CUSTOMIZED MIDSOLE DEVELOPMENT TO ADDRESS PLANTAR HEEL PAIN

THE OUTLOOK OF MASS CUSTOMIZATION IN THE FUTURE OF ATHLETIC FOOTWEAR

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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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Before the 1500s, shoes were custom-made for each individual client since the machinery to create more shoes on a larger scale did not exist yet. When more efficient ways of producing shoes emerged, shoemakers began mass-producing according to standardized sizes and stocking them for instant transactions (Independent Shoemakers, n.d.). In 2017, mass-produced sneakers dominated the market, but the technology for creating customized athletic shoes existed. Major shoe companies saw 3D printing as the primary method of manufacturing shoes with specific mechanical properties or unique designs. Later in 2017, Adidas launched their Futurecraft 4D campaign which aimed to print an entire midsole cushion customized to the customer's feet in the near future. For the first few years, Adidas and Carbon's Futurecraft printed midsoles would not be customized for commercial use, but Adidas aimed to have 3D printers with running analysis devices at every store (Kim, 2018, para.12). With a possible return to customized footwear, an opportunity presents itself for athletic shoe design to draw on knowledge from the biological and orthopedic community.

A typical athletic shoe is principally made of three parts: the upper, the midsole, and the sole. Primarily, those in the biomechanics community focus on innovating the midsole and the cushion system inside it to improve how individuals move biomechanically. Shoes can have a profound effect on how the body moves and the state of muscles in the lower extremities. Characteristics of the shoe such as the hardness of the cushion or the lift in the heels can cause permanent repercussions and great pain (Stevenson, n.d.). Every person has different feet and different needs for those feet. To solve this problem, the tightly coupled technical research and STS research topic discussing how there may be a niche need for better customized footwear and how to create that customized footwear. The technical aspect of the project will involve creating a method for scanning a patient's foot and deriving a shoe cushion contoured to his foot and 3D

printing the midsole cushion. With a truly customized shoe midsole, common foot and lower extremity afflictions can be treated by modifying certain characteristics of the midsole such as adjusting the arch height and density of specific areas of support. Closely aligned to the technical project, the STS research explores the scalability and outlook of mass customization in athletic footwear. By exploring costs and how similar services have fared in their respective industries, it is possible to predict and rate commercial success and stabilization.

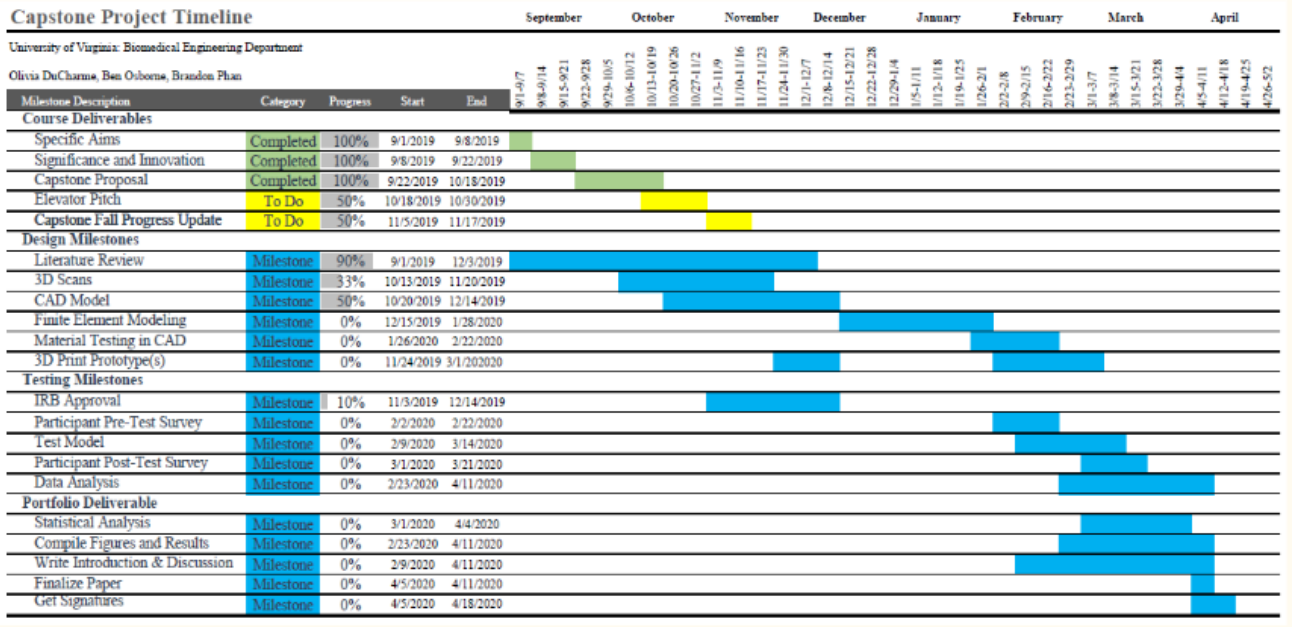

Figure 1: Gantt Chart of the Project Timeline. The chart visualizes the concurrent processes that occur during the technical project and when the team expects to complete certain tasks (DuCharme, 2019).

CUSTOMIZED MIDSOLE DEVELOPMENT TO ADDRESS PLANTAR HEEL PAIN

Under supervision of Professor Shawn Russell and Professor Silvia Blemker in the Mechanical and Biomedical Engineering departments, the technical project intends to devise a method for scanning, analyzing, and printing a midsole for an athletic sneaker with the intended use of customizing based on foot impairments such as flat feet or plantar fasciitis. Plantar fasciitis is the inflammation of the tissue running beneath the ball of the feet and connecting with the calcaneal tuberosity or the heel bone. Frequently, the tissue becomes inflamed or starts

deteriorating when the arch is overstressed and the other muscles supporting the ankles such as the plantar dorsiflexors are less effective (Stevenson, n.d.). According to Young (2019), plantar fasciitis is very common especially the latter where "approximately 10% of the United States population experiences bouts of heel pain, which results in 1 million visits per year to medical professionals for treatment of plantar fasciitis" (Background section, para. 2) with those above the age of 45 having a higher risk of inflaming the plantar fascia. The total indirect costs of plantar fasciitis add up to around $390 million per year in the United States (Bishop et al. 2018). Current treatments of plantar fasciitis include arch support insoles and custom castings used to shape the insole of an orthopedic shoe. More invasive treatments for plantar fasciitis involve medication, injections, or even surgical modification or removal. Dr. Baravarian, a podiatrist who noticed how current treatments with cortisone were ineffective, discusses how he used an algorithm with levels of progress to guarantee plantar pain relief (Baravarian, 2019). Nagano and Begg (2018) stated that foot maladies directly increase risk of injury or musculoskeletal disease in the related areas of the body, but the maladies could be alleviated using shoe technologies focusing on the underfoot such as midsoles and insoles (p. 1). Using a customized shoe insole, Bishop et al. (2018) performed a clinical trial on patients with plantar fasciitis indicating that the proper customized arch support and pressure distribution the custom insole offered reduced the amount of pain in the heel on first step (p. 4).

Over the course of two semesters in Professor Timothy Allen's capstone class, the technical project will aim to test gaits and scan foot structures in the Motion Analysis and Motion Performance Lab at UVA. The first months will be focused on researching and scanning feet with plantar fasciitis or similar afflictions like flat feet. After obtaining a 3D foot model with a photogrammetry program, the midsole modelers can build a midsole shaped and contoured to

the bottom of the foot creating a 1:1 unique midsole for the patient's feet. The physical design of the midsole will be influenced by other similar patented 3D midsoles but unique due to the method and process of modelling and printing. After creating the midsole in the modelling software, the next steps will change the support system and height of the midsole cushion according to the needs of the patient.

The literature is divided on whether minimal or contoured midsoles for arch support are more beneficial for plantar fasciitis. Firminger et al. (2016) believed that minimal cushioned running shoes are better for the joints as the results showed that minimalist shoes increased energy absorption and work. On the other hand, Hannigan and Pollard (2019) concluded that minimalist shoes resulted in much greater ground reaction forces meaning greater risk for plantar fasciitis. Casey Kerrigan (2019), from Oesh Shoes in Charlottesville, Virginia, firmly believes in her company's stance on flat minimalist shoes acting as a spring instead of an arch crutch. The examinee will be fitted with the midsole and his gait, lower leg muscle strain, and foot pressure will be compared to initial results without the custom midsole using the motion capture cameras and markers at Professor Russell's motion lab. Using these results, the team hopes to see dramatic decreases in pain during the first steps and aligned ankle angles to show that the mechanics of walking are improved. The data and research used in the technical project will be a scholarly article outlining how the process can be applied to plantar fasciitis and how scientists could explore changing the midsole to treat other lower body ailments. Eventually, the team including Brandon Phan, Ben Osborne, and Olivia Ducharme aims to make a patent out of the process as the idea of a customized 3D printed midsole is established prior art.

THE OUTLOOK OF MASS CUSTOMIZATION IN THE FUTURE OF ATHLETIC FOOTWEAR

The STS topic will focus on determining the mass customization trend in the shoe market and whether it will become common place in the future. This topic will be written in a journal article context as the technical project relates market trends and prices towards how a future technology will perform. While some may see it as a gimmick, 3D printing shoes invaded the market as Nike, Adidas, and Under Armour all released shoes featuring 3D printing for high prices. Due to the high prices, only the athletes signed onto the brand or very early adopters were able to purchase the new technology. Eventually, the prices may recede as technology cheapens operating costs and material is cheaper. In order for 3D printed shoes to become common place, there must be competition causing each company to attempt to release the best product, and there must also be demand for new technology in the shoe. In terms of STS frameworks and approaches, the current situation fits most with the technology transfer framework (Moravcsik, 2002). The engineers who are aiming at commercially mass-customizing these shoes will need to appease the four main groups in the sneaker community, executives, early adopters of the tech, budget/average consumers, and those in the resale market as shown in Figure 2 (p. 6). Recently, the resale market for sneakers has become much more popular as sneakers have become investment pieces that raise in equity when less of the sneaker are in circulation. StockX is a company that is a dedicated sneaker resale market selling shoes like stocks and tracking the price behind each sale. The engineers may have a problem appealing to these resellers as the shoes are made unique to one person. While the customized sneaker is indeed rare as it is the only one in the world, all the sneakers will be unique in the world rendering the resale price unimpressive most likely. The early adopters are those who are interested in the art behind shoes and possibly

the medical science behind shoes. Since they tend to adopt and start the trend, the engineer would have to appeal to them as they would be the first people to experience the technology. The budget/average consumer will have a hard time listening to the engineers as the price for non-customized 3D printed shoes is expensive. A customized midsole will most likely increase the

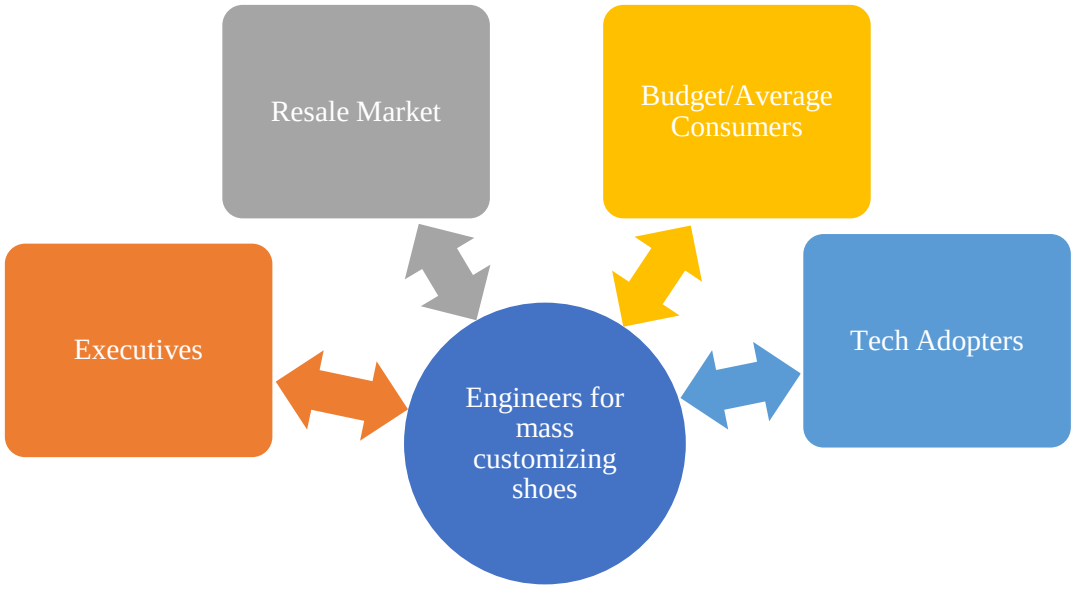

Figure 3: STS Framework Applied to Engineers for Mass Customization. The engineer has to appease multiple groups to accept his newer technology in order to further the diffusion of innovation and further the field (Phan, 2019).

price. Lastly the engineers need to show the executives that their endeavor is worth proceeding with and seen as a worthwhile investment by the company. Government organizations like the Patent and Trademark Office will have an increase of patent applications related to the field and the innovation will grow and diffuse into society through increased social media coverage. In order for this to happen, the relevant consumer groups need to provide feedback on improving the models and production processes. As the onus is placed on the groups of consumers to voice what they want to buy with their purchases, the industry engineers can see which models are worth pursuing from a financial standpoint. If the 3D printed shoes perform well while in the market, physical stores will likely be positively affected. Customers will go into stores to see the

spectacle of seeing a foot scanned and how it is printed. Also, it will be implausible for the near future for the foot scans to happen from home so customers will be forced to visit brick-and-mortar stores. If the release of 3D printed shoes into the market does not perform well commercially, the manufacturers of the printers and the companies who design the shoes will not be invested in carrying on the project to make custom biomechanical 3D printed shoes later on as shown in Figure 3 (p. 7).

The STS topic supports the technical topic by investigating the prospect of bringing the technical method to open market and whether it will make a difference in how accessible the customization process is for consumers. The problem of costs limits many consumers and may limit the range and potential of the technical project. By observing how past iterations and related initiatives have done in the open market, the project intends to answer whether mass customization of midsoles specifically will be commercially viable in the future. The fashion

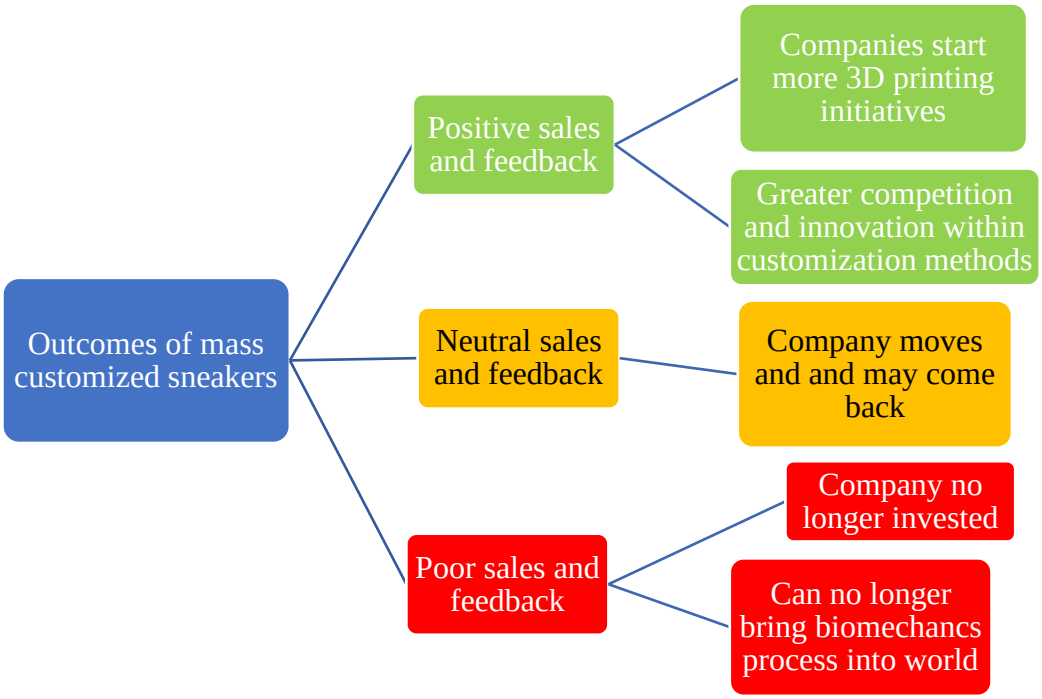

Figure 2: Outcome Tree Depending on Success of Mass Customization. The tree illustrates how different results on commercial performance may impact how the industry may or may not move forward with 3D printing (Phan, 2019).

industry is similar in that it has stores dedicated to serving many people but tailoring and customizing each piece according to their preferences. The market on these stores is not widespread and only the upper percentages of society can afford custom suiting but, the niche has been created. The mass-customization of athletic shoes may run the same way.

With the process for producing each regular midsole gradually speeding up, the dream for printing a customized midsole on the spot is growing closer. Carbon's unique "Digital Light Synthesis" printers and process has improved from 1.5 hours per midsole to 15 minutes (Flower, 2017, p. 3). However, the retail price of any Futurecraft shoe is at least $300. With the median price of Adidas' athletic shoes being approximately $70 according to Priceonomics Data Studio (2017), the Futurecraft 4D technology is at least four times greater than the median price (Price of Popular Sneaker Brands section, para. 1). Some models featuring the 4D midsole are priced at up to $900. The average consumers will likely not be able to purchase these types of shoes, and the custom technology might be limited to wealthy athletes or Adidas influencers. Certain models are even sitting on shelves in Footlockers, both in-store and online, since they are too pricey and not as comfortable to the consumers (Footlocker, 2019). The future of Futurecraft is uncertain as the next iteration in the initiative is a fully recyclable shoe made fully from plastic but not 3D printed like the Futurecraft 4D (Wilson, 2019). Unfortunately, it does not seem that the Futurecraft initiative, specifically, will be commercially successful and establish closure as a technology unless Adidas reduces the price point. Another company like Oesh Shoes can still establish itself in the market, but the novelty of 3D printing itself may be lost. Having an item be manufactured through 3D printing is becoming commonplace but companies that use 3D printing as a marketing gimmick will only lose when the novelty factor ends.

WORKS CITED

Baravarian, B. (2019). Rethinking the treatment options for plantar fasciitis. Podiatry Today, 32(3), 60–62.

Bishop, C., Thewlis, D., & Hillier, S. (2018). Custom foot orthoses improve first-step pain in individuals with unilateral plantar fasciopathy: A pragmatic randomised controlled trial. *BMC Musculoskeletal Disorders, 19*. doi:10.1186/s12891-018-2131-6

DuCharme, O. (2019) *Gantt chart of project timeline.* [Figure 1]. *STS Research Paper: Customized Midsole Development to Address Plantar Heel Pain* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Firminger, C. R., & Edwards, W. B. (2016). The influence of minimalist footwear and stride length reduction on lower-extremity running mechanics and cumulative loading—ScienceDirect. Journal of Science and Medicine in Sport, 19(12), 975–979.

Flower, I. (2017, October 24). Is mass customization the future of footwear? *Wall Street Journal.* Retrieved from https://www.wsj.com/articles/is-mass-customization-the-future-of-footwear-1508850000

Footlocker. (2019). Adidas alphaedge 4D - men's | Foot Locker. Retrieved from Footlocker website: https://www.footlocker.com/product/adidas-alphaedge-4d-mens/EF3454.html

Hannigan, J. J., & Pollard, C. D. (2019). Differences in running biomechanics between a maximal, traditional, and minimal running shoe. Journal of Science and Medicine in Sport, S1440244019304736. https://doi.org/10.1016/j.jsams.2019.08.008

Independent Shoemakers. (n.d.). History of shoemaking. Retrieved from Shoemakers website: http://shoemakers.org.uk/history-of-shoemaking/

Kim, A. (2018, July 6). Adidas' vision for the future: Personalization, fast. Retrieved from CNNMoney website: https://money.cnn.com/2018/07/06/technology/adidas-speedfactory/index.html

Kerrigan, C. (2019, October 18). Interview with Casey Kerrigan about Oesh and shoe manufacturing [Interview].

Moravcsik, M. J. (2002). The role of science in technology transfer—ScienceDirect. Retrieved from ScienceDirect website: https://www.sciencedirect.com/science/article/abs/pii/0048733383900203

Nagano, H., & Begg, R. K. (2018). Shoe-insole technology for injury prevention in walking. *Sensors, 18*(5). doi:10.3390/s18051468

Phan, B. (2019). *STS framework applied to engineers for mass customization.*[Figure 2]. *STS Research Paper: Customized Midsole Development to Address Plantar Heel Pain* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Phan, B. (2019). *Outcome tree depending on success of mass customization.*[Figure 3]. *STS Research Paper: Customized Midsole Development to Address Plantar Heel Pain* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Priceonomics Data Studio. (2017, June 8). How much do shoes cost (for men vs women)? Retrieved from Priceonomics website: https://priceonomics.com/how-much-do-shoes-cost-for-men-vs-women/

Stevenson, B. (n.d.). Plantar Fasciitis: An illustrated explanation of why your foot hurts—Why Things Hurt. Retrieved from Why Things Hurt website:

http://www.whythingshurt.com/plantar-fasciitis-an-illustrated-explanation-of-why-your-foot-hurts/

Wilson, M., & Wilson, M. (2019, April 17). Exclusive: Adidas's radical new shoe could change how the world buys sneakers. Retrieved October 24, 2019, from Fast Company website: https://www.fastcompany.com/90335038/exclusive-adidass-radical-new-shoe-could-change-how-the-world-buys-sneakers

Young, C. (2019, February 3). Plantar fasciitis: Background, anatomy, pathophysiology. Retrieved from MedScape website: https://emedicine.medscape.com/article/86143-overview