon dioxide for manual metal arc welding (MMAW), laser arc-hybrid welding (LAHW), and gas metal arc welding (GMAW), both standard and modified versions. From the results, it is shown that manual welding creates the most emissions for all gases measured (Kaliudis, 2017).

When robots are implemented in industry, there is a displacement of human jobs. For example, in some cases, humans can lose their positions to robots that perform the same job as them. Conversely, according to *Forbes* magazine, when Wing Enterprises implemented robotic welders in their production system, they produced enough parts to enable them to open another facility, expanding their job force from 20 to 400 employees (Ellingrud, 2018). However, an understanding of only the increase in the number of job positions does not fully capture the effect that robots in manufacturing have on the industry and current workers.

Implementing robotic welders in manufacturing impacts the tasks that humans currently perform. The impact is primarily due to robots more efficiently performing the exact job of manual welders. Therefore, to secure the job of the human welder, a new relationship between the robot and person is established. Brookings Institution, an American research group, discusses one possible relationship shift between the two actors; when robots are implemented in industry, training for the human workers is needed to further their skills to work alongside robots. The new training would enable the workers to understand the technology behind the robots, allowing them to troubleshoot or complement the new technologies (Casey, 2019). An additional relationship that could develop would be master welders training robots how to perform human skills. *Control Engineering* discusses an increase in demand for master welders due to the lack of training in the industry, which creates new opportunities for welders. Mastery welders who possess the needed skills, such as the sequencing of welding processes, travel angles, and amperage, can train robotic welders through computer coding (Anandan, 2017). The idea of using the welders to train the robots creates a teacher-student relationship, where the robot is taught welding skills by the master welder. An additional outcome shown through the relationship is that the skillsets of the welders would be utilized through two features: training and precise welding.

To fully understand the impact that implementing robotic welders in manufacturing has on the relationship between robotic and human welders, it is important to understand the problem definition and solution (PDS) model by Gary Downey. Downey states, “As PDS engineers, their work in interviewing stakeholders would include the additional responsibility to learn and explicitly map how all stakeholders understand the problem, what addressing the issue appears to mean to their future positions and identities, and how they understand their responsibilities" (Downey, 2005, p. 591). Working through the PDS model will provide an understanding of the values that need to be upheld when evaluating the relationship shifts. To continue the analysis of the relationship shift between the nonhuman and human actors, I will examine other possible relationships that can occur from implementing robots in industry. By understanding the relationships, I will possess a better conceptual understanding on which implementation aspects better feature the values human welders have. A comprehensive analysis of the relationship shift between robots and welders would result in an understanding of how to implement sustainable automation in industry, while maintaining worker satisfaction.

Conclusion:

The desire to produce sustainable transportation methods and manufacturing provides opportunities and challenges regarding the balance of consumer and production demands. My capstone group and I will design and manufacture an operational human powered vehicle that is sustainable, efficient, operational, durable, and user-friendly for the 2020 ASME HPVC. The calculation of the life cycle carbon footprint will increase awareness of sustainable standards and manufacturing processes. Further, my STS research will provide a better understanding of how the relationships between robotic and human welders shift as robotic welders are implemented in industry. Analyzing implementation methods that uphold human welders' values in the relationship shift and making use of Gary Downey's model on defining the deeper problems in sociotechnical systems will generate a better understanding of how to successfully implement welding automation in manufacturing. By manufacturing a human powered vehicle with a low carbon footprint and better understanding the relationship shift between human and robotic welders, sustainable automation in industry can be implemented, while upholding worker's values.

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