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AN ABSTRACT OF THE THESIS OF

Mishal Albassam for the degree of Honors Baccalaureate of Science in Industrial and Manufacturing Engineering presented on February 21st, 2014. Title: The steps taken to design, select, and manufacture a shoe press for a small shoe manufacturing company

Abstract approved: ________________________________

Javier Calvo-Amodio, PhD

The purpose of this project was to research, design and build a shoe press for a local company called Soft Star Shoes. Soft Star Shoes were looking for different ways to replace their barking process, which is the process of attaching the rubber sole of the shoe to the upper leather. To perform this process, Soft Star Shoes used hammering, which was physically straining, caused operators to get frustrated, as well as, slowed the production process.

After receiving the problem description and customer requirements, a decision to go with an automated press was made. The team researched existing shoe presses to use as benchmarks in the design process. The team then performed ergonomic analysis to understand the severity of the problem, and stress-strain and reliability analyses to find maximum loads, and fracturing points. In addition, the team interviewed Soft Star Shoes barge employees to determine the requirements that needed to be met for the press to be considered a good replacement for the hammering process.

Using this information, the team designed and built a shoe press that meets the customer’s needs. The new device is a 17" by 17" by 12" press that is held by five vertical columns. These columns are attached to two 0.5" thick steel plates (one on the top and one on the bottom). The press is powered using a 115 V ball screw device, which is inserted through a hole in the top steel plate, and carries a 14” x 14” x 0.5” pressing plate. The device travels a vertical distance of 10” to perform the pressing process.

Tests were started upon finishing the design process. The tests were conducted based on the engineering requirements generated. The press passed all these tests, which meant that the team has achieved the sponsor’s needs. However, the project was not done at that point. The press was dirty and the steel was rusted. So cosmetic operations were performed. Cleaning, Painting and adding lights to the press were a critical factor in delivering a good-looking press. After completing the cosmetics, the press was delivered to the sponsoring company.

Furthermore, the press had a big impact on Soft Star Shoes’ production floor. It allowed the company to replace the existing barking process, which improved their ergonomic rating, as well as, their shoe output. Operators did not need to apply any physical force to barge the shoes, which reduced the chances of musculoskeletal disorders within the company's walls. In addition, the new press barged a pair of shoes in 4 minutes and 5 seconds, which meant more than a 60% improvement on the process output.
The steps taken to design, select, and manufacture a shoe press for a small shoe manufacturing company

By

Mishal Albassam

A THESIS

Submitted to

Oregon State University

University Honors College

In partial fulfillment of the requirements for the degree of

Honors Baccalaureate of Science in Industrial and Manufacturing Engineering (Honors Associate)

Presented Date: February 21st, 2014
Commencement: June 2014

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes the release of my thesis to any reader upon request.

Mishal Albassam, Author
ACKNOWLEDGEMENTS

I would like to acknowledge and extend my heartfelt gratitude to the following persons who have made the completion of this project possible:

My sponsor: Soft Star Shoes, for their vital encouragement and support.

My team members: Tim Soderlund and Curtis Shimotsu, for the work, energy and time they put in completing this project; the ideas they gave me for writing the report; and the help and support they extended me throughout this experience.

Dr. Calvo-Amadio, my advisor and mentor; for his assistance and direction throughout this project.

Dr. Hapaala and Mr. McGrath, my committee members; for their help, encouragement, and support.

Tracy Ann Robinson, Coordinator of the MIME Communications and Corporate Relations, for her direction, comments and much needed motivation.

Mr. Don Heer, for the help he extended.

All the MIME faculty members and Staff.

Dr. Parmigiani, Mrs. deTal, Mr. Atanasoy, and Rugh Electric for assisting the team in completing the project.

Most especially to my family and friends.

And to God, who made all things possible.
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DEDICATION

This thesis is dedicated to:

My father (Fuad), and my mother (Wafa), the two people that stood beside me along my journey and supported me in all my decisions.

My siblings, Faisal and Khalid, for their love, encouragement, and support.

My team members, Curtis Shimotsu and Time Soderlund, for their help in this project and report.

Dr. Calvo-Amadio, for his guidance and support.
1 INTRODUCTION

1.1 Background Information

Soft Star Shoes operates of a small factory in Corvallis, OR. Their factory manufactures minimalistic running shoes. Their original sole attachment process was physically and ergonomically demanding. The process, known as barging, involved individually hammering the sole fabric to the bottom of the shoe while glue adheres the two pieces. Due to the ergonomically stressing nature of this process, Soft Star Shoes asked the team to research, design, manufacture, and implement a more ergonomically friendly press that can glue the sole material to the top of the shoe efficiently and automatically. With a more ergonomic press, Soft Star Shoes can provide their employees a better work environment with higher standards of comfort and safety.

1.2 Original System

The original sole attachment system used by Soft Star Shoes lacked safety checks and strained the user. It involved the use of a rubber mallet and a hammering block (a steel plate about one square foot in size). The original methodology entailed placing the sole material onto the shoe and hammering it until the two materials have sufficiently adhered together by the glue that is applied between them beforehand.

This section describes the original system’s structure, the original system’s operation, and the original system’s deficiencies.

1.2.1 Original System Structure

The physical structure of the original system had a convenient setup that led to dependable material flow. There is not a lot of waste that goes in this system due to the minimal transportation involved. Figure 1 shows a layout of the current system.
The team worked on one part of this system, which is the hammering (barging) area. Barging tools and materials include a rubber mallet, latex gloves, a steel block to hammer on, a brush to apply the primer and glue, a vented drying rack, and the leather shoe and sole material.

Most of the machines that go in this system are sub-automatic, meaning they need an operator to be present at all times. These machines can be described as a sanding machine and a 3-in-1 trimming machine. In addition to these machines, there is an air-ventilated area where the shoes are placed after applying the adhesive for reasons of toxicity, and a storage area that has brushes and scissors. Furthermore, the sub-system that was replaced by the team’s design can be described as a hammer and a metal table to place shoes on while being hammered. One picture of the hammering area is shown in Figure 2 and more are attached in Appendix A.

![Figure 2: Shoe hammering process](image)

Further detail about the factory layout and station setup is restricted, as Soft Star Shoes has expressed hesitancy to publish this proprietary information.

1.2.2 Original System Operation

The original system proposed a risk of musculoskeletal disorders for operators. This was proved by the Rapid Upper Limb Assessment (RULA) completed (description of RULA is found in section 2.3.2). Results of that assessment dictate that the worker is exposed to limb fatigue, and indicated that the system needed to be changed immediately. A copy of the RULA assessment sheet can be found in Appendix B. Table 1, shows the steps that operators took to complete the original barging process. The team replaced steps 7-9 of this process.
Table 1: Soft Star Shoes’ original barging process

<table>
<thead>
<tr>
<th>Original Soft Star Shoes Barge Process Steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Open ventilated dry rack</td>
</tr>
<tr>
<td>2. Put on thick latex gloves</td>
</tr>
<tr>
<td>3. Apply primer to both shoe and sole and let them sit for roughly ten minutes</td>
</tr>
<tr>
<td>4. Apply Ortec glue to both shoe and sole and let them sit for roughly ten minutes</td>
</tr>
<tr>
<td>5. Place sole on hammering block with glued side up</td>
</tr>
<tr>
<td>6. Center and place shoe on sole material so glued sides touch each other</td>
</tr>
<tr>
<td>7. Use mallet to hammer down the middle of shoe</td>
</tr>
<tr>
<td>8. Use mallet to hammer inside the shoe and along its’ edge</td>
</tr>
<tr>
<td>9. Use mallet to hammer outside the shoe and along its’ edge</td>
</tr>
<tr>
<td>10. Quality check the shoe to ensure that the sole and saddle are adhered to the shoe bottom</td>
</tr>
<tr>
<td>11. Let glue cure overnight</td>
</tr>
</tbody>
</table>

1.2.3 Original System Performance

The following performance characteristics of the original system were gathered through multiple interviews with the company and its qualified barge workers. The team met with these workers on several occasions to have them individually describe the barging process and demonstrate how it is completed. This gave the team a broad experience base that enabled us to establish accurate performance data relating to process times, production volumes and production consistency.

Soft Star Shoes approximate their annual demand at 3,000-4,000 pairs of shoes. Their operating hours are 8 a day on a 5-day week. Looking at table 2 and given that there are 52 weeks/year, this gives a total of 2,080 hours/year for barging. Soft Star Shoes had a cycle time of 10/60 = 0.167 hours/pair (assuming that one operator does the whole process). Thus, the factory had a production capacity of 2,080/0.167 = 12,455 pairs of shoes annually. Table 2 shows the cycle times of each task within the barging process.

Although this would be more than enough if shoe orders were distributed evenly throughout the year, this is not the case at Soft Star Shoes. Holiday seasons bring a higher demand, which leaves Soft Star Shoes in a critical situation. In addition, idle times were often a problem at the gluing station. Moreover, Soft Star Shoes rarely had any quality problems with the original system; however, they did not have any way to measure the approximate pressure needed for each kind of sole. Thus, experiments that measured the amount of pressure needed to dis-attach each type of sole from the shoe were completed at the factory to serve as a baseline.
Table 2: Soft Star Shoes’ system performance

<table>
<thead>
<tr>
<th>Task</th>
<th>Time required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean the shoe</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Open the guard of the ventilated area</td>
<td>0.5 minutes</td>
</tr>
<tr>
<td>Turn on the ventilation</td>
<td>0.2 minutes</td>
</tr>
<tr>
<td>Apply Ortec adhesive to the sole and the upper shoe</td>
<td>1.5 minutes</td>
</tr>
<tr>
<td>Place them on the ventilation rack</td>
<td>0.2 minutes</td>
</tr>
<tr>
<td>Let the shoe sit</td>
<td>2 minutes</td>
</tr>
<tr>
<td>Apply a mix of Ortec adhesive and thinner to both the sole and the upper shoe</td>
<td>2 minutes</td>
</tr>
<tr>
<td>Place them on the ventilation rack and let them sit there</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Center the sole on the hammering table with the glued side facing up</td>
<td>1 minute</td>
</tr>
<tr>
<td>Manually attach the sole to the upper shoe</td>
<td>0.5 minute</td>
</tr>
<tr>
<td>Hammer the center and the sides of the shoe – System changed</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Check the quality of the shoe to ensure that it is in good shape</td>
<td>2 minutes</td>
</tr>
<tr>
<td>Let the shoe sit over night</td>
<td>18 hours</td>
</tr>
<tr>
<td>Move the shoe to the next process</td>
<td>1 minute</td>
</tr>
</tbody>
</table>

1.2.4 Original System Deficiencies

The original system did not satisfy many of the customer requirements dictated by this project. One fundamental issue with the system was the variable performance characteristics it had where results depended on which worker completed the barge process. It specifically did not meet customer requirements 2, 5, 7, and 11, found in section 3.1.1. The original system was very physically demanding as well as ergonomically stressing. All these factors resulted in an inconsistent product quality. Furthermore, the RULA analysis highlighted the physical stress characteristics of the original system, and ultimately pointed to the conclusion that the system should be immediately changed. The strong force applied resulted in overloading muscles and tendons. In addition, the hammering process was a loud process that left operators in other areas annoyed.

The barging process was also an inconsistent manual process. Its output depended on the physical state of the operator. The current system also defied some of the engineering requirements, found in section 3.1.2. A requirement like having no repetitive motion in the process was far from met. Integrated computer aided manufacturing for functional modeling (IDEF) diagrams, which are explained in section 2.3.2, were also drawn to breakdown the current state of the system. This clearly pointed out uncritical factors and allowed easier replacement. Copies of the IDEF diagrams can be found in Appendix C. Finally, the current system was not capable of supporting the growing seasonal production quantities necessary to meet increasing consumer demand. This is very detrimental to Soft Star Shoes as a business, and it further highlighted the importance of implementing a new system.
2 LITERATURE REVIEW

This chapter has three sections. The first discusses some of the designs available in the market. A description of the press, as well as, its system and subsystem levels is provided. The second discusses the negative effects of work-related disorders. And the third explains a testing technique used in evaluating the severity of work postures, and a computer aided manufacturing visual method.

2.1 Part 1: Existing Designs

In this section, methods of research and systems and subsystems of existing presses will be discussed.

2.1.1 Design Research

The barging process is an uncommon practice. This limited the design research to: Soft Star Shoes, the web, and press manufacturers. Research and benchmarking surrounding this project involved visiting Soft Star Shoes on several occasions and taking notes about their original process. This allowed the team to understand the original barging process and how it worked on a manufacturing level. In addition, the team researched advantages and disadvantages of some manufactured systems to distinguish how they meet customer requirements. Finally, the cost of each press design was looked into. Considering that most presses stress the project budget, the team then looked deeper into designs and methods for building a press that could satisfy customer and engineering requirements.

2.1.2 System Level

The following existing designs range from home-built presses to mass manufactured models. Each design has different pros and cons, but all were useful in helping the team generate potential new design solutions.

2.1.2.1 Existing Design #1 – Double Hydraulic Press

One existing design was a press manufactured by the Yuan Yi Precise Machinery Works Company. Pictured in Figure 3, the machine couples a hydraulic press with electronic controls. Its pressing time and pressure are also adjustable.
2.1.2.2 **Existing Design #2 – Pneumatic Press**

Another existing design consisted of fairly common materials and tools. The press, which is shown in Figure 4, is a hand built model that uses an air bladder to apply pressure to a secured shoe. Adjustments on the press are not user friendly, and take time. However, the design is cost efficient.

---

*Figure 3: Double hydraulic press.*


*Figure 4: Pneumatic press*

2.1.2.3 Existing Design #3 – Single Hydraulic Press

The single hydraulic press is a mass manufactured one. It can only press one shoe at a time, but according to reviews of the press through Hercules (the company that manufactures the press), it does it well. Speed and pressure of the press are adjustable via knobs on the machine. This press is shown in Figure 5.

![Figure 5: Single hydraulic press](http://www.shoesystemsplus.com/hercules-pneum.html)

2.1.2.4 Existing Design #4 – Pivoting Double Hydraulic Press

The Pivoting Double Hydraulic Press is an industrial version of the last design. The press will more likely meet production quantity requirements as it can press two shoes, one right after the other. Changeover time is reduced this way. A picture of this press is shown in Figure 6.

![Figure 6: Pivoting double hydraulic press](http://www.shoesystemsplus.com/benchpress.html)
2.1.3 Subsystem Level

The decomposition of the barging process consists of three subsystems: adapting to different shoe sizes, correct sole placement on each shoe, and adequate pressure applied to each shoe. In addition, sole placement has its own subsystems of centering the sole and the shoe, while the pressure applying process has subsystems of creating the force of pressure, and distributing that force evenly against the shoe sole. Figure 7 illustrates the functional decomposition of the process.

![Functional decomposition of the sole process](image_url)

Figure 7: Functional decomposition of the sole process

2.1.3.1 Subsystem # 1 – Shoe Sole Adaptation

This subsystem stems from a shoe press that must be able to adapt to all sizes and shapes of shoes. Thus, the team examined designs that must accommodate all shoe sizes. The designs examined were mainly through brainstorming and adjusting systems that were used in other settings to be used in shoe pressing.

2.1.3.1.1 Existing Design # 1- Multiple Shoe Lasts

Used to setup the hammering process at Soft Star Shoes, one of the designs used to accommodate the wide variety of shoe shapes and sizes is interchangeable shoe lasts. A last is a rigid template that fits inside a shoe, ensuring that the entirety of the shoe sole is pressed. They exist in all sorts of shapes and sizes. Including interchangeable lasts into our system will allow all shoe sizes to be pressed, however, this will require the user to setup the last before pressing each pair. If the lasts are heavy, this design will strain the user and could potentially cause ergonomic complications.
2.1.3.1.2  **Existing Design # 2 – Adjustable Air Bladder**

One design that is not common in the shoe industry is an adjustable air bladder. According to Aero Tech Laboratories, this design is mainly used to setup molds used in industries such as, defense, aerospace, and marine (atlinc.com). Following this design will help the team in meeting the customer requirement that the press be able to work on any shoe size. This air bladder will be large enough to press the largest shoes. It will inflate and conform to the right size for any shoe being pressed.

2.1.3.1.3  **Existing Design # 3 – Adaptable Last Pieces**

A method that is partially used by shoe accessory manufacturers, this design takes the concept of combining multiple pieces to create one solid object, and applies it to the last tool. It is better than the idea of having a single last design for each shoe because with this method, only one last exists. This last will allow the press to accommodate the smallest shoe sizes. If a larger shoe needs to be pressed, then last adaptation pieces can be secured to the press’ base.

2.1.3.2  **Subsystem # 2 – Sole/Shoe Placement**

To ensure that the sole covers the entire shoe, it needs to be placed in the right spot. If this does not happen then quality standards will suffer. Designs applicable to this subsystem must help ensure that the sole is centered below the shoe throughout the pressing process. Also, this placement must be repeatable and consistent from shoe to shoe.

2.1.3.2.1  **Existing Design # 1- Piston Regulated**

This design requires the piston that delivers pressure on the shoe to be centered on the sole material. The shoe has to be centered correctly over the sole as the piston presses and brings the shoe into contact with the sole. This will meet requirements of consistent production and correct sole placement from shoe to shoe.

2.1.3.2.2  **Existing Design # 2 – Material Cassette**

From the experience of Tim Soderlund, one of the team members, this design stems from a method that is common in the ski building industry. In order to ensure materials that comprise a ski are centered and positioned correctly, cassettes guide where each material type sits. These cassettes are secured and never move with relation to each other. A cassette could be applied to the shoe press design to allow the soles to be centered with relation to the shoe. The cassette can be designed to accommodate all sizes of soles. This will enable every shoe size to be pressed with one single cassette.

2.1.3.2.3  **Existing Design # 3 – Spray Adhesive with Guide Marks**

The use of guidelines that help printers position t-shirts is common in the screen-printing industry. This guideline allows designs to be printed in the right spot. In addition to these guide marks, the printer applies a sticky spray adhesion to secure the shirt in the right spot while
printing. This same methodology can be applied to shoe sole pressing. The worker can locate each sole with guide marks, and then secure the sole with adhesive spray before they initiate the press. This will help ensure that each shoe has its sole correctly lined up and steady. The ultimate result of this method will be a consistent sole adhesion from shoe to shoe.

2.1.4 **Subsystem # 3 – Apply Pressure**

Pressure creation and application is arguably the most important subsystem of the process. Without consistent pressure, the shoes will not have soles attached in a consistent manner. This will result in subpar production consistency. Designs for this subsystem must ensure that forces pressing the shoe to the sole are created in an easily repeatable fashion. They must also guarantee that pressure distribution throughout the shoe is consistent.

2.1.4.1 **Existing Design # 1 – Electric Vehicle Jack**

This existing design will serve as a way to apply pressure to the shoe sole in a consistent manner. An electric car jack can be used to push up on the bottom of a sole and press the shoe into a rigid metal or plastic last. Car jacks, although not common in the shoe industry, will easily be able to meet any high-pressure requirement that this project requires. They can lift an entire side of a truck up. In addition, an electric jack can be regulated to provide a consistent pressure throughout the press, as it increases pressure at a linear consistent rate.

2.1.4.2 **Existing Design # 2 – Hydraulic Piston Press**

This existing design is clearly a viable option. A hydraulic piston is arguably the most common device used to apply pressure. Its benefits are high, as it meets requirements of sufficient force application at regulated rates. In addition, a compressor that runs off of a 115 V electricity system can power it.

2.1.4.3 **Existing Design # 3 – Mechanical Ball Screw Design**

This existing design entails the use of a mechanical and electric ball screw system to create and distribute the forces that press the sole to the shoe. Ball screw devices convert rotary motion to linear motion and are most prominent within the aerospace industry, as they have a minimum efficiency of 90% (beaver aerospace and defense Inc.). For example, Boeing uses ball screws to convert the rotary movement of the wing flaps to linear movement (beaver aerospace and defense Inc.). The design is potentially applicable to this project because it can generate high forces at a completely consistent rate. This is done as a threaded rod spins a housing block that forces the press either up or down. An electric motor spins a threaded push rod and mechanically applies force to the sole. The press can be regulated through electronic controls, as seen within the airplane industry. An additional benefit to this design is that it does not involve the use of a compressor, which is loud. Rather, the design can be powered from a 115 V electricity source. Furthermore, Due to the ease of implementing electric controls and safety switches within the circuit of the ball screw drive motor, the design will create space for ergonomic changes. This will enable the team to analyze the best placement for such controls.
2.2 Part 2: Work-Related Disorders

A lot of studies were done to show that repetitive and forceful work is harmful to the human body, especially to the cardiovascular system. In this section, journal articles that relate repetitive work to bodily injuries will be examined and explained. Disorders such as carpal tunnel syndrome, upper limb musculoskeletal disorders, tendinitis, tenosynovitis, and posture issues will be looked at.

The first part of this chapter discusses carpal tunnel syndrome.

2.2.1 Carpal Tunnel Syndrome

Barging employees at Soft Star Shoes have to do a lot of manual, repetitive work. This type of labor causes a lot of problems in the cardiovascular system, and one of the most common disorders that affect the cardiovascular system is carpal tunnel syndrome. The national institute of neurological disorders and stroke (2012) state that carpal tunnel syndrome is a work-related disorder. It occurs when the median nerve becomes pressed or squeezed at the wrist. This causes a lot of discomfort to the worker, which might require them to stop working in some occasions. Scott Barnhart (1991) conducted tests on ski manufacturer workers. These workers, much like shoe manufacturer workers, are required to perform heavy, manual, repetitive work. His method included identifying the workers that clearly performed repetitive tasks. His team then performed a cross-sectional study that included electrophysiological testing, physical examinations and questionnaires to compare the prevalence of carpal tunnel syndrome between workers with repetitive and non-repetitive jobs. The results of his experiment, which was conducted on 400 employees, show that the symptoms of having paresthesias, or nocturnal pain were more common among workers with repetitive jobs than among those with non-repetitive ones. His results showed that 33.7% of the workers with repetitive jobs exhibited signs of pain, compared to only 18.8% of the workers with non-repetitive jobs.

Leclerc and Franchi (1998), on the other hand, conducted a study on several industrial sectors including the shoe industry. They discuss signs of carpal tunnel syndrome in repetitive industrial work. Their method was to perform physical exams on the workers and determine the relevance of that type of job to carpal tunnel symptoms. Their experiment was done on a total of 1,210 workers, distributed among 53 companies all of whom worked in repetitive environments. The results were then compared with the results of 337 workers who were in controlled work environments. Their experiment yielded that repetitive work was associated with carpal tunnel syndrome. Their results also showed that dissatisfaction with work, lack of job control, short cycle times, and having to press repeatedly with the hand were associated with the syndrome. The results of the experiment showed that 11.8% of the workers in repetitive environments reported pain in both hands, compared to only 2.4% for those in the controlled group.

These studies, although very different in nature and results, all point to one direction; that carpal tunnel syndrome has a direct relationship with repetitive work.

In the next part, a second but very similar type of repetitive work disorder is discussed. The type discussed is upper limb musculoskeletal disorders, which is pain that affects certain nerves, tendons, muscles, and supporting structures in the human body. Like carpal tunnel syndrome, upper limb musculoskeletal disorders are caused by repetitive and manual labor.

2.2.2 Upper Limb Musculoskeletal Disorders

The frequency of manual labor that barge employees perform on a daily basis makes them at risk of getting a lot of different types of musculoskeletal disorders. The health and safety executive (HSE) states that upper limb musculoskeletal disorder is a type of pain that affects the
nerves, tendons, muscles, and supporting structures of the upper body. It can affect soft tissues, muscles, tendons and ligaments and is mainly caused as a result of incorrect postures and working in unusual positions for long periods of time (HSE). Latko and Armstrong (1999) conducted a study to relate the significance of upper limb musculoskeletal disorders with work repetitiveness. In their study, they examined the relationship between repetitive work and upper limb discomfort, tendinitis, and carpal tunnel syndrome. Their study examined 352 workers from three companies and was conducted using a numerical scale that gave a result of 0 if no stress was exhibited and 10 if maximum stress was exhibited. Their results indicated that “repetitiveness of work was found to be significantly associated with prevalence of reported discomfort in the wrist, hand, or fingers (22% for workers in the low repetition jobs to 46.5% for workers in the high repetition jobs), tendinitis in the distal upper extremity (Prevalence rates increased from 4.2% for workers in low repetition jobs to 14.5% for workers in the high repetition jobs), and symptoms consistent with carpal tunnel syndrome (prevalence increased from 6.8% for workers in the low repetition jobs to 17.4% for workers in the high repetition jobs)” (248). These results asserted that repetitive work is directly related to upper limb discomfort, tendinitis, and carpal tunnel syndrome. The more repetitive work, the more pain the worker is going to exhibit, thus the more they are prone to disorders such as upper limb musculoskeletal disorders. In the case of Soft Star Shoes, workers have to work 8-hour shifts, doing repetitive work 75% of that time, which makes them extremely prone to repetitive work disorders.

Likewise, Leclerc and Landre (2001) conducted a study to determine the personal and occupational factors with respect to upper-limb disorders in occupations requiring repetitive work. They sampled 598 workers in five sectors. These workers had to complete a self-administered questionnaire, as well as, physical exams that were conducted over the course of 3 years. The results showed a 12.2% increase in the number of subjects who showed signs of pain after the three-year period ended.

These results show that repetitive work is directly related to upper limb musculoskeletal disorders. The higher the repetitions, the more prone to disorders the employee becomes.

Moving on, the next part of this section discusses a disorder called tendinitis, which affects the bones and muscles of certain areas of the body.

### 2.2.3 Tendinitis

Soft Star Shoes barge employees use their arms in an unconventional movement for most of the day. They have to hammer a shoe for 10 consecutive minutes, which exposes them to a lot of pain in their arms and hands. One of the problems that barge employees might face is a disorder called tendinitis. According to the Mayo clinic, tendinitis is an inflammation of the thick cord that attaches the bone to the muscle. Its main cause is repetitive work and could happen suddenly or develop over time. Frost and Bonde (2002) discussed the impact of repetitive work on developing shoulder tendinitis. The method they used was to examine 1,961 workers in highly repetitive environments. They asked workers to report the pain they felt on four scales, each ranging from 0-9. The four categories they chose were: “severity of worst and average pain within the last 3 months, severity of average pain within the last 7 days, and severity of impairment of daily activities within the last 3 months due to shoulder pain. Zero indicates no pain or impairment and nine indicates worst possible pain or impairment” (14). Their results were not conclusive, however, they noticed that workers who worked in repetitive environments had a 40% increase in the prevalence of getting shoulder tendinitis.

Likewise, Svendsen and Bonde (2004) examined the relationship between shoulder tendinitis and repetitive work. They used 1,886 male workers from three different occupational groups. They then sampled 72 random subjects for four consecutive days. Individual work histories were obtained and physical examinations were performed to detect the symptoms. Their conclusions
were that highly elevated arms (above 90 degrees) increased the chances of shoulder tendinitis with an average odds ratio\(^1\) of 1.  

In addition, Armstrong and Fine (1987) discuss the implications of high repetition jobs on hand and wrist tendinitis. They said, “Epidemiologic data show that the risk of hand and wrist tendinitis in persons who perform highly repetitive and forceful jobs is 29 times greater than in persons who perform jobs that are low in repetitiveness and force” (830). They also suggest that risks of tendinitis can be reduced by decreasing the amount of repetitiveness and forcefulness of the work, however, they were clear that this hypothesis has not been fully tested.

Stenlund and Hagberg (1993) performed another study as well. Their study compares categories of construction workers. It was conducted on 207 workers who are bricklayers, rock blasters or foremen. Their method included conducting structured interviews, performing clinical examinations that looked at medical histories, and working on a detailed shoulder examination. Their results reported that the higher the vibration, the higher the risk. Their reported odds ratio was 2.49 for the left side and 1.86 for the right side.

Again, all these studies show that repetitive work has a direct relationship with tendinitis and other cardiovascular disorders.

Moving on, the next part in this section discusses tenosynovitis, which is a disorder that affects the cords that attaches the bones to the muscles.

### 2.2.4 Tenosynovitis

Soft Star Shoes barge employees face a lot of challenges in their everyday job. They are required to perform a lot of hard repetitive labor. Tenosynovitis is another disorder that might affect their muscles and daily lives. According to the US national library of medicine, tenosynovitis is an inflammation of the cord that connects muscles to bones. It is one of the most common work repetition diseases. This disorder is caused by infection, injury, overuse, or strain to the tendon.

Tuulikki and Ilkka (1979) examined the prevalence of tenosynovitis and other injuries of the upper extremities in repetitive work, specifically in packaging and shop assistant jobs. They examined a total of 163 female assembly line packers and 143 female shop assistants. These females had an average age of 39 years and had been employed for 6 years. The method they used to test these subjects was by assessing their medical histories, observing the workers in random days, and diagnosing the syndrome using a criteria developed by a group of specialists. The results, on the other hand, were that 37% of the packers and 28% of the shop assistants had neck problems, while 18% of the packers and 10% of the shop assistants had some kind of upper limb problems.

Likewise, Thompson and Plewes (1951) examined different cases where workers had tenosynovitis. They then investigated possible causes for the injuries and reported results. Their results stated that 77% of the objects reported radial extensor, abductors of the wrist and thumb injuries. And out of these 77%, 16.5% were because of repetitive movements.

Also, Roto and Kivi (1984) assessed the effects of forceful work on meat cutters. Their analysis included 90 meat cutters and 77 construction referents. They analyzed their subjects by instructing them to fill out a self-administered questionnaire about subjective symptoms of the upper extremities. They then examined the subjects and reported that tenosynovitis was present in 4.5% of them.

Again, these results show the implications of repetitive work on tenosynovitis, and although it is not as severely related to repetitive motion as the other disorders, it is still a concern and a problem for workers in highly repetitive and force requiring environments.

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\(^1\) Odds ratios indicate the relationship strength between a given variable and the outcome when compared to the other variables. Odd ratios simply compare odds of an event happening (Szumilas, 2010).
The next part of this section discusses different posture issues. These issues are big contributors to musculoskeletal and other work-related disorders because operators might not realize the impact of their postures on their health.

2.2.5 Posture Issues

Employees at the barging station spend 6-7 hours a day hammering. This process requires them to adopt unconventional postures, especially when it is late in the day or when tiredness has gotten the best of them. Eui Jung (1996) discusses the limitations of the human body by doing a regression analysis on several factors. She states that the human body has hundreds of degrees of freedom, which gives us great flexibility and redundancy, but makes it hard to get accurate experimental results. However, a simplified representation can be achieved under the following assumptions: “Upper limb is symmetrical about the sagittal plane; lower limb is fixed and the L5/S1 joint functions as a virtual joint in upper body; hip rotation, wrist rotation and wrist abduction-adduction is minimized during the reach activities within the comfortable reach area” (177). In her study, the author states that the worker will adopt the most comfortable position while performing the job, however, the most comfortable is not necessarily a healthy posture. This tendency often requires the worker to adopt a weird posture, which in turn leads to a lot of ergonomic issues.

Likewise, Kivi and Mattila (1991) present statistics that were obtained from occupations within the building industry. The building industry, like many other industries that require manual labor, emphasizes on forceful actions and heavy lifting. Their statistics stated that occupational diseases in Finland show that, in 1988, 46.2% of all occupational diseases were caused by physical work load. They also stated that, in the same year, 19.1% of all occupational injuries in Finland were caused by physically heavy tasks. They used a method called OWAS (Ovako Working Posture Analysis System), a system that analyses work postures to conduct a broader analysis. This system uses four-digit codes to describe positions of the back, arms, and legs, and the force needed on each of them. They then added a fifth code to specify the activity in question so it becomes easier to connect the poor postures with the work methods used. They observed a total of 6,457 postures in 30 second intervals and 1.5 hours per task. Their results indicated that poor postures were present at an average of 10.1% for 12 different jobs within the construction business. The highest were the cement workers with 27.8% and lowest were electricians with 1.9%.

All these work-related disorders can be related to barging employees at Soft Star Shoes. With hammering specifically, operators have to bend their backs to get more force. This posture, force requirement, and repeatability, although less harmful in the short term, will have very severe consequences in the long term.
2.3 Part 3: Testing Techniques

This section of the chapter discusses the different testing techniques used to understand the severity of the problem. These testing techniques are rapid upper limb assessment and integrated computer aided manufacturing for functional modeling.

2.3.1 Rapid Upper Limb Assessment (RULA)

McAtamney and Corlett (1993) state that RULA is a method developed for the evaluation of posture, force and muscle use. Part of this tool’s development took place in the garment-making industry. The developers assessed operators who participated in tasks like cutting, sewing, clipping, inspection, and packing. They developed it by evaluating the postures adopted, forces required, and muscle actions of operators in risk of upper limb disorders.

RULA uses diagrams of body postures and three scoring tables to provide evaluation of risk factors. These factors are called external risk factors, which include: number of movements, static muscle work, force, work posture, and time worked without a break.

In addition, they state that RULA uses two different groups to evaluate different segments, groups A and B. Group A includes the upper and lower arm and wrist, while group B includes the neck, trunk and legs. These groups are then given different codes to evaluate different risk factors. The range of movement of each body part is divided into different segments. Each segment is then numbered so that 1 is given to the natural body position and higher numbers are given to extreme postures. If there is additional motion that could not be described by the scoring method, an explanation of the additional scoring can be found next to the diagram.

After getting the scoring methods of each different muscle group, a single score must be developed for each group. Each score will represent the level of loading of the musculoskeletal system due to the combined part postures. Finally, these two scores must be combined to a single score through methods explained on the RULA sheet. This final score serves as a guide to the priority of subsequent investigation. For example, a score of 1 or 2 indicates that posture is acceptable if it is not maintained or repeated for long periods, while a score of 7 means that investigation and changes are immediately required.

2.3.2 Integrated Computer Aided Manufacturing for Functional Modeling (IDEF)

Sandie Kapps (1997) states that IDEF models have been used to analyze business processes and identify business process improvement opportunities. This model helped in identifying over 1,400 improvement opportunities for the Department of Defense. Another major outcome of this process has been the vast amount of knowledge gained on the business processes examined. To develop an IDEF model, a rigorous method with definite rules must be followed. This method involves following a detailed structured form and decomposing it to the lowest level needed for the analysis. To regard an IDEF model complete, the questions posed by the analysis must be answered by the information in the model.

An example of the structure used to form the IDEF model is shown in figure 8.
The top level in this model represents the subject of the analysis, and it is always called A0. The other levels (children of the parent) are then called based on their appearance in the chart. The parent’s number and a unique number must represent each child after the second level. For Example, the first number in A11 represents the parent’s (A1) while the second is unique to that child.

Moreover, each child represents a certain activity of the parent, and in each activity, four types of data are collected. These are:

1. Inputs: Data used to produce an output.
2. Controls: Data that constrains the transformation of inputs to outputs.
3. Outputs: Data resulting from the activity.
4. Mechanisms: Resources that help perform the activity.

These along with the different activities and processes are used to simplify, analyze and improve the final process.

### 2.4 Literature Review Conclusions

This chapter provided the information needed to setup the methodology and further understand the scope of the project. The first section of this chapter, which discussed the existing designs, helped the team gather information about different types of presses and systems that powered them. The second section, on the other hand, allowed the team to understand the severity of the current system on the operator’s upper body. Carpal tunnel syndrome, upper limb musculoskeletal disorders, tendinitis, tenosynovitis, and posture issues exposed some of the dangers of such an intensive manual repetitive process. After performing the first two steps in understanding the problem, two testing techniques were used to quantify and visualize the severity of the problem. The RULA sheet was used to quantify the severity of the problem, while IDEF diagrams were used to enhance the understanding of the system.

Furthermore, studying the existing designs, the work-related disorders, and the results provided by the RULA and IDEF analyses enhanced the team’s project understanding and helped define its scope. This further helped in converting the customer requirements to engineering requirements.
3 METHODOLOGY

This chapter discusses the methodology used in this project and provides the founding bricks to the next chapter, which explains the designs considered.

3.1 Engineering Design Process

To solve this project, the engineering design process was used. Yousef Haik (2003) and the Accreditation Board for Engineering and Technology (ABET) state that the engineering design process is a process of devising a system, component, or process to meet desired needs. The steps of this process are: defining the problem, performing background research, specifying requirements, brainstorming solutions, choosing the best solution, building a prototype, testing, and redesigning. During this process, it is very common to perform up to ten iterations to solve existing issues or to find new solutions. Moreover, specifying the requirements of the project is arguably the most important step in the method. In this step, engineers relate the requirements they get from their customers with measurable engineering requirements. They then devise testing procedures to make sure that these engineering requirements are met. To relate these requirements together in an easier way, engineers often construct a house of quality.

This chapter discusses customer requirements (CRs), engineering requirements (ERs), testing procedures (TPs), and design links (DLs). A house of quality (HoQ) that links all these components is also presented. The HoQ can be found in Appendix D.

3.1.1 Customer Requirements (CRs)

Customer Requirements reflect the customer’s specifications of the system desired. These requirements are typically given weights to demonstrate their relative technical importance. Following are the final customer requirements along with their respective weights. An LTE weight means low technical effort but while it carries a zero numeric value, the associated CR must be satisfied.

1. Make a press (35)
   Soft Star Shoes specified that the team should design and build a press. This requirement was given the highest weight because none of the other requirements could be met without having a press.

2. Quiet machine (30)
   Soft Star Shoes stressed that the press should be quiet because the company is above a music store and loud noises will be very disrespectful to their neighbors. In addition, the sponsor stated that tests proved 80 dBs to be the highest acceptable noise pollution in the factory.

3. Self-contained (30)
   Soft Star Shoes specified that the machine should be self-contained and should not need any outside pressure system to operate. This requirement was given a high weight because the machine would be a safety hazard if this requirement was not satisfied.

4. Short pressing time (15)
   Soft Star Shoes has a business that requires them to produce more than 2,000 pairs of shoes a year and long pressing times will deprive them of that. This requirement was given a medium weight because the company needs to have an adequate cycle time.
5. **Ergonomic (30)**

Soft Star Shoes wanted to change their original barging process because it is not ergonomic. This requirement is especially important because the sponsor strives for high worker safety and health. The high weighting was given based on the importance of ergonomics, as well as, the insistence of the sponsor on building an ergonomic factory.

6. **Fits in a small area (20)**

The press needed to fit in a specified area in the factory. If the team designed and built a press that did not fit in the specified area, then the press will be useless. The high weighting was given to this requirement because the press will be a problem if it did not fit in the specified area.

7. **Delivers consistent pressure (30)**

Soft Star Shoes stressed that the press should deliver the same amount of pressure throughout the shoe. The high weighting was given to this requirement because Soft Star Shoes would have to deal with a lot of complaining customers and useless shoes if the press did not deliver consistent pressure.

8. **Moveable (LTE)**

Soft Star Shoes said that it would be fine to have a press that requires up to five men to lift. The only reason they wanted a moveable press is because of a possible factory expansion.

9. **Accommodates all sizes (20)**

Soft Star Shoes stressed that the press has a cushion that fits all sizes of shoes. Being a custom shoe manufacturer, Soft Star Shoes design shoes for both children and adults. Having this requirement was one of the critical factors to the success of the project, and that was the reason behind giving it a medium-high weighting.

10. **Works for different types of shoes (20)**

Soft Star Shoes specified that the press should press all kinds of flat shoes. The reason for the medium-high weighting was because the press needed to press all kinds of flat shoes otherwise they will be pressed using the current barging process, which will defy other requirements of the project.

11. **Short changeover time (10)**

Soft Star Shoes explicitly stated that the press should have an adequate changeover (C/O) time. Soft Star Shoes is a small company that processes their orders by small batches of less than nine un-identical pairs. That being said, it would be very inconvenient to have a long C/O time after every shoe processed. The medium weighting was given to this requirement because this problem can be fixed with rearranging the order priority process.

12. **Safe (10)**

The sponsor stressed the importance of having a safe environment throughout the company. A medium weighting was given because it was very important for the press to operate safely to avoid unexpected circumstances.
3.1.2 Engineering Requirements (ERs)

ERs were developed for each of the customer requirements provided in the previous section. These requirements provide the team with measurable specifications. Table 3 relates each CR to its corresponding ERs and states the target values the team needed to meet, as well as the acceptable tolerances. Some ERs were joined in description because they are related to each other.

Table 3: Description of the ERs developed

<table>
<thead>
<tr>
<th>CR</th>
<th>ERs</th>
<th>Targets and Tolerances</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Make a Press</td>
<td>Shall not exceed $5,000</td>
<td>3,500 &lt; 5,000 [S]</td>
<td>The sponsor provided us with a maximum of $5,000. Our design will be approved, as long as our expenses do not exceed this value.</td>
</tr>
<tr>
<td>2. Quiet Machine</td>
<td>Shall not exceed 80 dB if standing next to the machine</td>
<td>75 &lt; 80 [dB]</td>
<td>80 dB should be the maximum sound level produced if a person is standing next to the press. As long as the sound level is less than 80 dB, the press will be approved.</td>
</tr>
<tr>
<td>3. Self-Contained</td>
<td>Shall not have an external pressure system</td>
<td>Yes, Yes</td>
<td>The press needs to produce pressure in a concealed environment. One example is a completely sealed air compressor.</td>
</tr>
<tr>
<td>4. Short pressing time</td>
<td>Shall take less than 5 minutes to press a pair</td>
<td>4 +/- 1 [min]</td>
<td>Due to the demand of Soft Star Shoes, the company needs a rapid cycle time.</td>
</tr>
<tr>
<td>5. Ergonomic</td>
<td>Should not involve any repetitive manual work</td>
<td>Yes, Yes</td>
<td>Due to ergonomic issues, any repetitive work was forbidden by the sponsor.</td>
</tr>
<tr>
<td></td>
<td>Shall stand at 3 ft. above the ground</td>
<td>2.7 +/- 0.3 [ft]</td>
<td>The appropriate height was specified, by the sponsor, to be 3 feet.</td>
</tr>
<tr>
<td>6. Fits in a small area</td>
<td>Shall fit in a 5' X 5' area</td>
<td>4 X 4 &lt; 5 X 5 [feet]</td>
<td>The sponsor specified that the press should be able to fit in a 5' X 5' area.</td>
</tr>
<tr>
<td></td>
<td>Press length shall be &gt; 12.5&quot; (size 16)</td>
<td>13 &gt; 12.5</td>
<td>The press should accommodate two shoes being placed next to each other. The shoe width is ~ 2.5”, and its maximum length is ~ 12”.</td>
</tr>
<tr>
<td></td>
<td>Press width shall be &gt; 5&quot;</td>
<td>5.5 &gt; 5 [inches]</td>
<td></td>
</tr>
<tr>
<td>7. Delivers consistent pressure</td>
<td>Should not damage shoe</td>
<td>Yes, Yes</td>
<td>Damaging the shoe would hurt the sales and reputation of Soft Star Shoes, thus having a quality product is critical.</td>
</tr>
<tr>
<td>8. Moveable</td>
<td>Shall weight less than 400 lbs.</td>
<td>375 &lt; 400 [lbs]</td>
<td>The sponsor specified that the press should weigh less than 400 lbs. if placed on a certified scale</td>
</tr>
<tr>
<td></td>
<td>Press length shall be &gt; 12.5&quot; (size 16)</td>
<td>13 &gt; 12.5 [inches]</td>
<td>Explained in CR # 6</td>
</tr>
<tr>
<td></td>
<td>Press width shall be &gt; 5&quot;</td>
<td>5.5 &gt; 5 [inches]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shall stand at 3 ft. above the ground</td>
<td>2.7 +/- 0.3 [ft]</td>
<td>Explained in CR # 5</td>
</tr>
<tr>
<td>CR</td>
<td>ERs</td>
<td>Targets and Tolerances [unit]</td>
<td>Description</td>
</tr>
<tr>
<td>----</td>
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<td>-------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>9. Accommodate all sizes</td>
<td>Press length shall be &gt; 12.5&quot; (size 16)</td>
<td>13 &gt; 12.5 [inches]</td>
<td>Explained in CR # 6</td>
</tr>
<tr>
<td></td>
<td>Press width shall be &gt; 5&quot;</td>
<td>5.5 &gt; 5 [inches]</td>
<td>All types of flat shoes will be pressed using the press.</td>
</tr>
<tr>
<td>10. Works for different types of shoes</td>
<td>Shall work for flat shoes</td>
<td>Yes, Yes</td>
<td></td>
</tr>
<tr>
<td>11. Short C/O time</td>
<td>Shall have &lt; 5 minutes C/O time</td>
<td>4.5 +/- 0.5 [mins]</td>
<td>Due to the high demand, it would be inconvenient if operators had to change fixtures every time.</td>
</tr>
<tr>
<td></td>
<td>Should not need to change fixtures when changing sizes</td>
<td>Yes, Yes</td>
<td></td>
</tr>
<tr>
<td>12. Safe</td>
<td>Shall have a covered On/Off button</td>
<td>Yes, Yes</td>
<td>A mistake should not operate the press. That is why it is important to have a covered on/off button.</td>
</tr>
</tbody>
</table>

### 3.1.3 Testing Procedures (TPs)

Below is a description of the testing procedures used to ensure that every ER was satisfied by the press. Testing results are documented in the chapter 5.

**ER # 1. Shall not exceed $5,000**

TP #1: Check the receipts that the team accumulated (visual test).

**ER # 2. Shall not exceed 80 dB if standing next to the machine**

TP #2: Use decibel meters to measure the sound. Decibel meters will be 10 feet from the device, at 3 different locations around the press. This will test how loud the press is in different places throughout the factory (instrument test).

**ER # 3. Shall not have an external pressure system**

TP #3: Check whether there is an external pressure device needed to operate the press or not. In this case, external refers to a system not directly attached to the press (visual test).

**ER # 4. Shall take less than 5 minutes to press a pair**

TP #4: Check with a stopwatch, the smallest and largest shoe pressing cycle times (time instrument test).

**ER # 5. Should not involve any repetitive manual work**

TP #5: Check if there is repetitive manual work in the process (visual test).
ER # 6. Shall fit in a 5’ X 5’ area

TP # 6: Use a tape measurer to get the dimensions of the press (measurement test).

ER # 7. Shall weigh less than 400 lbs.

TP # 7: Place on a certified scale (instrument test).

ER # 8. Press length shall be > 12.5” (size 16)

TP # 8: Use a tape measurer to get the dimensions (measurement test).

ER # 9. Press width shall be > 5”

TP # 9: Use a tape measurer to get the dimensions (measurement test).

ER # 10. Shall stand at 3 feet above the ground

TP # 10: Use a tape measurer to get the dimensions (measurement test).

ER # 11. Shall have < 5 minutes C/O time

TP # 11: Use a stopwatch to document the amount of time needed to change shoe sizes (time trial measurement test).

ER # 12. Should not need to change fixtures when changing sizes

TP # 12: Press two different shoe sizes and check them for defects (pressing and visual test).

ER # 13. Shall work for flat shoes

TP # 13: Press two different kinds of shoes and check them for defects (pressing and visual test).

ER # 14. Should not damage shoes

TP # 14: Press a shoe and visually check whether the shoe has press related damages or not (visual test).

ER # 15. Shall have a covered On/Off button

TP # 15: Check whether the on/off button is covered or not (visual test).
3.1.4 Design Links (DLs)

Below is a description of the design links that were followed to ensure that the selected design, described in section 4.2 satisfied the project’s ERs.

**ER # 1. Shall not exceed $5,000**

DL # 1: The material and manufacturing costs of the press shall not exceed $4,000. This will leave a $1,000 buffer for any issues that arise after the manufacturing process.

**ER # 2. Shall not exceed 80 dB if standing next to the machine**

DL # 2: The electric motor that powers the ball screw device shall not exceed 80 dB. This is the loudest part of the press. As long as the motor is lower than 80 dB, this ER will be satisfied. The motor sits on top of the press and the enclosure will not conflict with any other part. The dB meter used to measure the loudness of the machine will be placed 10 feet from the press, at three different locations throughout the factory floor. The meter will record sound levels throughout the pressing process to ensure that the sound limit is not exceeded.

**ER # 3. Shall not have an external pressure system**

DL # 3: The design did not require the installation of an external pressure source, such as a pressure system installed throughout the factory of Soft Star Shoes. Since the pressure force is built from a mechanical and electrical source, a compressor system was not necessary. The motor was capable of running off of a standard shop power i.e. 115 volt single-phase power.

**ER # 4. Shall take less than 5 minutes to press a pair**

DL # 4: The pressing system shall not take more than 4.5 minutes to complete each pair. This will leave 0.5 minutes for shoe change outs. The ball screw device will have to engage and disengage within the 5-minute time period, thus the motor that powers the device will need to meet certain rpm requirements.

**ER # 5. Should not involve any repetitive manual work**

DL # 5: The press was automated. The purpose of the repetitive manual work was to deliver pressure that adheres the sole to the shoe. The ball screw device delivers ample and consistent automatic pressure to the shoe and sole. The motorized ball screw device eliminated the necessity for repetitive manual work, creating a more consistent and ergonomically friendly process.

**ER # 6. Shall fit in a 5’ X 5’ area**

DL # 6: The press design including the ball screw device shall fit in a 5’ X 5’ area.

**ER # 7. Shall weight less than 400 lbs.**

DL # 7: The press system, including the ball screw pressure device and drive unit, will weigh less than 400 lbs.
ER # 8. Press length shall be > 12.5” (size 16)

DL # 8: The press design incorporated a press pad that fits all shoe sizes. This requires the system to have a pressing length greater than 12.5 inches. Thus, the press pad will be at least 12.5 inches in length.

ER # 9. Press width shall be > 5”

DL # 9: The press pad width shall be greater than 5” in order to accommodate all shoe sizes.

ER # 10. Shall stand at 3 feet above the ground

DL # 10: To satisfy ergonomic standards, the press stood 3 feet above the ground. This enabled the user to meet their natural position and minimize strain and stress on the body.

ER # 11. Shall have < 5 minutes C/O time

DL # 11: Removing one pair of shoes and installing another pair will not exceed 5 minutes. This includes any tool and part changes.

ER # 12. Should not need to change fixtures when changing sizes

DL # 12: Pressing platforms will not be changed to press each pair. By having an adaptable pressing platform, the user will not need to install a new press platform for each different shoe size.

ER # 13. Shall work for flat shoes

DL # 13: The pressing area is designed for all types of flat shoes. Additionally, pressing lasts will be supplied, if needed.

ER # 14. Should not damage shoes

DL # 14: The press will have a malleable press pad that evenly delivers the pressing force throughout the shoe area. This will reduce any strain on the pressed shoe. Additionally, if a last is necessary, one can be inserted to limit the locations of pressing.

ER # 15. Shall have a covered On/Off button

DL # 15: The button to initiate the press will be electric and covered with a safety case made from aluminum. This will reduce the risk of accidentally pressing the button.
4 DESIGN CONSIDERATIONS AND RESULTS

This chapter discusses the different designs that the team considered viable, and describes the design chosen by the team.

4.1 Designs Considered

The team agreed that the best press convention designs were a pneumatic press, a manual press, a ball screw press, and a hydraulic press. Both the hydraulic and ball screw presses were evaluated with a C-shape frame and a multiple-column frame.

In this section, the team will compare each of the designs listed above to the sub systems presented in section 2.1.3.

4.1.1 Design # 1 - Ball Screw with C-Shaped Frame

This electrical and mechanical press utilizes a ball screw device that enables the user to have an open interface to work with and place shoes around. The ball screw device can use standard shop power to run the single-phase 115 V motor. An air bladder and a pressure gauge will be installed to help gauge the pressure, but actual pressure controls will be through an electric control interface. The C-shaped frame requires expensive materials and machine work to build. This is a direct result of the moment that will be created from the ball screw device to the frame while pressing. This moment will need to get supported through a very strong metal frame to be able to handle these forces. This will result in a heavy frame. Furthermore, this design will meet all the CRs and ERs of this project.

Table 4 compares the functionality of a ball screw C-shaped frame press to each criterion presented in the functional decomposition.

<table>
<thead>
<tr>
<th>Pros and cons of a C-shaped frame ball screw press</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional decomposition criterion</strong></td>
</tr>
<tr>
<td>Shoe size adaption</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Sole placement</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Applying pressure</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
A drawing of the proposed design is presented in Figure 9.

Figure 9: C-shaped ball screw press design

4.1.2 Design # 2 - Manual Press

A manual press will be the easiest choice due to the minimal number of parts needed to build it. It does not need electronic boards/controls or power sources. However, it does not fulfill CRs 4, 5, and 7. Furthermore, Table 5 compares the functionality of a manual press to each criterion presented in the functional decomposition.

Table 5: Pros and cons of a manual press

<table>
<thead>
<tr>
<th>Functional decomposition criterion</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoe size adaption</td>
<td>Easy to adapt press to shoe size</td>
<td>Air bladder will allow for bigger room</td>
</tr>
<tr>
<td>Sole placement</td>
<td>A lot of room to place the sole</td>
<td>Adjustable rack</td>
</tr>
<tr>
<td>Pros and cons of a manual press</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Functional decomposition</strong></td>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td><strong>criterion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applying pressure</td>
<td>Pressure system easily adjusted</td>
<td>Not ergonomic</td>
</tr>
<tr>
<td></td>
<td>Quiet</td>
<td>Hard to apply consistent pressure</td>
</tr>
</tbody>
</table>

A drawing of the proposed design is presented in Figure 10.

4.1.3 Design # 3 - Pneumatic Press

A pneumatic press has a great potential of succeeding because it does not need as much sophistication and extra parts as the other presses need. Additionally, it meets all the CRs and ERs. A pneumatic press will need minimal power, as well as, minimal controls. Table 6 compares the functionality of a pneumatic press to each criterion presented in the functional decomposition.
### Table 6: Pros and cons of a pneumatic press

<table>
<thead>
<tr>
<th>Functional decomposition criterion</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoe size adaption</td>
<td>Easy to adapt press to shoe size</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air bladder will allow for bigger room</td>
<td></td>
</tr>
<tr>
<td>Sole placement</td>
<td>Adjustable rack</td>
<td>Easy to change shoe sizes</td>
</tr>
<tr>
<td></td>
<td>A lot of room to place the sole</td>
<td></td>
</tr>
<tr>
<td>Applying pressure</td>
<td>Easily adjustable pressure</td>
<td>Lower force</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loud air compressor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Longer cycle time</td>
</tr>
</tbody>
</table>

A drawing of the proposed design is presented in Figure 11.

![Figure 11: Pneumatic press](image)
4.1.4 Design # 4 - Ball Screw with Six-Column Frame

The assembly time required for this press will result in lower machining and material costs compared to its C-shape counter design. Ultimately, this will reduce overall costs. Besides the increase in assembly time, another downfall is that the column frame can restrict the user’s operating room. Additionally, the press will be lighter than the C-shape design. Furthermore, this design will meet all the CRs and ERs of this project.

Table 7 compares the functionality of a six-column ball screw press to each criterion presented in the functional decomposition.

Table 7: Pros and cons of a ball screw press with a column frame

<table>
<thead>
<tr>
<th>Functional decomposition criterion</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoe size adaption</td>
<td>Easy to adapt press to shoe size</td>
<td>Low C/O time</td>
</tr>
<tr>
<td>Sole placement</td>
<td>Standardized operation</td>
<td>Columns restrict user work area</td>
</tr>
<tr>
<td></td>
<td>Reduced human error</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safety control friendly</td>
<td></td>
</tr>
<tr>
<td>Applying pressure</td>
<td>Repeatable process</td>
<td>High potential power usage</td>
</tr>
<tr>
<td></td>
<td>Consistent pressure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rapid press time, adjustable through motor speed controls</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressure regulation through motor controls</td>
<td></td>
</tr>
</tbody>
</table>

A drawing of the proposed design is presented in Figure 12.
4.1.5 Design # 5 - Hydraulic Press with C-Shaped Frame

An air compressor, which drives the hydraulic piston to apply pressure to the shoe powers this press. Table 8 compares the functionality of a hydraulic press to each criterion presented in the functional decomposition.

<table>
<thead>
<tr>
<th>Pros and cons of a C-shaped base hydraulic piston press</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional decomposition criterion</strong></td>
</tr>
<tr>
<td>Shoe size adaptation</td>
</tr>
<tr>
<td>Sole placement</td>
</tr>
<tr>
<td>Applying pressure</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Furthermore, one customer requirement is to have a quiet machine. This machine is relatively quiet, but the air compressor that powers it is loud. To rectify this problem, a sound-absorbing box can be made to hold the air compressor and keep the sound down to a minimal level.
This design is ergonomic. There will be minimal twisting, turning, rotating, and bending. The controls will be near waist height and the shoes will be at eye level to reduce the stress on the neck.

A drawing of the proposed design is presented in Figure 13.

![Figure 13: C-shaped hydraulic press](image)

### 4.1.6 Design #6 - Hydraulic Press with Four-Column Frame

This is a redesign of the C-shaped hydraulic piston press. This design meets the same standards that were discussed in the previous section. Table 9 shows the pros and cons of this design compared to the functional decomposition criterions.

**Table 9: Pros and cons of a four-column hydraulic press**

<table>
<thead>
<tr>
<th>Functional decomposition criterion</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoe size adaption</td>
<td>Easy to adapt press to shoe size</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low C/O time</td>
<td></td>
</tr>
<tr>
<td>Sole placement</td>
<td>Standardized operation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced human error</td>
<td></td>
</tr>
<tr>
<td>Applying pressure</td>
<td>Repeatable process</td>
<td>Loud air compressor</td>
</tr>
<tr>
<td></td>
<td>Consistent pressure</td>
<td>Difficult to regulate pressure</td>
</tr>
<tr>
<td></td>
<td>Ample amount of pressure applied</td>
<td></td>
</tr>
</tbody>
</table>
This design uses four support columns to reduce the amount of stress on the base of the machine. The four-columns create a sturdier machine that creates an evenly distributed pressure. A drawing of the proposed design is presented in Figure 14.

![Figure 14: Four-column hydraulic press](image)

4.2 Design Selected

The team evaluated the pros and cons of all the designs presented in section 4.1. After comparing those designs, the team decided to move forward with design # 4, an electrical and mechanical press with a frame constructed of six vertical supports. The press utilizes a ball screw device for pressure. The device contains a movement lock to prevent it from moving further when the desired pressure is reached. This design was chosen based on how it compared to every other press design with regards to press construction, potential cost, performance, reliability, and ergonomics. The rationale for design selection and the design description are discussed in the following sections.

4.2.1 Rationale for Design Selection

The following is a detailed justification of the decision and how it was influenced by factors pertaining to press construction, potential cost, performance, reliability, and ergonomics.

4.2.1.1 Press Construction and Cost

The decision to go with a six-column base came after a thorough analysis between it and a C-shaped press. It was found that a six-column base provided a more stable press since the force is distributed among six columns. This also helps in regulating the accuracy of the pressure delivered. In a six-column base, the pad will have a stronger support.

Moreover, an electrical power source was chosen since electricity is the most reliable power source, as well as, the quietest. Furthermore, an electric source made adding controls to the system easier.
Finally, the cost of a six-column base is much lower than that of a C-shaped base. This was because the team can manufacture most of the six-column parts, however, the C-shaped parts will require an outside contractor. A six-column base was estimated to be $1,000, while the C-shaped base was estimated to be $3,500. This includes all the parts that go in manufacturing the base such as rods, plates and screws.

4.2.1.2 Press Performance and Reliability

The chosen press design met all performance standards in a consistent and repeatable way. The ball screw device was powered by a standard drive motor designed with mediation between torque, power and rpm speed in mind. This made it ideal for driving the ball screw in a manner that is rapid enough to meet cycle time criterions, yet strong enough to exceed pressure force criteria. Furthermore, ball screw devices are renown for their high performance efficiencies in the aeronautical industry. The drive motor was a single-phase 115-volt motor. This allowed Soft Star Shoes to use their standard workshop electricity to power the press.

4.2.1.3 Press Ergonomics

The design that was selected is electrically powered. This means that safety regulations on the press could be applied easier. The on/off button is covered to ensure that the press does not accidentally activate, the press is placed on a 3 feet table that the company suggested, and the controls for this device were placed on the front of the machine to ensure that operators do not have to reach around the press and put extra stress on their bodies.

A model of the proposed design is shown in Figure 15.

Figure 15: Selected six-column ball screw press

In addition, a Delmia analysis, which is a program that analyzes the possible postures and ease of reach and grasp for different types of the population, was done to check the ease of reach and grasp. In the analysis, two manikins were inserted to simulate the shop’s work conditions. These
manikins were a 95\textsuperscript{th} percentile man, and a 5\textsuperscript{th} percentile woman. From Figure 16, both, the man and woman were able to easily reach different parts of the press. This proved that the proposed press design was conceptually ergonomic.

\begin{figure}[h]
\centering
\includegraphics[width=0.6\textwidth]{selected_press.png}
\caption{Delmia model of the selected press}
\end{figure}

4.2.2 Design Description

In this section, the team explains the technical aspects of the proposed design. The design is an inverted ball screw device with a six-column frame. The press is 2 ft. long, 1.6 ft. wide and 2.9 ft. high. The inside design of the press will be described in five parts: the lower part, upper part, ball screw part, frames, and controls. The lower part contains a steel plate. The upper part contains a steel plate. The ball screw part contains the ball screw device, ball screw motor and a steel pressing plate. The frame consists of six threaded rods, fifty-two grade 8 nuts, and an aluminum sheet that wraps around the press. The controls consist of a momentary power switch, an emergency switch, two fuses, and a reverse drum power switch. A detailed design with labeled parts is shown in Figures 17 and 18.

There are three reasons for going with the inverted ball screw press:

1. It delivers a set amount of pressure.
2. It has a short cycle time.
3. It causes the least amount of ergonomic strain on the operator.
Figure 17: Detailed press design

Figure 18: Isometric view of the press
5 TESTING, IMPLEMENTATION AND RESULTS

This chapter presents a description of the steps taken to perform the preliminary testing, the actual implementation, and the final testing results.

5.1 Preliminary Testing

Due to the lack of sufficient time, the team had to use a method of trial and error to find the technical requirements that the press needed to meet. A better method that the team wasn’t able to conduct was experimental design.

Using a pneumatic testing device (jig), the team did preliminary testing to find the amount of pressure needed to produce a fully functional shoe. The testing jig can be seen in Figure 19.

![Figure 19: Pneumatic testing jig](image)

There are nine steps to press a shoe using the jig. These were:

1. Placing an aluminum sheet with screws inserted upside down, while the jig is on the floor.
2. Inserting the water hose between the four screws.
3. Placing a piece of plexiglass and hard rubber above the hose.
4. Placing the shoe above the hard rubber piece.
5. Covering the shoe with a piece of hard rubber and plexiglass.
6. Inserting the air compressor’s valve into the specified area in the hose, as shown in figure 19.
7. Adding the top aluminum plate above the plexiglass and screwing the two aluminum plates together.
8. Turning on the air compressor, which causes the water hose to inflate.
9. Pressing the shoe between the two aluminum plates, as shown in Figure 20.
After pressing the shoes for the allotted time, the top part of the testing jig has to be unscrewed to take the shoe out. In Figure 21, the Dash, which is a minimal material running shoe was barged using the testing jig. The results were promising since the shoe came out barged and in perfect condition.

With this setup, the team did two rounds of testing. For the first round; type of test, pressure used, setup used, and result of the test are shown in Table 10. Inserts, which are pieces of rubber that make the shoe more rigid, were placed inside the shoe.
Table 10: Round one testing

<table>
<thead>
<tr>
<th>Sample Group</th>
<th>Number of Samples</th>
<th>Pressure (psi)</th>
<th>Time (sec)</th>
<th>Setup</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>40</td>
<td>150</td>
<td>Rubber on top and glass on bottom. With inserts</td>
<td>Slightly weak bond inside edge. Couple of spots did not get glued all the way.</td>
</tr>
<tr>
<td>A2</td>
<td>1</td>
<td>30</td>
<td>150</td>
<td>No rubber pad on top and shoes sticking out from one of the sides (only air bladder at bottom). With inserts</td>
<td>A lot of gaps in shoes. Slightly weak bonds at the middle of the inside sole.</td>
</tr>
<tr>
<td>A3</td>
<td>1</td>
<td>50</td>
<td>160</td>
<td>Air bladder on bottom and rubber mat and plastic sheet on top. With inserts</td>
<td>Weak in some spots. Slightly weak bonds in the middle of the inside sole.</td>
</tr>
<tr>
<td>A4</td>
<td>1</td>
<td>45</td>
<td>150</td>
<td>Glass piece on bottom, glass piece and rubber pad on top. With inserts</td>
<td>Failed in a lot of spots. Toe still weak at edges.</td>
</tr>
<tr>
<td>A5</td>
<td>1</td>
<td>20</td>
<td>150</td>
<td>Glass piece on bottom, glass piece and rubber pad on top. With no inserts</td>
<td>Some gaps. Toe still weak at edges.</td>
</tr>
<tr>
<td>A6</td>
<td>1</td>
<td>60</td>
<td>150</td>
<td>Glass piece on bottom, glass piece and rubber pad on top. With inserts</td>
<td>Some missed spots. Toe still weak at edges.</td>
</tr>
<tr>
<td>A7</td>
<td>1</td>
<td>60</td>
<td>150</td>
<td>Glass piece on bottom, glass piece and rubber pad on top. With no inserts</td>
<td>Looks great. One missed spot</td>
</tr>
<tr>
<td>A8</td>
<td>1</td>
<td>60</td>
<td>150</td>
<td>Glass piece on bottom, glass piece and rubber pad on top. With no inserts</td>
<td>Some missed spots. Weak outside and inside middle.</td>
</tr>
<tr>
<td>A9</td>
<td>1</td>
<td>60</td>
<td>150</td>
<td>Glass piece on bottom, glass piece and rubber pad on top. With no inserts</td>
<td>Toe did not press well. Other than that, it is perfect.</td>
</tr>
<tr>
<td>A10</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Glass piece on bottom, glass piece and rubber pad on top. With no inserts</td>
<td>Perfect.</td>
</tr>
</tbody>
</table>

The first round of tests was done to make the team familiar with the pressure and cycle time required. After sample A4, the setup was held constant because it proved to be the most consistent. Finally, having a pressing time of 4 minutes (240 seconds) gave the best results for round 1.

The second round was completed on the next day. This allowed the team to study the results of the first round and determine what combinations would be best. For the second round, A10’s setup and cycle time were used. This was done to make sure that the results are consistent and that A10’s perfect output was not just a coincidence. Round 2 testing results can be seen in table 11.
Table 11: Round two testing

<table>
<thead>
<tr>
<th>Sample Group</th>
<th>Number of Samples</th>
<th>Pressure (psi)</th>
<th>Time (sec)</th>
<th>Notes</th>
<th>Type of Shoe</th>
<th>Sole</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Perfect other than toe displaced. Without insert</td>
<td>Mary Jane</td>
<td>Cherry</td>
</tr>
<tr>
<td>B2</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Perfect (added piece of rubber to back of shoe because of the curvature). Without insert</td>
<td>Mary Jane</td>
<td>Cherry</td>
</tr>
<tr>
<td>B3</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Perfect. Without insert</td>
<td>Dash</td>
<td>Trail</td>
</tr>
<tr>
<td>B4</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Perfect. Small spot (Rubber placed on back). Without insert</td>
<td>Dash</td>
<td>Trail</td>
</tr>
<tr>
<td>B5</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Back and middle did not get glued properly. Without insert</td>
<td>Dash</td>
<td>Street</td>
</tr>
<tr>
<td>B6</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Back and toe did not get glued properly (rubber was added to middle and back of the shoe). Without insert</td>
<td>Dash</td>
<td>Street</td>
</tr>
<tr>
<td>B7</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Heel and front did not get glued very well. Without insert</td>
<td>Dash</td>
<td>Leather</td>
</tr>
<tr>
<td>B8</td>
<td>1</td>
<td>60</td>
<td>240</td>
<td>Toe did not get glued very well. With insert</td>
<td>Dash</td>
<td>Leather</td>
</tr>
</tbody>
</table>

The results of the second test proved promising because all the shoes pressed came out barged properly. When the pressing time increased from 2.5 minutes to 4 minutes, better results were observed. Small variability was noticed in the toe and heal areas, however, it is believed that the size of the hose was the problem. The hose was not big enough to accommodate the whole shoe. From testing, removing the inserts from inside the shoe gave better pressing results. Finally, a pressure of 60 psi proved to be the perfect pressure for the system.

Mathematical calculations were then developed to find out the parameters of other parts of the system. To Figure out what class of ball screw and motor are needed, the amount of force necessary to press a satisfactory shoe must be calculated. From the pneumatic testing jigg, the team concluded that 60 psi was the needed pressure. Furthermore, it was noted that the largest shoe produced by Soft Star Shoes has a footprint that is 3.5 inches by 11 inches.

To calculate the surface area of a pair:

- \(3.5'' \times 11'' \times 2 = 77 \text{ inches squared.}\)
- \(60 \text{ psi} \times 77'' = 4,620 \text{ pounds.}\)
- \((4,620 \text{ lbs.} / 2,000 \text{ lbs. per ton}) = 2.31 \text{ tons.}\)

Thus, to press a pair of shoes successfully, the ball screw device needs to exert 2.31 tons. This led the team to design a press that holds a 3-5 ton ball screw device.

Finally, 4,620 lbs. \times 1.5 safety factor = 6,930 lbs. Each of the six vertical supports needs to hold 6,930 lbs. / 6 supports = 1,155 lbs.
After looking at this result and given that the force necessary to pull out one of the threaded grade 8 nuts from the support is 110,000 lbs, a design reexamination was recommended. The six vertical supports would make the press heavier and would allow for a larger portion of the press to be inaccessible. This reexamination resulted in a recalculation of the force required with 5 vertical supports and the results were:

- 6,930 lbs. / 5 supports = 1,386 lbs. / support

The five column recalculation proved adequate for the design to be successful, so it was supported. It was later decided that each support will be held by two grade 8 nuts to allow for any excess pressure to be absorbed. Nevertheless, although it was concluded that five supports were adequate enough, the press was built so that it supports the addition of two extra supports, if needed, through extra holes that were drilled in it.

Finally, the next section discusses implementation. The implementation of the press into Soft Star Shoes occurred in four stages: assembly, installation, training and support. These stages lead to a logical and an intuitional way of manufacturing and installing the press into the soft star shoes sole attachment process.

5.2 Implementation

The press was built following four major steps:

1. The assembly process.
   a. This step happened in the MIME shop and it involved manufacturing all the appropriate pieces and combining them with the items that must be purchased. Table 12 shows a detailed bill of materials (BOM) of the parts used and their corresponding prices. The parts listed were purchased through certain manufacturers, which are listed in the BOM. After purchasing the parts, modifications were made to them to allow the assembly process to be completed. As seen by the BOM, each part had a required quantity, the part’s supported sub-system, the total price for the product (accounting for the quantity ordered), and the vendor for each product.

Table 12: Bill of materials

<table>
<thead>
<tr>
<th>Name</th>
<th>Quantity</th>
<th>Sub-system</th>
<th>Total Merchandise Price ($)</th>
<th>Vendor</th>
</tr>
</thead>
<tbody>
<tr>
<td>30&quot; long 5/8&quot; Threaded Rod</td>
<td>7</td>
<td>Vertical Supports</td>
<td>35.84</td>
<td>Home Depot</td>
</tr>
<tr>
<td>17&quot;x17&quot; steel plate 1/2&quot; thick</td>
<td>2</td>
<td>Frame</td>
<td>119.39</td>
<td>Ram Steel</td>
</tr>
<tr>
<td>5/8&quot; hex Nuts grade 8</td>
<td>50</td>
<td>Frame</td>
<td>13.77</td>
<td>Home Depot</td>
</tr>
<tr>
<td>Spray paint</td>
<td>1</td>
<td>Frame</td>
<td>3.84</td>
<td>Home Depot</td>
</tr>
<tr>
<td>5/8&quot; * 11&quot; Hex bolts</td>
<td>12</td>
<td>Frame</td>
<td>4.40</td>
<td>Home Depot</td>
</tr>
<tr>
<td>1/8&quot; thick aluminum sheet metal 2'x4'</td>
<td>1</td>
<td>Frame aesthetics</td>
<td>0.00</td>
<td>MIME Shop</td>
</tr>
<tr>
<td>14&quot;x14&quot; rubber mat 0.2&quot; thick</td>
<td>1</td>
<td>Pressure System</td>
<td>0.00</td>
<td>Soft Star Shoes</td>
</tr>
<tr>
<td>17&quot;x17&quot; rubber mat 0.2&quot; thick</td>
<td>4</td>
<td>Pressure system</td>
<td>19.99</td>
<td>Kmart</td>
</tr>
</tbody>
</table>
### Bill of Materials

<table>
<thead>
<tr>
<th>Name</th>
<th>Quantity</th>
<th>Sub-system</th>
<th>Total Merchandise Price ($)</th>
<th>Vendor</th>
</tr>
</thead>
<tbody>
<tr>
<td>14”x14” 1/2” thick Steel Plate</td>
<td>1</td>
<td>Pressure System</td>
<td>22.36</td>
<td>Ram Steel</td>
</tr>
<tr>
<td>Inverted Ball Screw Device + Motor</td>
<td>1</td>
<td>Pressure System</td>
<td>2853.65</td>
<td>Joyce Dayton</td>
</tr>
<tr>
<td>0.093” thick Plexiglass 18”x24”</td>
<td>1</td>
<td>Safety Guard</td>
<td>14.12</td>
<td>Home Depot</td>
</tr>
<tr>
<td>1/8” Threaded Bolts</td>
<td>8</td>
<td>Platform</td>
<td>0.00</td>
<td>MIME Shop</td>
</tr>
<tr>
<td>1/8” Threaded Nuts</td>
<td>8</td>
<td>Platform</td>
<td>0.00</td>
<td>MIME Shop</td>
</tr>
<tr>
<td>1/8” Washers</td>
<td>16</td>
<td>Platform</td>
<td>0.00</td>
<td>MIME Shop</td>
</tr>
<tr>
<td>1/4” Threaded Bolts</td>
<td>8</td>
<td>Platform</td>
<td>0.00</td>
<td>MIME Shop</td>
</tr>
<tr>
<td>1/4” Threaded Nuts</td>
<td>8</td>
<td>Platform</td>
<td>0.00</td>
<td>MIME Shop</td>
</tr>
<tr>
<td>1/4” Washers</td>
<td>16</td>
<td>Platform</td>
<td>0.00</td>
<td>MIME Shop</td>
</tr>
<tr>
<td>Momentary Push Button</td>
<td>1</td>
<td>Controls</td>
<td>36.40</td>
<td>Grainger</td>
</tr>
<tr>
<td>Reverse drum power switch</td>
<td>1</td>
<td>Controls</td>
<td>69.00</td>
<td>Grainger</td>
</tr>
<tr>
<td>On/Off Button</td>
<td>1</td>
<td>Controls</td>
<td>3.19</td>
<td>RadioShack</td>
</tr>
<tr>
<td>40 A Contactor</td>
<td>1</td>
<td>Controls</td>
<td>70.60</td>
<td>Grainger</td>
</tr>
<tr>
<td>Fuses and fuse holders</td>
<td>2</td>
<td>Controls</td>
<td>5.38</td>
<td>RadioShack</td>
</tr>
<tr>
<td>5’ 1/2” Wire wrap</td>
<td>1</td>
<td>Controls</td>
<td>5.99</td>
<td>RadioShack</td>
</tr>
<tr>
<td>Pack of 2 LED Lights</td>
<td>1</td>
<td>Controls</td>
<td>2.49</td>
<td>RadioShack</td>
</tr>
<tr>
<td>Pack of 2 LED Light holders</td>
<td>1</td>
<td>Controls</td>
<td>1.99</td>
<td>RadioShack</td>
</tr>
<tr>
<td>Pack of 2 Light Switches</td>
<td>1</td>
<td>Controls</td>
<td>3.19</td>
<td>RadioShack</td>
</tr>
<tr>
<td>Battery holder</td>
<td>1</td>
<td>Controls</td>
<td>2.19</td>
<td>RadioShack</td>
</tr>
<tr>
<td>Circuit breaker</td>
<td>1</td>
<td>Controls</td>
<td>3.15</td>
<td>Home Depot</td>
</tr>
<tr>
<td>3/4” Conduit</td>
<td>1</td>
<td>Controls</td>
<td>5.69</td>
<td>AutoZone</td>
</tr>
<tr>
<td>20’ Electrical wires</td>
<td>2</td>
<td>Controls</td>
<td>21.98</td>
<td>RadioShack</td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
<td></td>
<td>3,318.60</td>
<td></td>
</tr>
<tr>
<td>Total Budget</td>
<td></td>
<td></td>
<td>5,000</td>
<td></td>
</tr>
<tr>
<td>Surplus</td>
<td></td>
<td></td>
<td>1,681.40</td>
<td></td>
</tr>
</tbody>
</table>

b. This step also entailed assembling the press and wiring in the control modules and safety switches. Assembly was broken down into the four basic subsystems: assembly of the frame; assembly of the ball screw device and motor; assembly of the pressing pad; and assembly of the control module and safety, respectively. The total cost for completely building and supplying the press was $3,318.60, which meant that there was a surplus of $1,681.40 from our budget.

2. The installation process.
   a. This step included delivering the press to the factory and implementing it into their production flow. This process involved testing the press at the factory to ensure it functioned properly, and bolting the press to one of the factory’s tables.

3. The training process.
   a. This step involved hosting a session at the factory. The purpose of this session was to inform and teach the company founders, as well as the three employees responsible for the bargaining process, how to use and maintain the press. During this process, the team talked to the employees about the design of the press and answered questions raised by them. The only person, from Soft Star Shoes, that
was up to date with the status and progress of the design was the founder of the company. Thus, many of the factory workers were surprised by the delivery of the press and had a lot of questions about the design and manufacturing behind its creation. By furthering the understanding the employees had of the press, the operation and maintenance training was more effective.

4. The support process.
   a. This step is arguably the most important one. The purpose of the support process is to ensure that the press functioned adequately not just for a week from delivery, but for years to come. Soft Star Shoes has demonstrated a great level of support, trust, and funding to the team. The best way for the team to show their gratitude was to deliver a functional product in a professional manner. Part of this professional attitude is to support the press and the preventative maintenance it might need by showing Soft Star Shoes how to maintain the press. The team did not want to exhaust the budget, but we believed it was important to leave Soft Star Shoes with a press and spares of the parts that were likely to fatigue and fail over time. This included fuses, supports and nuts.

Finally, figures 22 and 23 show the implementation schedule that was followed to build the press. The schedule is split into two parts for visual reasons.

<table>
<thead>
<tr>
<th>#</th>
<th>Task Theme</th>
<th>Start</th>
<th>Finish</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive materials</td>
<td>3/7/2013</td>
<td>1/7/2013</td>
<td>1d</td>
</tr>
<tr>
<td>2</td>
<td>Move materials to the shop</td>
<td>3/7/2013</td>
<td>1/7/2013</td>
<td>1d</td>
</tr>
<tr>
<td>3</td>
<td>Modify the mental and aluminum sheets</td>
<td>3/8/2013</td>
<td>1/8/2013</td>
<td>1st</td>
</tr>
<tr>
<td>4</td>
<td>Drills holes in metal and aluminum sheets</td>
<td>3/8/2013</td>
<td>1/8/2013</td>
<td>1d</td>
</tr>
<tr>
<td>5</td>
<td>Modify the threaded rod</td>
<td>3/15/2013</td>
<td>5/1/2013</td>
<td>2d</td>
</tr>
<tr>
<td>6</td>
<td>Make sure that all parts meet required specifications</td>
<td>3/16/2013</td>
<td>1/16/2013</td>
<td>1st</td>
</tr>
<tr>
<td>7</td>
<td>Add the base and the columns of the press</td>
<td>3/17/2013</td>
<td>1/17/2013</td>
<td>1d</td>
</tr>
<tr>
<td>8</td>
<td>Add the upper frame to the press</td>
<td>3/22/2013</td>
<td>2/22/2013</td>
<td>3d</td>
</tr>
<tr>
<td>9</td>
<td>Add the lower rubber pad, air bladder and lower plies to the press</td>
<td>3/23/2013</td>
<td>3/24/2013</td>
<td>2d</td>
</tr>
<tr>
<td>10</td>
<td>Add the upper pad, air bladder and upper plies to the press</td>
<td>3/25/2013</td>
<td>3/26/2013</td>
<td>3d</td>
</tr>
<tr>
<td>11</td>
<td>Add the ball screw device and motor to the press</td>
<td>3/25/2013</td>
<td>3/26/2013</td>
<td>3d</td>
</tr>
<tr>
<td>12</td>
<td>Add the controls to the press</td>
<td>3/30/2013</td>
<td>4/30/2013</td>
<td>3d</td>
</tr>
<tr>
<td>13</td>
<td>Add the emergency system, pressure regulator system and the pressure gauge to the press</td>
<td>2/4/2013</td>
<td>2/5/2013</td>
<td>3d</td>
</tr>
<tr>
<td>14</td>
<td>Screw down the adjustable table</td>
<td>2/7/2013</td>
<td>2/7/2013</td>
<td>1d</td>
</tr>
<tr>
<td>15</td>
<td>Get ready for evaluation/fitting</td>
<td>2/8/2013</td>
<td>2/14/2013</td>
<td>5d</td>
</tr>
<tr>
<td>16</td>
<td>Further testing for all the problems</td>
<td>2/15/2013</td>
<td>2/20/2013</td>
<td>1st</td>
</tr>
<tr>
<td>17</td>
<td>Get ready for final presentation</td>
<td>3/7/2013</td>
<td>3/11/2013</td>
<td>3d</td>
</tr>
<tr>
<td>19</td>
<td>Prepare for evaluation 2</td>
<td>3/13/2013</td>
<td>3/13/2013</td>
<td>6d</td>
</tr>
<tr>
<td>20</td>
<td>Write final report</td>
<td>3/14/2013</td>
<td>3/20/2013</td>
<td>6d</td>
</tr>
</tbody>
</table>

*Figure 22: Actual implementation schedule (Jan. 7 - Mar. 06 2013)*
Figure 23: Actual implementation schedule (Mar. 06 - Mar. 20 2013)

Finally, a picture of the press is provided in Figure 24.

Figure 24: Final press

After finishing the implementation process, it was time to start testing the design and presenting the results.
5.3 Testing Results

After building the press, the testing procedures were used to test the engineering requirements. This section describes how each engineering requirement was satisfied. The approach will be to state each customer requirement and its corresponding engineering requirement(s), and then explain how the testing procedure was met and whether the end result was satisfactory or not.

1. CR # 1: Supply a Press
   a. ER # 1: Shall not exceed $5,000

   To test this requirement, the team collected receipts of all the materials that were bought to build the press and added the total amount. The total amount came out to be $3,318.60, which meant that this requirement was satisfied.

2. CR # 2: Quiet Machine
   a. ER # 2: Shall not exceed 80 dB if standing next to the machine

   To test this requirement, the team downloaded a calibrated audiometer from the android store. The audiometer was checked for accuracy by reading a lot of reviews and looking at different ratings. The device was placed 10 feet from the press in three different locations around it, and the average sound level was found to be 67 dB, which meant that this requirement was satisfied.

3. CR # 3: Self-Contained
   a. ER # 3: Shall not have an external pressure system

   To test this requirement, the team used a visual test to look and see if there was any external pressure device around the press. The result was that there were no external pressure devices, which meant that this requirement was satisfied.

4. CR # 4: Short pressing time
   a. ER # 4: Shall take less than 5 minutes to press a pair

   To test this requirement, the team used an iPhone’s stopwatch to measure the amount of time it takes the press to go down, press the shoes, and go back up. The result was 4 minutes and 5 seconds for the whole process, which meant that this requirement was satisfied.

5. CR # 5: Ergonomic
   a. ER# 5: Should not involve any repetitive manual work

   To test this requirement, the team used a visual test to check if there was any repetitive manual work in the pressing process. The result was that there is no repetitive work and that the pressing process is completely automated, which meant that this requirement was satisfied.
b. ER # 10: Shall stand at 3 ft. above the ground

To test this requirement, the team used a tape measurer to measure the height of the table that was going to carry the press. The result was that the height of the table was 3 feet, which meant that this requirement was satisfied.

6. CR # 6: Fits in a small area
   a. ER # 6: Shall fit in a 5′ X 5′ area

To test this requirement, the team used a tape measurer to measure the length and width of the press. The measured length was found to be 22” and the width was found to be 17.2”, which meant that this requirement was satisfied.

   b. ER # 8: Press length shall be > 12.5” (size 16)

To test this requirement, the team used a tape measurer to measure the length of the pressing plate. The measured length was found to be 14”, which meant that this requirement was satisfied.

   c. ER # 9: Press width shall be > 5"

To test this requirement, the team used a tape measurer to measure the width of the pressing plate. The measured width was found to be 14”, which meant that this requirement was satisfied.

7. CR # 7: Delivers consistent pressure
   a. ER # 14: Should not damage shoe

To test this requirement, the team used a visual test to check whether the shoe was completely barged or not and whether it was damaged or not. The result was that the shoe was completely barged and was not damaged, which meant that this requirement was satisfied.

8. CR # 8: Moveable
   a. ER # 7: Shall weight less than 400 lbs.

To test this requirement, the team used a technical 450-pound scale to weigh the press. The weight of the press was found to be 258 lbs., which meant that this requirement was satisfied.

   b. ER # 8: Press length shall be > 12.5" (size 16)

To test this requirement, the team used a tape measurer to measure the length of the pressing plate. The measured length was found to be 14”, which meant that this requirement was satisfied.
c. ER # 9: Press width shall be > 5"

To test this requirement, the team used a tape measurer to measure the width of the pressing plate. The measured width was found to be 14”, which meant that this requirement was satisfied.

d. ER # 10: Shall stand at 3 ft. above the ground

To test this requirement, the team used a tape measurer to measure the height of the table that was going to carry the press. The result was that the height of the table was 3 feet, which meant that this requirement was satisfied.

9. CR # 9: Accommodate all sizes

   a. ER # 8: Press length shall be > 12.5” (size 16)

   To test this requirement, the team used a tape measurer to measure the length of the pressing plate. The measured length was found to be 14”, which meant that this requirement was satisfied.

   b. ER # 9: Press width shall be > 5"

   To test this requirement, the team used a tape measurer to measure the width of the pressing plate. The measured width was found to be 14”, which meant that this requirement was satisfied.

10. CR # 10: Works for different types of shoes

   a. ER # 13: Shall work for flat shoes

   To test this requirement, the team barged three different types of soles and leathers. The result was that all these types were barged and no defects were noticed in any of them, which meant that this requirement was satisfied.

11. CR # 11: Short C/O time

   a. ER # 11: Shall have < 5 minutes C/O time

   To test this requirement, the team used an iPhone’s stopwatch to check the time it takes a person to replace the two barged shoes with two that were not. The result was 30 seconds, which meant that this requirement was satisfied.

   b. ER # 12: Should not need to change fixtures when changing sizes

   To test this requirement, the team used a visual check to see whether there is any need for fixtures or not. The result was that there is no need for fixtures, which meant that this requirement was satisfied.
12. CR # 12: Safe

   a. ER # 15: Shall have a covered On/Off button

   To test this requirement, the team used a visual test to see whether the on/off button is covered or not. The result was that there was a cover on the on/off switch and the momentary push switch, which meant that this requirement was satisfied.
6 CONCLUSIONS AND FUTURE WORK

This chapter presents conclusions about the entire project experience and recommendations for next steps.

6.1 Conclusions and Lessons Learned

Upon receiving the project description, it initially looked like the project could be completed in three months, however, this proved to be unreasonable. Types of existing presses and reasons that justify changing the current barging process had to be researched. The research process was harder than expected because of the limitations in acceptable and cost efficient designs. Most presses available were expensive and more sophisticated than needed. Moreover, problems were encountered during the design and implementation phases, which taught the team that things do not always go as planned.

6.1.1 Research Conclusions

Existing designs research yielded results that helped familiarize the team with the project requirements. More familiarity with different power sources, and ideas on frame materials and shapes were exhibited after concluding the design research phase. To design a fully functional press; ergonomics, which is an important limitation to manual repetitive work had to be researched and justified. The research yielded disorders that are caused by hard repetitive manual work. Carpal tunnel syndrome, upper limb musculoskeletal disorders and tendonitis are examples of such disorders. Looking at these results, visualizing the process using IDEF diagrams, and performing the RULA analysis allowed conclusions to be made, and reasons for changing the process to be justified. Results showed that the barging process had to be changed immediately.

6.1.2 Problems Faced

Problems were faced during both, the design and implementation phases. The problems that were faced in the design phase fell into two categories:

1. Requirement issues

The project was ambiguous in the beginning, which made developing reasonable CRs and ERs hard. The sponsor wanted to buy an industrial type press, however, this would not have been reasonable, as it would mean that the scope of the project would be small. After some discussions with the sponsor and the advisor, it was concluded that a press would be built. The team’s argument was that this press will cost less and have the same reliability as any other press in the market. After presenting this argument and showing the sponsor confidence, they agreed to go with the building option. After this decision, the project became clearer and meetings were conducted with the sponsor to understand their vision. After a couple of meetings, a list of requirements that the sponsor wanted was generated. After that, technical functionalities of the press were discussed and engineering requirements were generated based on them. These were shown to the sponsor and were approved.
2. Powering source issues

After generating the different requirements, the team began to look into systems that would satisfy these requirements. 0.5” thick steel plates were chosen as frames, a 14”x14” pressing plate was chosen and a design was generated based on these. However, the team encountered a problem after finishing the frame design. All the powering options that were used to operate existing shoe presses were either expensive or unsatisfactory. This led the team to be more creative. Taking that one of the team members has worked with Boeing in the past, a ball screw device, which is a device used to convert rotary motion to linear motion, was suggested. After some research about such devices, a smaller version of this device was found to be perfect, so it was chosen.

Moving on, the problems that were faced during the implementation phase can be summarized as:

1. Ball screw delivery issues

After returning from winter break, the team found that the expected arrival date of the ball screw device was delayed. This delay put the team in a critical condition because this meant that the device would arrive a week before the first deadline. With this in mind, the team decided to finish most of the press’ frame and holes using engineering drawings of the device, and have the frame ready on the device’s arrival date.

2. Receipt of wrong motor

After finishing the holes and after receiving the device it was noticed that the company sent the wrong motor with the device. Calling the company and proving that the mistake was theirs resolved this problem rather quickly and allowed for the correct motor to be sent, however, this meant that timing would be tighter than previously planned.

3. Ball screw wiring issues

After receiving the correct motor, another problem was encountered. The motor was not wired and none of the team members had experience wiring industrial motors. This resulted in researching the routing options, consulting professionals and talking to electrical engineers. After figuring out the wiring options, the team constructed a wiring diagram and got it approved by Mr. Don Heer, an electrical and computer engineering faculty member. Upon approval, wiring was successfully completed.

4. Testing issues

Due to the lack of time, the team wasn’t able to conduct a scientific method to find the technical requirements of the press, rather the team was forced to use a method of trial and error. In addition, a decision by the sponsor to replace the existing motor with a faster one, three months after delivery, limited the testing that the team could conduct then. Experimental design wouldn’t be as beneficial in this case because one of the parameters, the speed of the motor, has changed since the device was last tested.
6.2 Recommendations and Future Work

The device that was built by the team replaced Soft Star Shoes’ hammering process. The press fits together very tightly, which removed any chances of press failure. However, one design glitch that could have been avoided was the size of the frame that goes around the press. The size of the frame was very tight, which made it very hard to install and take off. The reason being that the team didn’t decide to place the sheet metal until halfway through the building process. Therefore, the sheet metal wasn’t inserted into a design software for verification, but the size was taken using a tape measurer and aluminum was cut based on that, which meant that bend radiuses weren’t accounted for, as needed. However, although this has its disadvantages, it has its advantages as well. The advantages are that it holds the press together more tightly, which causes the windows and all the aesthetics to be stationary during the pressing process.

After testing and analyzing the final design for any malfunctions or sources of danger, it was concluded that the press could be used as a new alternative for the hammering process. From the tests, the press proved to be good in delivering consistent pressure and in attaching the rubber soles to the leather uppers. Upon delivery, a short lesson was given to operators that would operate the press to make them comfortable in taking charge of it.

As far as possible projects that could be performed to improve the performance of the press, these would be:

1. To design an experiment and find the optimal number of pairs of shoes that should be placed in the press at any time. The pressing plate being 14” by 14” allows for three pairs to be placed at the same time, which might compromise the pressure distribution. The pros of this project is that it will allow the company to weigh the benefits of pressing more than a pair at a time vs. the drawbacks.
2. To re-design the frame and plates so that they are designed for disassembly. This will make troubleshooting and moving the machine easier. The drawback of this project is, however, that it might compromise the press while force is being applied. Plates will have more room to move when experiencing large amounts of force.
3. To rewire the motor and add a digital pressure regulator system. This will allow the new press to be more accurate in presenting the pressure exerted, as well as, having a more consistent pressure applied from one pair to the other.

All in all, this was a successful project. The team learned a lot from this experience and the sponsor got an economic and ergonomic shoe press that eliminated their hammering process, which allowed operators to feel more comfortable in their work place.
7 WORKS CITED


8 BIBLIOGRAPHY


9 NOTES

1. Odd ratios indicate the relationship strength between a given variable and the outcome when compared to the other variables. Odd ratios simply compare odds of an event happening (Szumilas, 2010).
10 APPENDICIES
10.1 Appendix A: Pictures of the Hammering Process

The following are pictures of the hammering step that was used in the barging process.

*Figure 25: Hammering the shoe*

*Figure 26: Setting the shoe on the hammering table*
Figure 27: Hammering the shoe
10.2 Appendix B: Original Process RULA Assessment Sheet

The following is a RULA (Rapid Upper Limb Assessment) sheet of the hammering process.

Figure 28: RULA sheet
10.3 Appendix C: Original System IDEF Functional Decomposition

The following Figures contain the functional decomposition of the replaced bargeing process. These IDEF diagrams show the controls, mechanisms, inputs, and outputs of the process.

Figure 29: Functional decomposition level A-0

Figure 30: Functional decomposition level A0
Figure 31: Functional decomposition level A1

Figure 32: Functional decomposition level A2
Figure 33: Functional decomposition level A3

Figure 34: Functional decomposition level A4
### Appendix D: House of Quality (HoQ)

<table>
<thead>
<tr>
<th>Customer Requirement</th>
<th>Weight</th>
<th>Engineering Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Supply a Press</td>
<td>35</td>
<td>X</td>
</tr>
<tr>
<td>2. Quiet Machine</td>
<td>30</td>
<td>X</td>
</tr>
<tr>
<td>3. Self-Contained</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>4. Short pressing time</td>
<td>15</td>
<td>X</td>
</tr>
<tr>
<td>5. Ergonomic</td>
<td>30</td>
<td>X</td>
</tr>
<tr>
<td>6. Fits in a small area</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>7. Delivers consistent pressure</td>
<td>30</td>
<td>X</td>
</tr>
<tr>
<td>8. Moveable</td>
<td>LTE*</td>
<td>X X X X</td>
</tr>
<tr>
<td>9. Accommodate all sizes</td>
<td>20</td>
<td>X</td>
</tr>
<tr>
<td>10. Works for different types of shoes</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>11. Short C/O time</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>12. Safe</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

#### Target(s), with Tolerance(s)

| Target(s), with Tolerance(s) | 3500, <5000 | 75, <80 | Y, Y | 4 +/- 1 | Y, Y | 4 * 4', <5" ± 5' | 375, <400 | 13, >12.5 | 5.5, >5 | 2.7 +/- 0.3 | 4.5 +/- 0.5 | Y, Y | Y, Y | Y, Y | Y, Y |
| Check receipts                 | Use a decibel meter | No external pressure gauge needed to operate | Check with a Stop watch | No repetitive manual work observed | Measure with a tape measure | place on a certified scale | Measure with a tape measure | Measure with a tape measure | Measure with a tape measure | Change the fixture of the machine | Try two different sizes | Try two kinds of shoes | Barge one shoe | Is there a cover on the button? |

| Design Link (DL #)              | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |

Table 13: House of Quality (HoQ)

*LTE = Low Technical Effort