Customized Athletic Shoe Midsole Development to Address Plantar Heel Pain
(Technical Report)

Tactical Medicine & Weaponry: The Impact of Assault Rifle Advancements on Emergency Medical Services in the United States
(STS Topic)

A Thesis Prospectus in STS 4500
Presented 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 in Biomedical Engineering

Author
Olivia DuCharme
October 30th, 2019

Technical Project Team Members
Ben Osborne
Brandon Phan

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 October 30th, 2019

Approved ______________________ Date __________
Rider Foley, Department of Science, Technology, & Society

Approved ______________________ Date __________
Shawn Russell, Department of Mechanical Engineering

Part I. Technical Project Topic: Development of a Midsole Customization Method to Address Plantar Fasciitis

Introduction

For the majority of the global population, walking and running are critical tasks that contribute to a healthy lifestyle. These methods of locomotion are accompanied by injury risks that result from gait impairments and suboptimal foot pressure control (Nagano & Begg, 2018). One common foot impairment, plantar fasciitis, affects one in ten people during their lifetime and indirectly costs the United States healthcare system $390 million per year (Crawford, Atkins, & Edwards, 2001; Bishop, Thewlis, & Hillier, 2018). Plantar fasciitis is a degenerative condition that affects the plantar fascia ligament, a thick band of tissue that covers the bones on the base of the foot, and is associated with acute pain between the heel and metatarsals, falls, poor quality of life, and disability (Nahin, 2018). There are many potential causes of plantar fasciitis, including *pes planus* (flat feet), *pes cavus* (high-arched feet), overpronation (medial ankle inversion), limited ankle dorsiflexion, weak intrinsic and plantar flexor muscles, poor biomechanics or alignment, repetitive foot contact with hard surfaces, and poor footwear (Schwartz & Su, 2014). Footwear modifications offer a cost-effective and convenient method to prevent orthopedic foot injuries by addressing the fundamental biomechanics associated with an individual's gait pattern when walking and running.

There are a variety of footwear and orthotic insole options on the market to reduce undesirable loading of the joints and ligaments during the gait cycle. Most current shoe models have raised heels that causes weakening of the ankle dorsiflexor muscles and plantar fascia as well as imbalances in weight distribution, all of which can exacerbate plantar heel pain (Stevenson, 2013). Major athletic shoe companies market footwear to a broad population, however, mass-produced shoes are not designed to address locomotion impairments, joint pain, or gait abnormalities, all of which create a market for orthotic shoe inserts. Foot orthoses range from 'off-the-shelf' heel pads to contoured, prefabricated inner soles to custom orthoses. Custom-made foot orthoses are molded or milled from an impression of the foot and fabricated according to practitioner-prescribed specifications (Hawke, Burns, Radford, & Du Toit, 2008). These supplemental footwear accessories are used to counteract the shortcomings of shoes by providing additional cushioning and arch support as well as reducing plantar pressure by redistributing force over the contact area of the foot upon ground strike (Albert & Rinoie, 1994).

While many of these options have proven effective for some patients, the ability to address biomechanical abnormalities on a patient-by-patient basis via midsole design is currently unavailable. Midsole designs derived from a patients' specific needs may greatly reduce the loads on the knees and ankle joints, while also protecting against overuse injuries, such as plantar fasciitis. By creating a method to produce bespoke footwear for individuals with plantar fasciitis, or other types of locomotion-related pain, our Capstone team will formulate a midsole design process that is more customer-centric and will reduce plantar heel pain.

Technical Project Description

Development of an algorithm that informs the design of an optimized shoe midsole through the consideration of anatomical and biomechanical factors on a patient-by-patient basis can provide a novel approach to addressing overuse injuries of the foot, such as plantar fasciitis. The proposed algorithm will include parameters addressing body mass index (BMI), gait pattern, ankle pronation, and pressure centers of a patient's feet, see Figure 1. A 3D scan of the patient's feet will inform the size, shape, and cushioning implemented in the customized midsole, see Figure 2. Additionally, the formation of the midsole itself in the Computer-Aided Design (CAD) software will be informed from similar designs from existing company patents in the field, see Figure 1.

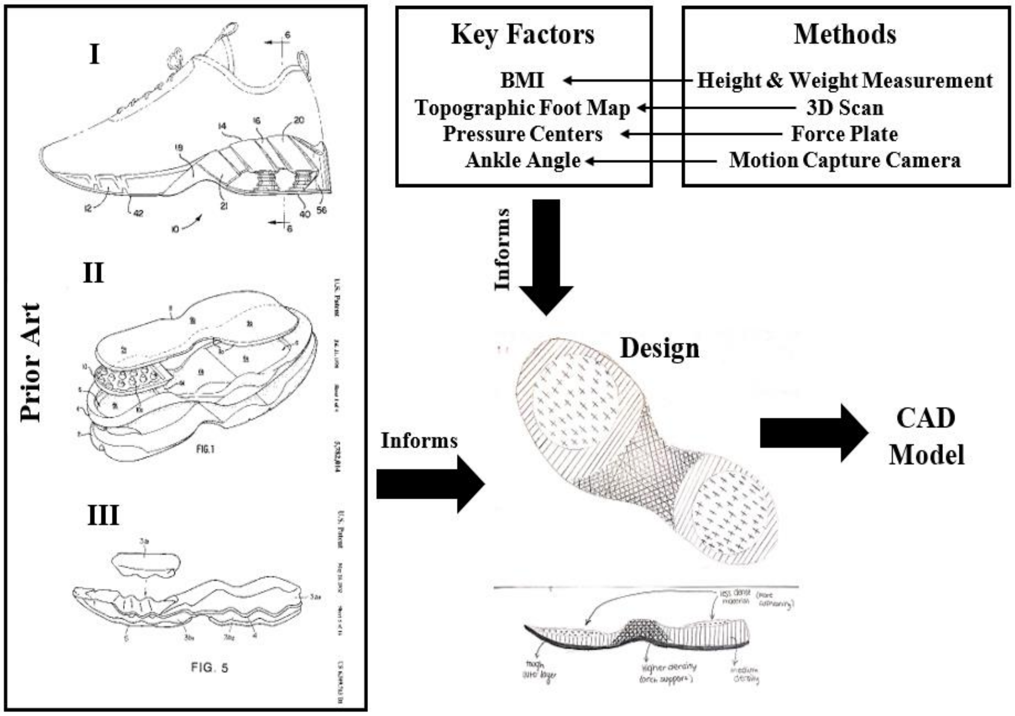

Figure 2. Innovation Process of Designing an Optimized Athletic Shoe Midsole to Address Plantar Fasciitis. Designs from prior art patents including I) Shock absorbing midsole for athletic shoe from LL International Shoe Company Inc., Dada Footwear, II) Athletic shoe having a spring cushioned midsole from K Swiss Inc., and III) Athletic shoe midsole design and construction from Mizuno Corporation, coupled with key biomechanical factors will inform the design of the optimized midsole (Image sources: United States Patent No. US6457261B1, 2002; United States Patent No. US5782014A, 1998; United States Patent No. US6389713B1, 2002). Our modified design will be created in a CAD software, 3D printed, and tested to determine if accounting for personalized biomechanical factors increase the comfort and support of the shoe (Image source: DuCharme, Osborne, & Phan, 2019).

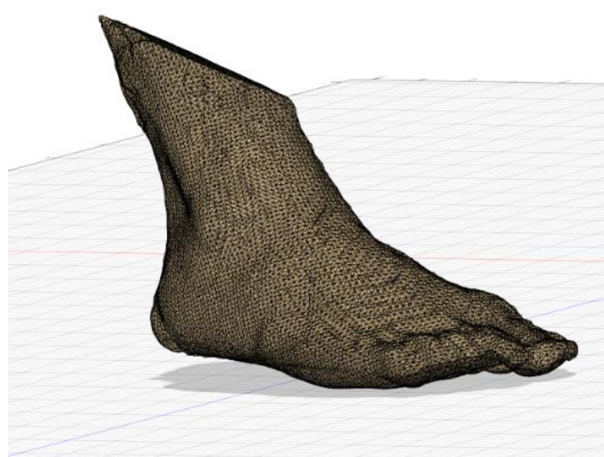

Figure 1. 3D Scan of Capstone Team Member's Foot in Autodesk Fusion 360®. This scan will be used as a topographical map off of which to build the midsole model. (Image Source: DuCharme, Osborne, & Phan, 2019)

Research Question and Methods

For addressing plantar fasciitis, the midsole will be shaped with arch support according to the positional data of the arches in the customized midsole CAD model, determined via the 3D scan of the patient's foot. A predesigned model will be fit to the patient's foot contours in CAD and using BMI information, the density of material in the arch and heel regions of the midsole will be adjusted via in-fill percentages to provide the optimal support and cushioning. The resulting customized model will be subject to finite element analysis and material testing within the CAD software to determine which 3D-printing material allows for optimized cushioning around the heel and ball of the foot. 3D printing the midsoles will provide a scalable manufacturing method that allows for precise material modifications, and potentially low cost. To test the 3D-printed prototype, motion analysis markers will be placed on the feet and midsole to observe changes in gait pattern, ankle angle, and stride length when walking with the optimized midsole in comparison to barefoot movement and movement in a comparable shoe model. To analyze forces on the foot during the gait cycle, study participants will walk over a force plate to determine the maximum vertical ground reaction force in the varying testing conditions. Finally, comfort of the shoe will be rated by the participants using a Likert scale[1] for each of the models and compared quantitatively. These analysis methods will determine if the algorithm method of designing a midsole creates a functional prototype that addresses plantar heel pain and whether this method can be a viable option for professionals in the field of orthotics and shoe design.

[1]A Likert scale is a rating system that measures attitudes or opinions by asking survey responders to rate items based on their level of agreement. For the purpose of our study, we will be using a five-item scale to rate agreeance, frequency, quality, likelihood, or importance from "Strongly Agree" = 5 to "Strongly Disagree" = 1 (Glen, 2015).

Timeline & Expected Outcomes

In order to achieve the aims of this technical project, our Capstone team has a number of milestones that we will complete to reach the final deliverables of a functional algorithm and midsole design. By the end of the fall semester, we will have developed a midsole model in CAD based on 3D scans of our feet to provide topographical maps of the foot contours, see Figures 2 and 3. The compliance of this developed model will be variable in CAD based on the physical parameters of our design and the selected in-fill percentage for 3D printing, which will be informed by the algorithm data, see Figure 1 above. Testing the model will begin in the spring semester, with Institutional Review Board (IRB) approval to be secured by the end of the fall semester, see Figure 3. All dates detailed in Figure 3 are subject to change as the project progresses, but serve to provide a guideline for tasks to be completed and time management.

Midsole stiffness and damping are critical components in determining ground reaction forces during the ground-contact phase of the gait cycle, however methods to quantify these components are lacking in the field (Naemi & Chockalingam, 2013). The aims of this project seek to expand upon this lack of methodology in the development of midsoles to target areas of the footwear most associated with plantar fasciitis-related pain. If the proposed aims are achieved, patient specific parameters can be used to succinctly inform the development of a midsole to address plantar fasciitis beyond what is currently available on the market. It is expected that the customized midsole will reduce pressure on the heel, increase comfort, and correct the center of pressure line and ankle angles towards a neutral position when compared to a barefoot control and a comparable shoe model.

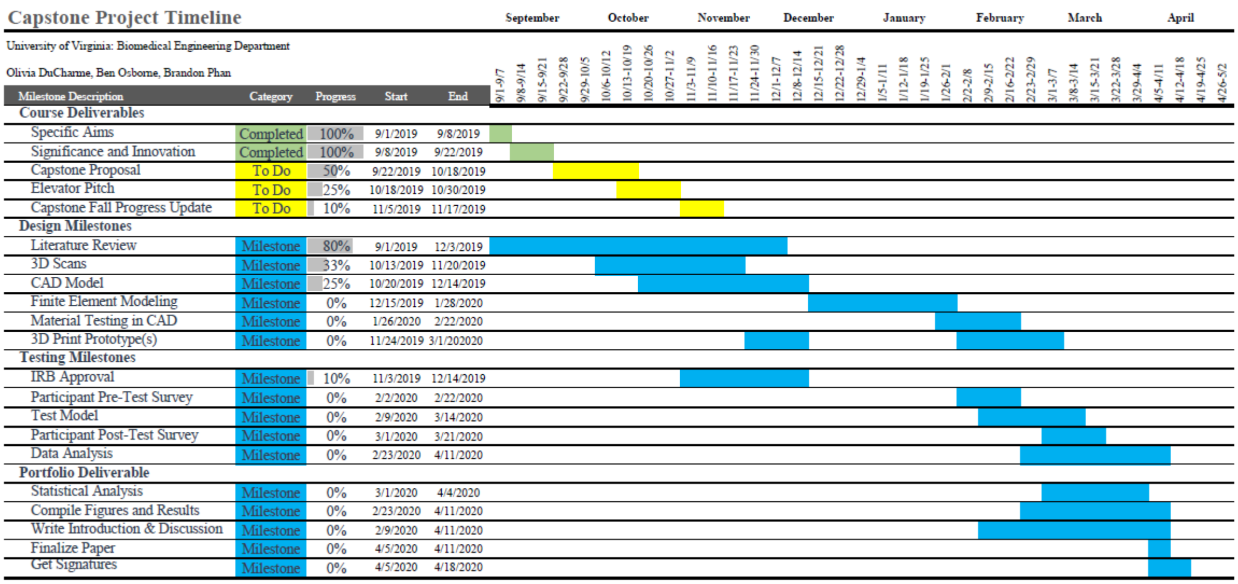

Figure 3. Gantt Chart Timeline for Completion of Tasks Related to the Technical Project Portion of the Thesis Portfolio (Image source: DuCharme, Osborne, & Phan, 2019)

Part II. STS Research Paper Topic: An Analysis of the Technical Evolution of Assault Rifles and the Impact on Emergency Medical Service Personnel

Introduction

According to the Small Arms Survey in 2007, of the estimated 650 million civilian owned firearms worldwide, United States civilians own approximately 270 million or just under 50% of all firearms (Berman, Krause, LeBrun, & McDonald, 2007). With civilian firearm ownership in the US exceeding countries plagued by violence and war, the US has endured mass shooting incidents at rates unparalleled by any other nation. Eighteen of the fifty deadliest global mass shootings have occurred on US soil—more than quadruple the next leading country (Dillinger, 2019). The proliferation of gun violence in the United States is an epidemic that threatens public safety. With the expiration of the Federal Assault Weapons Ban in 2004, assault style weapons became further integrated into society and caused considerable controversy over the dangers they pose to civilians (DiMaggio et al., 2019). The expiration led to an increase in active shooter incidents and production of assault weaponry, which contributed to the proliferation of high-profile gun violence events in the US in the twenty-first century (Blair & Schweit, 2014; Koper, Woods, & Roth, 2004). Due to the threat assault weaponry poses to public safety and the ongoing political debate regarding gun control, it is critical to understand the technical evolution of firearms and the resulting impacts on overlooked social groups such as EMS professionals.

Post-World War II Assault Weapon Advancement

The United States federal government currently regulates firearms using legislation based on originalist interpretations of the Second Amendment. Engineering advancements have fundamentally changed firearms, from how the trigger and reloading mechanisms have been altered to increase firing speed to the accessories that increase clip capacity or simulate automatic fire, which consequently changed their impact on society (ATF Bump-Stock-Type Devices, 2018). The most controversial weapons in the ongoing debate surrounding gun violence are assault weapons, which have received continuous public attention due to their involvement in many high-profile gun violence events in the US. This research paper will delve into the technical evolution of assault rifles in the post-World War II era and the consequential proliferation of gun violence. The focus of the technical discussion will revolve around the firing mechanisms of the weapons as well as supplemental accessories that augment firing capabilities. This technical research will demonstrate the evolving nature of firearms and illustrate the increased danger these weapons pose to society in an effort to prompt an informed discussion on the societal effect of these devices.

Sociotechnical Analysis of Assault Weapons on EMS Personnel

When discussing assault weaponry, it is critical to consider the societal effect. While it is widely accepted that firearms have a profound impact on society, as is demonstrated by political movements on the topic of gun control, not all societal effects are publicly broadcast. In addition to victims and their families who feel the aftermath of gun violence daily, EMS personnel are on the front lines of this public safety epidemic. Despite being shunned from the national gun violence conversation by the National Rifle Association (NRA) who urged medical professionals to “stay in their lane,” many physicians have publicly stated their perspectives in the gun violence debate with the #ThisISMyLane grassroots movement (Zheng & Mushatt, 2019). EMS personnel and medical professionals are a social group that experience the gun violence epidemic in a particular way and their experiences cannot be overlooked in this social and political debate.

In order to analyze the impact of assault rifle evolution on EMS personnel as a social group within society, the framework of descriptive technological determinism will be utilized. Technological determinism is the theory of historical development that views technological innovation as the primary motor for social, economic, and political change (Heywood, 2011). Descriptive technological determinism narrows the focus to the overarching idea that technology causes social change and that technological progress is fundamentally intertwined with social progress (Wyatt, 2008; Misa, 1988). Another view of technological determinism is that technological development is autonomous and occurs independent from external or social influences (Misa, 1988). While varying views of technological determinism exist based on the degrees of technological autonomy and influence over surrounding environments, the overarching theory is based in the notion that technological artifacts, such as assault weapons, are capable of influencing social, economic, and political spheres without human intervention (Wengenroth, 1998). These influences include the experiences EMS personnel who encounter the aftermath of gun violence inflicted by assault weaponry. This framework will facilitate analysis by viewing assault weapons as a determinant technology that has shaped of the EMS system in the US.

Another evaluative framework that will be used to analyze the sociotechnical relationship between assault weaponry advancements and EMS development in the US is the theory of technological citizenship. This theory evaluates how the rights and duties of citizens within a democratic system are impacted by technological development (Andrews, 2006). Citizen rights are broadly defined as knowledge access, public participation, informed consent, and reasonable risk exposure, while duties include technological literacy, problem engagement, and civic protection (Andrews, 2006). In order to make decisions on technological integration into society, it is critical to analyze the impact of the technology on the democratic society in which it is being adopted. For assault weapons, there is inherent risk due to the high-velocity projectile capabilities of firearms which could increase public risk exposure to an unreasonable level and decrease the ability to adequately protect the civic good of communities within the US. Additionally, legislative decisions surrounding assault weaponry have impacted technological literacy and problem engagement from the civilian population in the US. By utilizing this evaluative framework, the impact of assault weapons on overlooked social groups such as EMS personnel can be analyzed from the perspective of democratic citizenship, which will allow for an evaluation of the rights and duties of EMS personnel that are impacted by assault weapons.

Research Question and Methods

The research question motivating this paper is: how have assault rifles advancements post-World War II impacted the EMS in the United States? The methods that will be utilized to explore the question motivating this research paper will include historical analyses and case studies that illustrate the sociological and psychological effects of assault rifles and gun violence in the United States. Historical analysis will examine how societal experiences of firearms contributed to the United States' culture becoming increasingly gun-centric in the post-World War II era (Keaton, 2006). Additionally, research into the historical evolution of assault rifles through patent searches and firearm history timelines can provide insight into how the lethality of these weapons has evolved with their technical advancement, see Figure 4. Policy documents, such as the Public Safety and Recreational Firearms Use Protection Act (1994), will also be evaluated to provide legal definitions and to evaluate legislative decisions that impacted civilian access to assault weapons. A historical analysis on the development of standardized EMS procedures will be conducted to provide context on the evolution of the EMS that occurred in tandem with assault rifle advancement during the same time period, see Figure 4.

Relating the social effects to technical advancements will be achieved through rigorous analysis of case studies that delve into the EMS experience of gun violence. Firearm-related injury emergency department visits have been analyzed in case studies and provide statistics on the

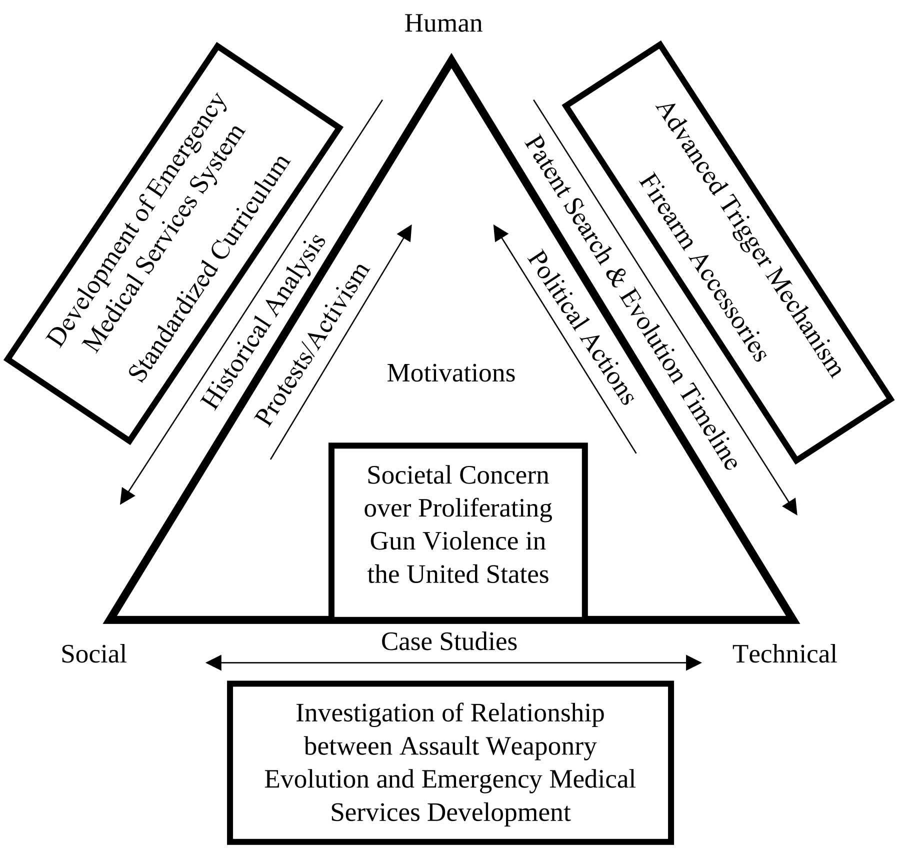

Figure 4. Human, Social, and Technical Connections of Assault Weaponry Advancement and the Emergency Medical Service System in the United States. A demonstration of the analytical methods and motivations for this sociotechnical analysis. (Image source: DuCharme, 2019)

injuries sustained, demographics affected, and economic burden (Gani, Sakran, & Canner, 2017; Moore et al., 2013). Another case study analyzes the ballistic traumas that EMS and emergency department personnel, particularly infectious disease physicians, are required to address following firearm-related injuries (Pinto et al., 2019). Additionally, Richardson, Davidson, and Miller (1996) conducted a study following a mass shooting with an assault weapon to analyze the psychological and social aftermath of the event. These case studies, coupled with the patents and timeline of assault rifle development, and reviewed through the lens of technological determinism, will provide a novel perspective on the societal impact of assault weapons on the civilian population.

Timeline & Expected Outcomes

In order to conduct the research for this sociotechnical analysis, I have established milestones throughout the remainder of the fall semester and the spring semester, see Figure 5. Research into case studies, historical analysis, and related relevant materials will continue throughout the writing process. The technical project will be conducted simultaneously to the research paper writing progress. Therefore, compilation of the thesis portfolio will occur as data and results become available from our design development and testing. All dates detailed in Figure 5 are subject to change as the paper progresses, but serve to provide a guideline for tasks to be completed and time management. The expected outcome from this research paper will be a product that provides social context to an ongoing political and social debate in the United States. It will allow for a more informed discussion on the lethality of assault rifles and the widespread impact by delving into the impacts on EMS personnel as a relevant social group.

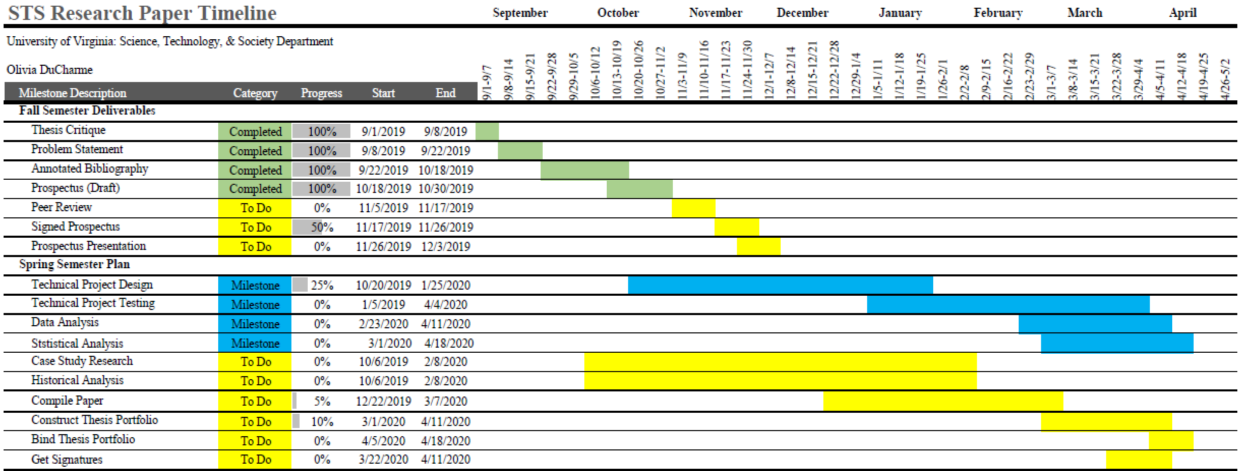

Figure 5. Gantt Chart Timeline for Completion of Tasks Related to the STS Research Paper Portion of the Thesis Portfolio (Image source: DuCharme, 2019)

Conclusion

As gun violence proliferated in recent decades and firearms have become more technically advanced, it can be expected that EMS practices and procedures have similarly evolved since the 1970s (Edgerly, 2013). To evaluate the social impact of assault rifle advancements, this research paper will explore how relevant medical procedures and emergency departments have developed. The focus will be on EMS training for firearm-related incidents and relevant emergency procedures that address bullet wounds. By analyzing how relevant medical practices and protocols have evolved in tandem with the expansion of assault rifle distributions, a sociotechnical relationship will be established to illustrate impacts that assault weapons upgrades have on EMS personnel.

References

Albert, S., & Rinoie, C. (1994). Effect of custom orthotics on plantar pressure distribution in the pronated diabetic foot. *The Journal of Foot and Ankle Surgery: Official Publication of the American College of Foot and Ankle Surgeons*, *33*(6), 598–604.

Andrews, C. J. (2006). Practicing technological citizenship. *IEEE Technology and Society Magazine, 25*(1), 4–5. https://doi.org/10.1109/MTAS.2006.1607713

ATF Bump-Stock-Type Devices, 27 C.F.R. § 447, 478, & 479. 2018

Berman, E. G., Krause, K., LeBrun, E., & McDonald, G. (Eds.). (2007). *Small arms survey 2007: Guns and the city*. Cambridge University Press.

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*. https://doi.org/10.1186/s12891-018-2131-6

Blair, J. P., and Schweit, K. W. (2014). A Study of Active Shooter Incidents, 2000 - 2013. Texas State University and Federal Bureau of Investigation, U.S. Department of Justice, Washington D.C. 2014.

Crary, N. (2002). *United States Patent No. US6457261B1*. Retrieved from https://patents.google.com/patent/US6457261B1/en

Crawford, F., Atkins, D., & Edwards, J. (2001). Interventions for treating plantar heel pain. *The Foot*, *11*(4), 228–250. https://doi.org/10.1054/foot.2002.0689

Dillinger, J. (2019). The Deadliest Mass Shootings in History. Retrieved from https://www.worldatlas.com/articles/the-deadliest-mass-shootings-in-history.html

DiMaggio, C., Avraham, J., Berry, C., Bukur, M., Feldman, J., Klein, M., Shah, N., Tandon, M., Frangos, S. (2019). Changes in US mass shooting deaths associated with the 1994-2004 federal assault weapons ban: Analysis of open-source data. *The Journal of Trauma and Acute Care Surgery*, *86*(1), 11–19. https://doi.org/10.1097/TA.0000000000002060

Edgerly, D. (2013). Birth of EMS: The History of the Paramedic. *Journal of Emergency Medical Services*, *38*(10).

Gani, F., Sakran, J. V., & Canner, J. K. (2017). Emergency Department Visits for Firearm-Related Injuries in The United States, 2006–14. *Health Affairs*, *36*(10), 1729–1738. https://doi.org/10.1377/hlthaff.2017.0625

Glen, S. (2015). Likert Scale Definition and Examples. Retrieved from https://www.statisticshowto.datasciencecentral.com/likert-scale-definition-and-examples/.

Hawke, F., Burns, J., Radford, J. A., & Du Toit, V. (2008). Custom-made foot orthoses for the treatment of foot pain. *Cochrane Database of Systematic Reviews*, (3). https://doi.org/10.1002/14651858.CD006801.pub2

Heywood, A. (2011). *Global politics*. Basingstoke: Palgrave Macmillan.

Keaton, A. (2006). Unholstered and Unquestioned: The Rise of Post-World War II American Gun Cultures. *Doctoral Dissertations*. Retrieved from https://trace.tennessee.edu/utk_graddiss/4263

Kita, K. (2002). *United States Patent No. US6389713B1*. Retrieved from https://patents.google.com/patent/US6389713B1/en

Koper, C. S., Woods, D. J., & Roth, J. A. (2004). *An Updated Assessment of the Federal Assault Weapons Ban: Impacts on Gun Markets and Gun Violence, 1994-2003*.

Misa, T. J. (1988). How Machines Make History, and How Historians (And Others) Help Them to Do So. *Science, Technology, & Human Values*, *13*(3/4), 308–331. Retrieved from JSTOR.

Moore, D. C., Yoneda, Z. T., Powell, M., Howard, D. L., Jahangir, A. A., Archer, K. R., Ehrenfeld, J., Obremsky, W., Sethi, M. K. (2013). Gunshot Victims at a Major Level I Trauma Center: A Study of 343,866 Emergency Department Visits. *The Journal of Emergency Medicine*, *44*(3), 585–591. https://doi.org/10.1016/j.jemermed.2012.07.058

Naemi, R., & Chockalingam, N. (2013). Development of a method for quantifying the midsole reaction model parameters. *Computer Methods in Biomechanics and Biomedical Engineering*, *16*(12), 1273–1277. https://doi.org/10.1080/10255842.2012.666795

Nagano, H., & Begg, R. K. (2018). Shoe-Insole Technology for Injury Prevention in Walking. *Sensors (Basel, Switzerland)*, *18*(5). https://doi.org/10.3390/s18051468

Nahin, R. L. (2018). Prevalence and Pharmaceutical Treatment of Plantar Fasciitis in United States Adults. *The Journal of Pain: Official Journal of the American Pain Society*, *19*(8), 885–896. https://doi.org/10.1016/j.jpain.2018.03.003

Peterson, W. R. (1998). *United States Patent No. US5782014A*. Retrieved from https://patents.google.com/patent/US5782014A/en

Pinto, A., Russo, A., Reginelli, A., Iacobellis, F., Di Serafino, M., Giovine, S., & Romano, L. (2019). Gunshot Wounds: Ballistics and Imaging Findings. *Seminars in Ultrasound, CT and MRI*, *40*(1), 25–35. https://doi.org/10.1053/j.sult.2018.10.018

Public Safety and Recreational Firearms Use Protection Act, H.R. 4296, 103d Cong. (1994)

Richardson, J. D., Davidson, D., & Miller, F. B. (1996). After the Shooting Stops: Follow-up on Victims of an Assault Rifle Attack. *Journal of Trauma and Acute Care Surgery*, *41*(5), 789.

Schwartz, E. N., & Su, J. (2014). Plantar Fasciitis: A Concise Review. *The Permanente Journal*, *18*(1), e105–e107. https://doi.org/10.7812/TPP/13-113

Stevenson, B. (2013) Plantar Fasciitis: An illustrated explanation of why your foot hurts. Retrieved from Why Things Hurt website: http://www.whythingshurt.com/plantar-fasciitis-an-illustrated-explanation-of-why-your-foot-hurts/

Wengenroth, U. (1998). Does Technology Drive History?: The Dilemma of Technological Determinism (review). *Technology and Culture*, *39*(4), 755–758. https://doi.org/10.1353/tech.1998.0088

Wyatt, S. (2008). Technological determinism is dead; Long live technological determinism. In E. Hackett (Ed.), *The handbook of science and technology studies* (pp. 165–180). Cambridge, MA: MIT Press.

Zheng, C., & Mushatt, D. (2019). Let’s Join the Lane: The Role of Infectious Diseases Physicians in Preventing Gun Violence. *Open Forum Infectious Diseases*, *6*(3). https://doi.org/10.1093/ofid/ofz026