Technical Report

Automating Bolt Manufacturing

MEM Team 43

Ryan Conrad
Khai Nguyen
Sebastian Carlo
Bryce Kim
Abbas Mirza

Collaborative Robot Implementation into Manufacturing Machining Industry (C.R.I.M.M.I.)

Abstract

Current companies like B&G Manufacturing use manual workers to run CNC machines for high production orders of various bolts. Some processes can take upwards of 9 minutes per bolt. Many companies like Fanuc, RAIS and Collaborative robot offer 3rd party automation solutions, but can cost at minimum $100,000 if not up to $250,000. Our goal is to implement an automation system, similar to those, where our system is cheaper using multiple 3rd party pieces. Automation may be difficult for the complete manufacturing process, but this fails to consider improving machinery with failsafes while retaining manual inspections and restricting automation to redundancy. Further research is necessary to gauge limits of automation and maximize efficiency to reduce operating costs. The CRIMMI project will include an analysis on labor vs. automation cost, current vs. projected process time, operation complexity, accuracy of final part dimensions, safety and hazards, and how the part materials fare under automation compared to human care. In this, we will be introducing a method of automation that satisfies the ongoing problems with human labor in CNC manufacturing. Additionally, the robotic arm will be equipped with custom 3-D designed end effector, to grip and manipulate parts in various fashion. This will work alongside a bolt orienting system, arduino control system, and the robot to fully automate the current manual system. The design of this project is aimed at significantly increasing efficiency, productivity, and accuracy while decreasing human strain in such automated repetitive tasks.

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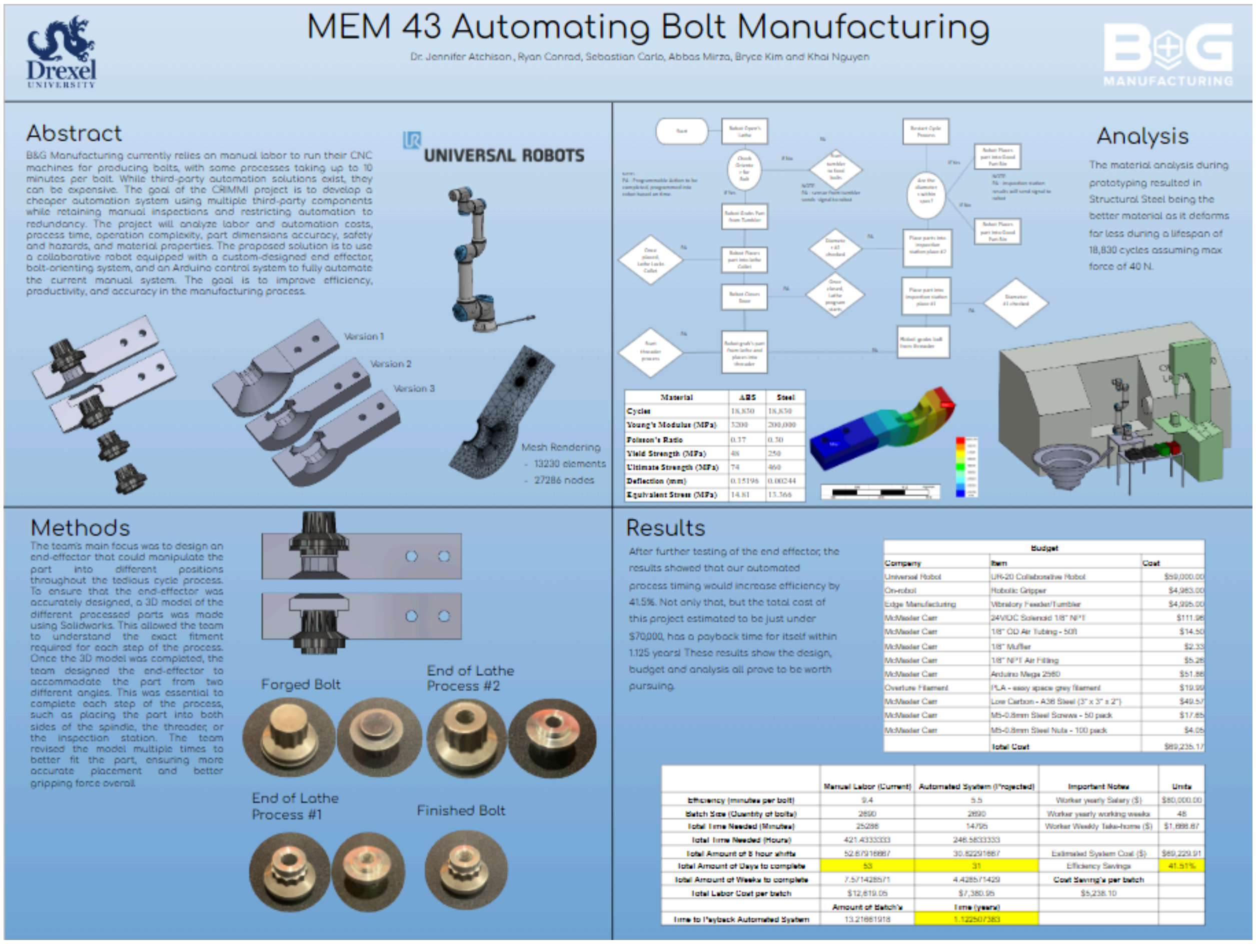
1. *Quad Chart*



2. *Introduction*

Motivation

The current manufacturing industry has to produce a high volume of nuts and bolts for very unique manufacturing processes/companies. The goal is to create a cell in which a collaborative robot can complete both the operation of loading the part and taking it out of whatever machining process. This is important, as currently manual workers conduct such a tedious job, on production orders that sometimes require thousands of parts, taking hundreds of hours to complete. The goal is to eliminate the required manual labor, while also increasing efficiency of such time heavy and labor intensive jobs.

Problem Statement

In completing such a large task, different variables will need to be identified in order to conduct such a project. As an example, B&G Manufacturing has some bolts that require a .001

tolerance, making them very difficult to manufacture. Using an Okuma lathe, the forged parts can be used to create these nuts and bolts after a programmed machining operation is complete. The main focus of this project starts with the design of the solution in its effectiveness to increase efficiency of production. While also pertaining to the cost effectiveness of the solution when compared to the current manual labor solution or possible alternatives within the industry. This means that the current market solutions will need to be explored and explained to understand the effectiveness of an inhouse solution, such as a collaborative robot implementation.

The physical space within the machine, as well as the physical bolt itself will be the constraining factor for the project, or more importantly the robot arm in particular. The part itself will need to be accounted for, or more specifically the weight and volume to effectively show a solution. The robot will need to specced out once all other systems are understood and designed/accounted for, such as the internal dimensions of the machine or part loading area. There are many current solutions within our market that show these various products and parts being used to abide by such constraints. Diving deeper into the current market solutions would help someone better understand the concept.

Stakeholders and Needs

A high volume of specialized bolts manufactured by B&G Manufacturing currently needs lots of time to manufacture, due to the process, and is for one of their leading customers in the industry. These high volumes of bolts currently need at least one operator, if not two, to complete the lathe, threading and inspection task for this item. B&G Manufacturing currently has data on the manufacturing time and cost it currently takes them to supply these bolts, and would like to increase efficiency time while still accounting for budget cost.

State of the Art

In the current industry, company's such as Fanuc and RAIS offer automated system solutions and third party engineering consulting to fit any manufacturing companies needs with industrial robots. Though, this can usually cost a large amount of money for the research and development, as well as the certifications and specifications needed behind every solution. In turn, this can cost companies at least $100,000, if not up to $300,000 some times. This leads us to other companies such as Universal Robots, which sells collaborative robots that are programmable UI built into the system. These robots can be sold for relatively cheap costs and can be highly effective and adaptive to put into almost any work environment. To compare the costs, the robots can range anywhere from $20,000 to $60,000 for the largest 5 foot length reach robot! These are important findings, as current state of the art solutions provided by third parties are very costly and ineffective when requiring more money on top of the solution to properly implement them. I believe this shows that the current possibilities for implementing our own solution could be beneficial and profitable. It will be important to investigate these findings and perform an analysis on which robots best fit our current scenario to increase efficiency.

Approach

The group will come up with a design automating the lathe, threading and inspection system process using a collaborative robot to ensure all operations are completed as efficiently as possible. Research on collaborative robots, along with custom end effectors and programming solutions must be better understood to complete this process. The team will focus on increasing efficiency, while not breaking the budget of the current manufacturing state.

Prototyping

The prototype will mainly consist of manufactured addons to the collaborative robot to aid in successfully moving the bolt(s) in and out of the different machine steps. To this goal we will model an End-Effector capable of this to test its efficiency, speed, and durability with computer simulation finding overall life and deformation. The automation cycle consists of going from the orienter, to the lathe, then threader, and finally scales for tolerance verification. The end program for the collaborative robot should be able to automate each of these steps with ability to multitask stations (e.g. operate the threader while another bolt is in lathe). The operation of the system should look like the flowchart seen in the appendix.

3. *Material and Methods*

Materials

The exact bill of materials for all products needed to be purchased and used can be found in the appendix on page 27. Once all the modeling was revised and completed for the end effector, the files were put into the ANSYS engineering simulation software to complete material testing for the models. This will allow the group members to accurately select the best material type for the amount of cycles needed for the intended production design. The analysis was done by using ABS (Acrylonitrile Butadiene Styrene) and Structural Steel as can be seen in table 1. With the computer simulation, specifications such as deflection distance (mm), equivalent stress (MPa) and cycles, can all be calculated and accounted for, using this engineering software.

End Effector Materials		
Material	**ABS**	**Steel**
Cycles	18,830	18,830
Young's Modulus (MPa)	3200	200,000
Poisson's Ratio	0.37	0.30
Yield Strength (MPa)	48	250
Ultimate Strength (MPa)	74	460
Deflection (mm)	0.15196	0.00244
Safety Factor	2-5	1.5-3

Table 1

Hardware

The team's hardware involved the collaborative robot, and end effector of the system. Other equipment, such as the Okuma Lathe, Threader & inspection station are all equipment provided by B&G Manufacturing that must be completely integrated. The most important aspect of this entire system is the collaborative robot, as it includes an onboarding programming system to automate and control the entire process flow. These systems must be integrated with the collaborative robot and software to work in-tail with the process flow chart shown. This will allow the robot to understand where the bolt is within the process, and allow for it to make decisions based on that. The integration process will use 5V wires to send signals to and from the robotic arm system in order to control the process.

Software

The software focused on throughout this project consisted of using Solidworks, Prusa Slicer, ANSYS, and collaborative robot's UI system. The solidworks modeling system will be used to design and create drawings for the custom end effector of the process. This will allow the students to make quick decision changes, adjust and create dimensionally accurate drawings, as well as create files for ANSYS and 3D printing testing. As talked about, the STL. a file from solidworks will be used with the prusa slicer to create 3D modeling g-code that is then used to 3D print our models. This software allows for extremely intense model decisions such as layer height, infill density & patterns, along with other dimensional needs. Along with using this STL. file, it can be plugged into ANSYS to understand the material properties of the design. This can be better explained as the deflection amount, or stress received, based on a certain material and amount of cycles due to a certain force. This is very key for the team to analyze, as the amount of cycles for high efficiency manufacturing processes is key to ensure when designing such a project. Lastly the group went to Universal Robot to learn about their collaborative robots and how they work with their integrated system. The robots use a built-in software that allows for easy access to control, manipulate and talk to the robot. This will allow the team to easily access the robots capabilities and responses within the system, while also understanding how it will integrate with the current needs of B&G manufacturing's manual system.

Fabrication methods

The team focused on the end-effector to manipulate the part in various positions throughout the tedious cycle process. First a 3D model of the different processed parts would be made in Solidworks to understand the exact fitment for each step. Once this is completed, the end effector itself was designed to accommodate the part from two different angles. This is done to complete each step of the process such as placing it into both sides of the spindle, the threader, or inspection station. The model was then revised multiple times, to better fit the part for more accurate placement and better gripping force overall. Team members with 3D printers allowed for quick prototype testing and research turn around for the end effector fitment. The following images for the Solidworks design, end effector drawing, and 3D printed testing, can all be seen below in figures 1 and 2.

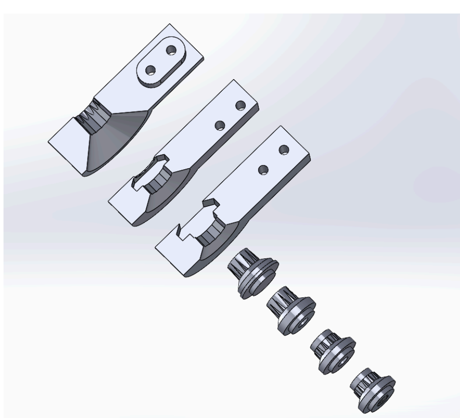


Figure 1

Figure 2

4. *Design Specifications and Results*

Specification, Constraints and Standards.

There are some factors which specify the quantitative specifications for a robot arm with an end effector such as payload capacity, reach, accuracy, speed, and safety.

- **Payload Capacity**: This refers to the maximum weight the robot arm can lift and manipulate. The specification should be determined based on the intended bolt weight.
- **Reach**: The reach of the robot arm defines the maximum distance from the base to the end effector. It determines the workspace the arm can cover. The reach specification should be determined based on the size and layout of the working area, as well as any other obstacles and hazards which may get in the way of the arm’s range of motion.
- **Accuracy**: The accuracy of this project refers to the ability of the robot arm to position its end effector precisely. It is usually specified in terms of the maximum allowable deviation from the desired position.
- **Speed**: It refers to the maximum velocity at which the robot arm can move. It is usually specified in terms of degrees per second or meters per second. The speed requirement depends on how quickly the robot arm is to complete its tasks as noted in the pseudocode flowchart and how much speed may impact attached parts.
- **Safety:** Safety is a crucial aspect of robotic systems. Specifications related to safety may include features like collision detection and avoidance, emergency stop mechanisms, and compliance with safety standards and regulations.

It's worth noting that specific industries and applications may have additional standards and codes that are relevant to the robot arm's design. As written on the official website for ISO standards, ISO 10218-1:2011 outlines safety requirements for industrial robots, including guidelines for their safe design, protective measures, and usage information. It addresses common robot hazards and provides requirements to eliminate or mitigate associated risks.

Final Design

Following the final design, Structural Steel will be primarily used for the End-Effector although ABS can suffice due to being inexpensive enough for smaller orders. When reaching the end of its use, the part can be easily manufactured in house and manually replaced.

Considering the weight of the end-effector, Structural Steel is a durable and robust material but it can also be heavy. Therefore, it's essential to consider the weight of the end-effector when designing it. Since the part can be easily manufactured in-house and manually replaced, consider making the end-effector modular so that it can be disassembled and reassembled quickly. This would also make it easier to reconfigure the setup in the future.

Using bolts of specified dimensions is a good practice, as it ensures compatibility with the existing setup. However, we can consider using standardized bolts such as ISO metric bolts, which are readily available and commonly used in engineering applications. If the end-effector is reconfigured in the future, it's crucial to perform material analysis to ensure that the new setup can handle the required loads and stresses. This analysis would also determine whether Structural Steel or ABS would be the best material for the new design.

Depending on the application, the end-effector may need to be designed with ergonomics in mind to ensure that it can be operated comfortably and efficiently. The complete understanding of the processing of the project will be shown at Figure 3.

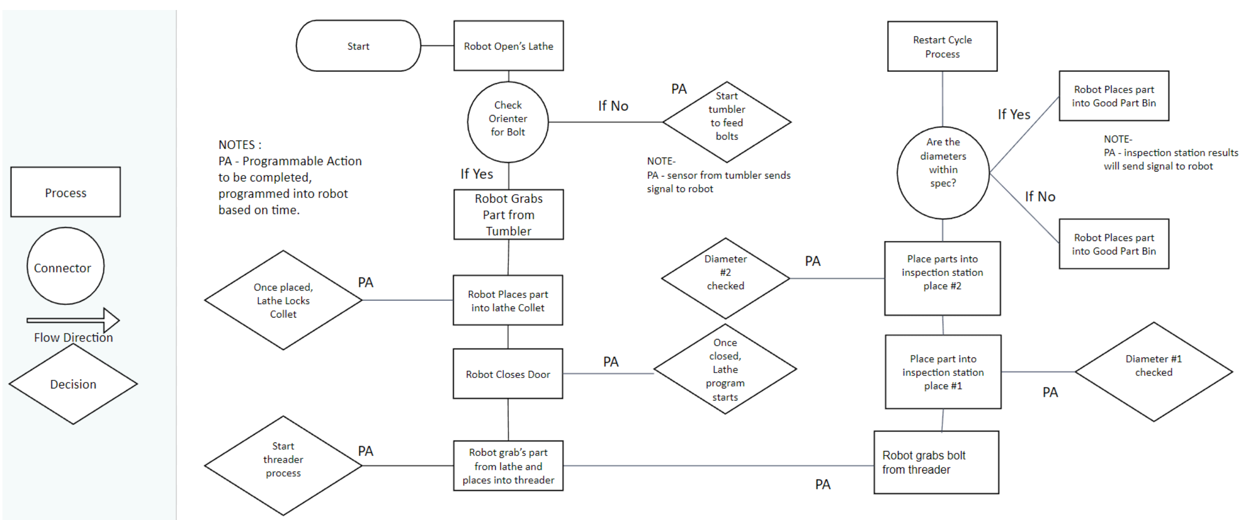


Figure 3: Process Flowchart

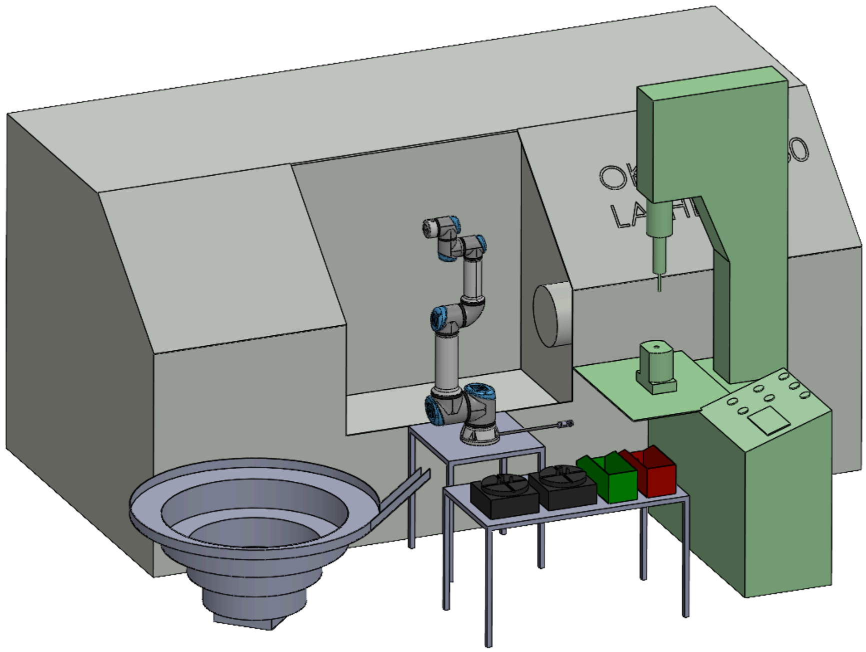


Figure 4: Cell Design

Detailed Design

a) ***Subsystem 1 - Tumbler***

i) ***Description***

A tumbler or vibratory bowl feeder is a versatile device used in automated assembly processes to feed and orient small parts or components. It consists of a bowl-shaped container, typically made of stainless steel, with a spiral track or conveyor system inside. The bowl is designed to hold and regulate the flow of parts, while the spiral track uses vibrations to move them along and orient them in a specific position. These tumblers come in various sizes to accommodate different part sizes and production requirements.

ii) ***Function***

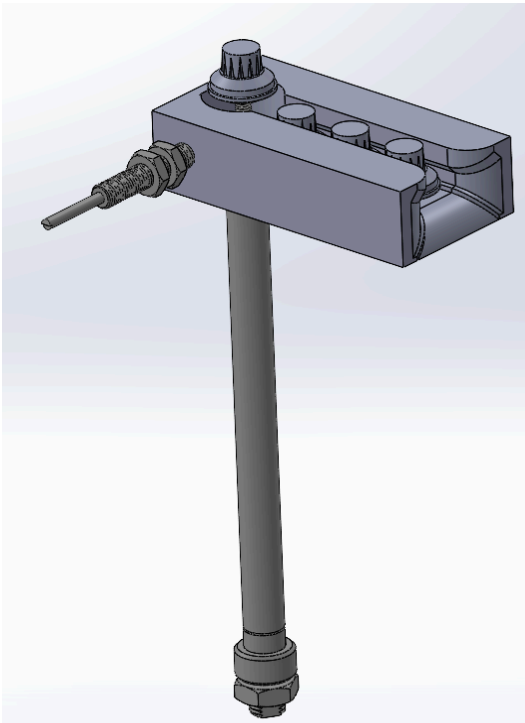


Figure 5: Tumbler Feeder System

The primary function of a tumbler is to efficiently and reliably feed small components such as bolts for automated assembly. The vibratory motion generated by the drive unit causes the pieces to move along the spiral track inside the bowl. As the parts move, the combination of centrifugal force, friction, and gravity assists to orient them in a desired position, such as heads up or threads down. The properly oriented parts are then discharged from the tumbler feeder for further processing or assembly. Tumblers are a great way to enhance productivity, reduce manual labor, and contribute to smoother assembly operations by ensuring a consistent and controlled flow of parts.

iii) Validation

The validation of a tumbler involves ensuring its proper functioning and adherence to specified requirements. During the validation process, various aspects are evaluated, including the bowl's structural integrity, dimensions, and material compatibility. Additionally, the performance of the drive unit, vibration settings, and part orientation capabilities are accessed. Validation typically involves conducting tests with representative parts to verify the feed rate, orientation accuracy, and reliability of the feeder. Regular maintenance and calibration may also be necessary to ensure ongoing validation and optimal performance of the tumbler in the assembly process.

b) Subsystem 2 - End-Effector/Robotic Arm

i) Description

The end effector is the tool or device attached to the robotic arms that enables it to interact and manipulate objects. It is specifically designed to collaborate and cooperate with human workers, rather than replacing them entirely. When equipped with an end effector, the collaborative robot becomes capable of performing a wide range of tasks. It is a mechanical device designed to grasp and hold objects securely. Collaborative robots can be equipped with various types of grippers. The collaborative robot with an end effector combines the safety features of a cobot with the functionality of the end effector to perform tasks collaboratively with humans. The cobot is equipped with sensors and control systems that enable it to detect the presence of humans and adjust its speed, force, or trajectory to ensure safe interaction.

ii) Function

The function of a collaborative robot with an end effector is to assist and collaborate with human workers in performing various tasks. The collaborative robot uses its end effector, such as grippers or suction cups, to pick up objects from one location and place them in another. This function is useful in tasks such as assembly, packaging, sorting, and material handling. By automating repetitive, physically demanding, or precise tasks, these robots improve productivity, reduce errors, and enhance overall efficiency in various industries.

iii) Validation

Collaborative robots with end effectors have been extensively deployed in various industries and have proven to be highly effective in improving productivity, enhancing safety, and streamlining operations by increasing efficiency with end effectors which can perform tasks with speed and precision. Improved safety which can slow down or stop to prevent collisions, ensuring a safe working environmen. Therefore, Structural steel generally has a slightly lower range compared to ABS. This can be attributed to steel's high strength and stiffness, which allows it to handle higher loads and stresses before reaching its failure point. Ergonomic benefits by handling heavy or repetitive tasks, collaborative robots alleviate physical strain and reduce the risk of injuries for human workers.

It also is that initial investment in collaborative robots may be significant, they offer long-term cost savings. Finally, it can be easily integrated into existing production lines or work cells, allowing for scalability and gradual automation adoption.

c) ***Overall System Integration***

i) ***Description***

The Collaborative Robot arm and the Vibratory Tumbler subsystems will work in tandem together in order to orient the bolts before being properly lifted by the Collaborative Robot through aid of the custom manufactured End-Effector. The robot should be able to open/close as well as startup the lathe in which to load/unload the bolts between stages as described in the flowchart in Figure 3 as well as be able to operate the threader and scales for validation.

ii) ***Validation***

The overall system is considered functional if the whole manufacturing process of the bolt being automated clocks in at about 5.5 minutes relative to the manual time of 9.4 minutes. As can be seen in table 4 the system should cut down on overall labor costs per batch which will allow a payback period of about 1 year assuming 13 batches can be made while operating an 8 hour work shift.

Analyses

a) ***Finite Element Analysis***

To test the effects of stress and wear and get an accurate read of fatigue life before the custom end effector needs replacement a FEA was performed through the use of ANSYS Workbench 2022. For the analysis a Quadratic Tetrahedron Mesh with element size of 5mm was chosen. The semicircular regions of the End-Effector including where the force is applied were further refined for improved accuracy, this yielded a total of 13230 elements and 27286 nodes. We then solved for the Equivalent Von Mises Stress of the whole body as well as Total Deformation. The material analysis during prototyping resulted in Structural Steel being the better material as it deforms far less during a lifespan of 18,830 cycles assuming max force of 40 N. Results for Steel seen in Figure 6.

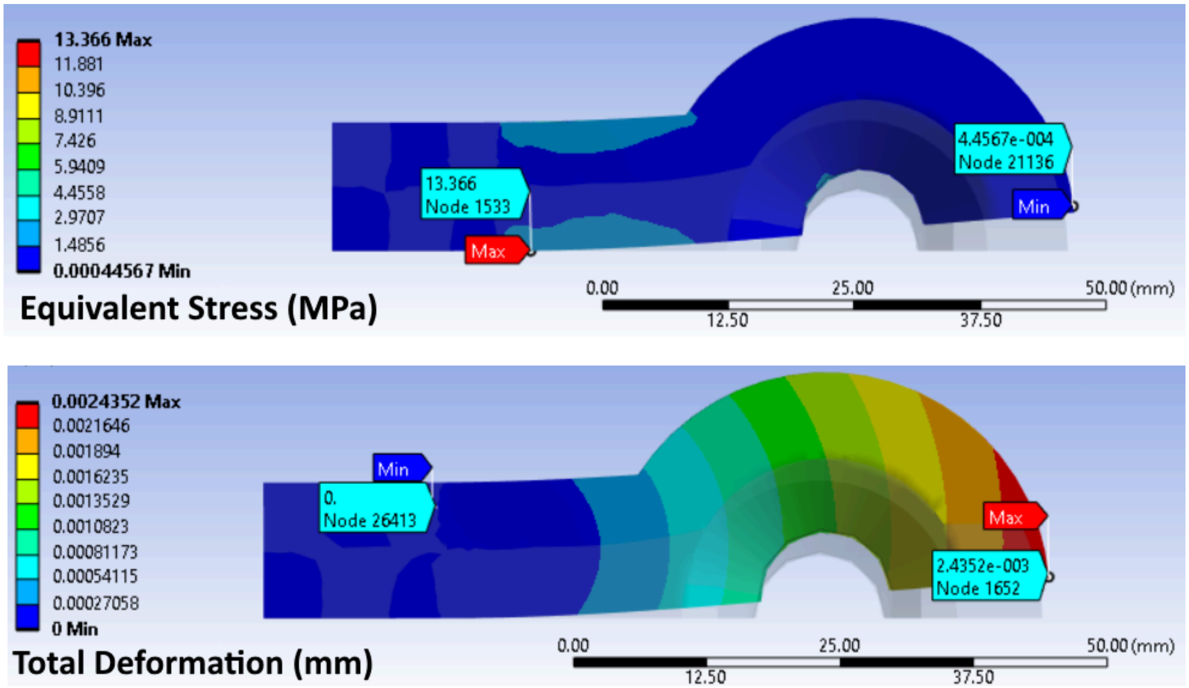


Figure 6

End Effector ANSYS Testing		
Material	**ABS**	**Steel**
Deflection (mm)	0.15196	0.00244
Equivalent Stress (MPa)	14.81	13.366

Table 2

b) FMEA

With this data derived from the FEA, we went about creating an FMEA Table (Failure Mode and Effect Analysis) to analyze possible failures that can arise from the End-Effector during operation. These failures are primarily based on the End-Effector deforming due to overuse, the possibility of snapping, and lastly being unable to move the bolts. As can be seen in the table created the parts manufactured fall below the robots maximum limit of 44 lbs, deformation is easily remedied via replacing the end-effector, and the applied stress is far below the materials failure point meaning during the 18,830 cycles it will not snap at the connection.

Process Step	Potential Failure Mode	Potential Failure Effect	SEV	Potential Causes	OCC	Current Process Controls	DET	RPN	Action Recommended
Robot moves bolts in/out of machine	End Effector Deforms/ Widens	Attachment no longer able to lift bolt	5	Deformation caused by overuse	8	Robot allows switching gripper when max deform occurs	10	400	Print/Construct duplicate End Effector
Robot moves bolts in/out of machine	End Effector snaps at connection	Proper operation of Robot is not possible	10	Fracture caused by applied force over time	2	Maximum stress over 10K cycles below material fracture	10	200	Print/Construct duplicate End Effector
Grab part from Orienter	Arm unable to lift	Proper operation of Robot is not possible	10	Bolt being worked with is too heavy	1	Current bolt is under 1 oz	10	100	Keep manufactured bolts under max weight of 44 lbs

Table 3: Failure Modes and Effects Analysis

c) *CAM/G-CODE Analysis*

Using the solidworks model designed by the team, G-code was created to 3D print test pieces for the end effector. This allowed for easy access to understand the much needed changes for gripping and manipulating the intended bolt. The group can also use the solidworks CAM software to create a G-Code program to mill the end effector. The team's future goal is to create a G-code program and simulated software showing the end effector manufacturing. This would allow for ease of access to manipulate the designed part when fully tested.

5. *Discussion*

The results of this experiment must first start with the corresponding manual manufacturing efficiency in order to determine the correct cause and effect. The manual labor manufacturing metrics can be found on table 4 below, along with the projected metrics of the automated system. The metrics from the designed system were taken through various testing within the project in order to validate the projected efficiency numbers. Important testing figures to note on, would be the accuracy of the end effector when picking up the bolt through the manufacturing process. Through solidworks design and 3D printing, multiple revisions of the end effector were able to be printed and tested to define the best gripping profile for the bolt. This allowed for the team to design multiple iterations and tests for the best possible manipulation of the bolt during this process. Overall the data shown below in the table projects the designed cell to increase efficiency by over 40% with a payback time well within 1 and a half years! These metrics are extremely important measures, as the company will in-turn manufacture more bolts within the same amount of time, while also maintaining and in the future, decreasing their labor costs.

	Manual Labor (Current)	Automated System (Projected)	Important Notes	Units
Efficiency (minutes per bolt)	9.4	5.5	Worker yearly Salary ($)	$80,000.00
Batch Size (Quantity of bolts)	2690	2690	Worker yearly working weeks	48
Total Time Needed (Minutes)	25286	14795	Worker Weekly Take-home ($)	$1,666.67
Total Time Needed (Hours)	421.4333333	246.5833333		
Total Amount of 8 hour shifts	52.67916667	30.82291667	Estimated System Cost ($)	$74,406.93
Total Amount of Days to complete	53	31	Amount of Day Saving's	41.51%
Total Amount of Weeks to complete	7.571428571	4.428571429	Cost Saving's per batch	
Total Labor Cost per batch	$12,619.05	$7,380.95	$5,238.10	
	Amount of Batch's	Time (years)		
Time to Payback Automated System	14.20495936	1.206448603		

Table 4

6. *Future Work*

Some concepts revolve around the functionality of new attachments for different types of bolts. For instance, there is a magnetic bolt holder that creates an attachment with a magnetic surface or a magnetic field generator capable of securely gripping metallic bolts of various sizes. The magnetic force can be adjusted to provide just enough hold on the bolt without causing any damage. Another idea involves a smart vision system integrated into the attachment, enabling it to identify and categorize bolts based on their size, shape, or markings. The robot arm can then adjust its grip or select the appropriate tool head accordingly.

Additionally, a novel approach is introduced where robotic manipulation is combined with non-destructive testing techniques to inspect and evaluate the integrity of bolts. This may involve equipping robotic arms with sensors for measurements, ultrasonic testing, or visual inspection to ensure the quality of the bolts. It could also include monitoring torque or tension to ensure that the bolts are tightened according to specifications, minimizing the risk of over or under-tightening.

To implement the bolt handling system on large machines like lathes and mills, modifications to the attachment design are necessary to meet the specific requirements of these machines. The attachment must be compatible with the machine's existing tooling or work-holding systems. This entails designing specialized tool heads or grippers that can securely handle bolts within the context of the machine's operations. Additionally, the development of software and control algorithms is crucial to enable the robot arm to effectively carry out bolt-handling tasks in coordination with the machine. This may involve programming the robot arm to retrieve bolts from designated locations, orient them correctly, and precisely position them within the machine's work area. Consideration should also be given to developing user-friendly interfaces or integrating with the machine's existing control software for ease of operation.

7. *Impact Statement*

a) Economic analysis

The project towards companies with bolt production lines, considerations when solving this solution involve buying a highly intelligent collaborative robot, though this could cost high amounts of money exceedings 250,000$ or more. As compared to paying a worker currently, 60,000-80,000$ a year to manage the machines but not be as efficient. While the initial investment in collaborative robots may be substantial, they can result in long-term cost savings. It will save cost and time for the company and also be high efficiency. The volume of bolts have increased, the cost of it will be decreased which is good for the economy in the assembly industry.

b) Environmental impact analysis

Life Cycle including five periods which are material, manufacturing, distribution, using, and disposal or recycle. Each period can affect the environment this way or another, using multi-phase steel which costs $100 per pound leading to environmental pollution by mining iron for fusing steel. Manufacturing also uses huge amounts of electricity which can put great pressure on the environment. The distribution and using are less effective for the environment, but this project will provide solutions. We can reuse or rework each bolt instead of disposing it, this will help the environment avoid metal pollution and cost savings on destruction. It also helps the company decrease material waste by improving precision and reducing errors, and collaborative robots minimize material waste during production This leads to more sustainable resource management and reduced environmental pollution associated with waste disposal.

c) Social impact analysis

The project will bring some positive and negative impacts to society. For the positive impact side, operators can improve skills, facilitate skill training for laborers, save the labor force, economic growth, and create a new change in bolt production. It can enhance worker safety and prioritize worker safety by implementing advanced sensors and control systems. On the other side, it also has a negative one such as unemployment for low skill laborers, creating environmental pollution by the continuous use of electric energy, and difficulty adapting to changes in the manufacturing industry for both employees and employers.

d) Ethical analysis

A holistic approach to the manufacturing process that focuses on good health for all involved. This means that a product’s design, creation, and use maintain sustainable standards and that the item and the process of making these have a positive impact on communities. An ethical project has oversight and cares about each section of its business and its own supply chain, prioritizing the well-being of both customers and staff, as well as the environment in which they work, shop, and source materials. The project wants to operate in the best interest of workers. The health and happiness of staff become priorities, going beyond the standard legal requirements. This means that safety is not sacrificed, and workers are treated fairly.

8. Budget Updated

The original budget for the project was to be within the same salary of a yearly worker for the machine operations, being approximately 80,000$. Over the course of testing and designing the manufacturing cell, the proposed materials used totaled to be within the budget coming to just under 75,000$. This is an important benchmark, as the company wants to implement a project that can be paid back for itself within the year. This will allow for a quick turnaround time for implementation and efficiency increases within the facility. The exact details for the bill of materials, companies and products required from each vendor as well as price can be found in the appendix on page 27. Please refer to this table in the appendix for any budgetary questions, issues or constraints.

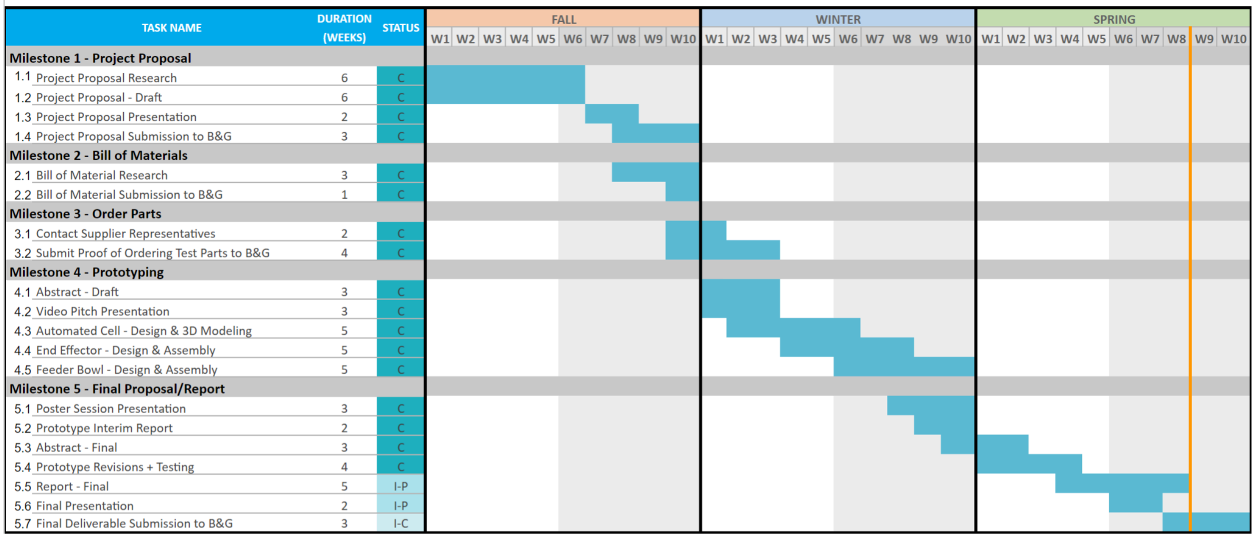
9. *Project Management Update*

Schedule and Milestone			
Fall Quarter 🍂			
Task	**Due Date**	**Status**	**Additional Notes**
Form Teams	9/16/2022	○ Complete	
Finalize Teams	9/23/2022	○ Complete	
Submit Project Qualification Form and Advisor Confirmation Form	9/30/2022	○ Complete	
Submit Value Sensitive Design Activity	10/10/2022	○ Complete	
Submit Written Proposal Draft	10/28/2022	○ Complete	
Submit Senior Design Invention Disclosure Form	11/4/2022	○ Complete	
Milestone Presentation (Proposal)	11/7/2022 - 11/11/2022	○ Complete	
Submit Bill of Materials, Proof of Ordering, Team Equity Charter, Final Written Proposal	12/3/2022	○ Complete	
Winter Quarter ❄️			
Task	**Due Date**	**Status**	**Additional Notes**
Submit Video Pitch	2/10/2023	○ Complete	
Submit Abstract Draft	2/24/2023	○ Complete	
Submit Poster	3/10/2023	○ Complete	
Submit Interim Reports on Prototyping Effort	3/10/2023	○ Complete	
Attend Poster Session	3/17/2023	○ Complete	
Spring Quarter 🌱			
Task	**Due Date**	**Status**	**Additional Notes**
Submit Final Abstract	4/14/2023	○ Complete	
Machine Shope will no longer take orders for Senior Design	5/1/2023	○ Complete	
Submit Final Report Draft	5/5/2023	○ Complete	
Submit Final Presentation Draft	5/12/2023	○ Complete	
Final Presentation	5/15/2023 - 5/19/2023	○ In-Progress	5/25/2023 - 1:30pm
Submit Final Report	5/26/2023	○ In-Progress	
Celebration of Engineering Design	6/1/2023	○ Not Started	

Table 5

The intention of table 5 is to provide structure for the team. This ensures that important deadlines/assignments are not missed and completed on time. The table is divided into 3 sections (fall, winter, and spring quarter) that represents the allotted time we are given to complete our project. Under each section, sub-sections have been created to showcase necessary information. This includes the name, due date, and status of a given task. The main purpose of the additional notes subsection is to comment on changes associated with its respective task. These changes may include but are not limited to due dates and/or finalized presentation dates. Additionally, all of the tasks on this table are chronologically ordered starting from top to bottom.

Timeline



TASK NAME	DURATION (WEEKS)	STATUS
Milestone 1 - Project Proposal		
1.1 Project Proposal Research	6	C
1.2 Project Proposal - Draft	6	C
1.3 Project Proposal Presentation	2	C
1.4 Project Proposal Submission to B&G	3	C
Milestone 2 - Bill of Materials		
2.1 Bill of Material Research	3	C
2.2 Bill of Material Submission to B&G	1	C
Milestone 3 - Order Parts		
3.1 Contact Supplier Representatives	2	C
3.2 Submit Proof of Ordering Test Parts to B&G	4	C
Milestone 4 - Prototyping		
4.1 Abstract - Draft	3	C
4.2 Video Pitch Presentation	3	C
4.3 Automated Cell - Design & 3D Modeling	5	C
4.4 End Effector - Design & Assembly	5	C
4.5 Feeder Bowl - Design & Assembly	5	C
Milestone 5 - Final Proposal/Report		
5.1 Poster Session Presentation	3	C
5.2 Prototype Interim Report	2	C
5.3 Abstract - Final	3	C
5.4 Prototype Revisions + Testing	4	C
5.5 Report - Final	5	I-P
5.6 Final Presentation	2	I-P
5.7 Final Deliverable Submission to B&G	3	I-C

Table 6: Gantt Chart

Team organization

Team Member 1 - Focus on the Solid works design of fixturing with interconnecting systems.

Team Member 2 - Extensive research on collaborative robots, capabilities and hardware functionality.

Team Member 3 - Programming / understanding of what hardware is needed for all functions to communicate.

Team Member 4 - Extensive research on vibratory feeder / tumblers for bolt presentation.

Team Member 5 - Creating understanding on effectiveness of product and goal intentions/completion.

10.References

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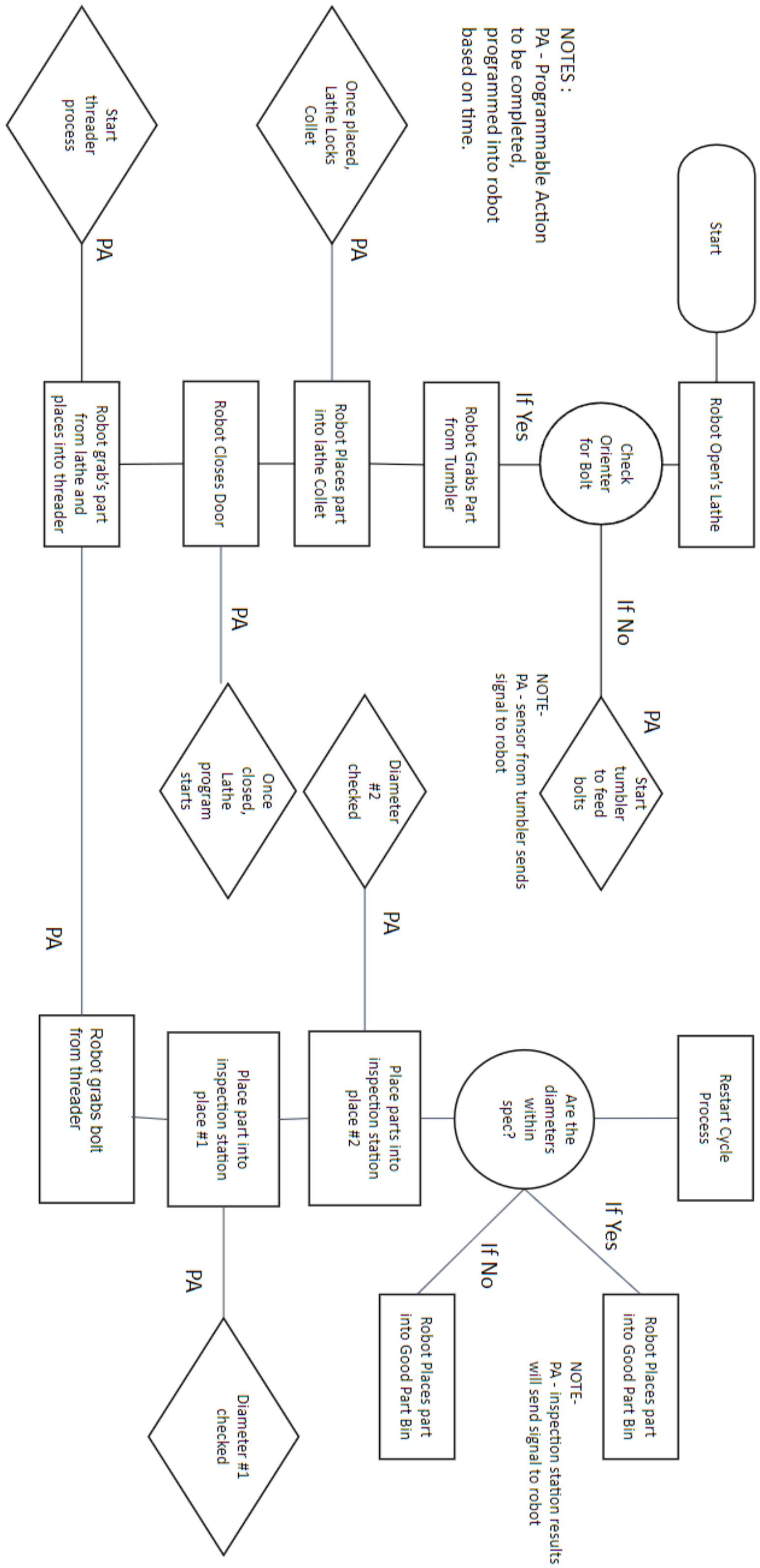
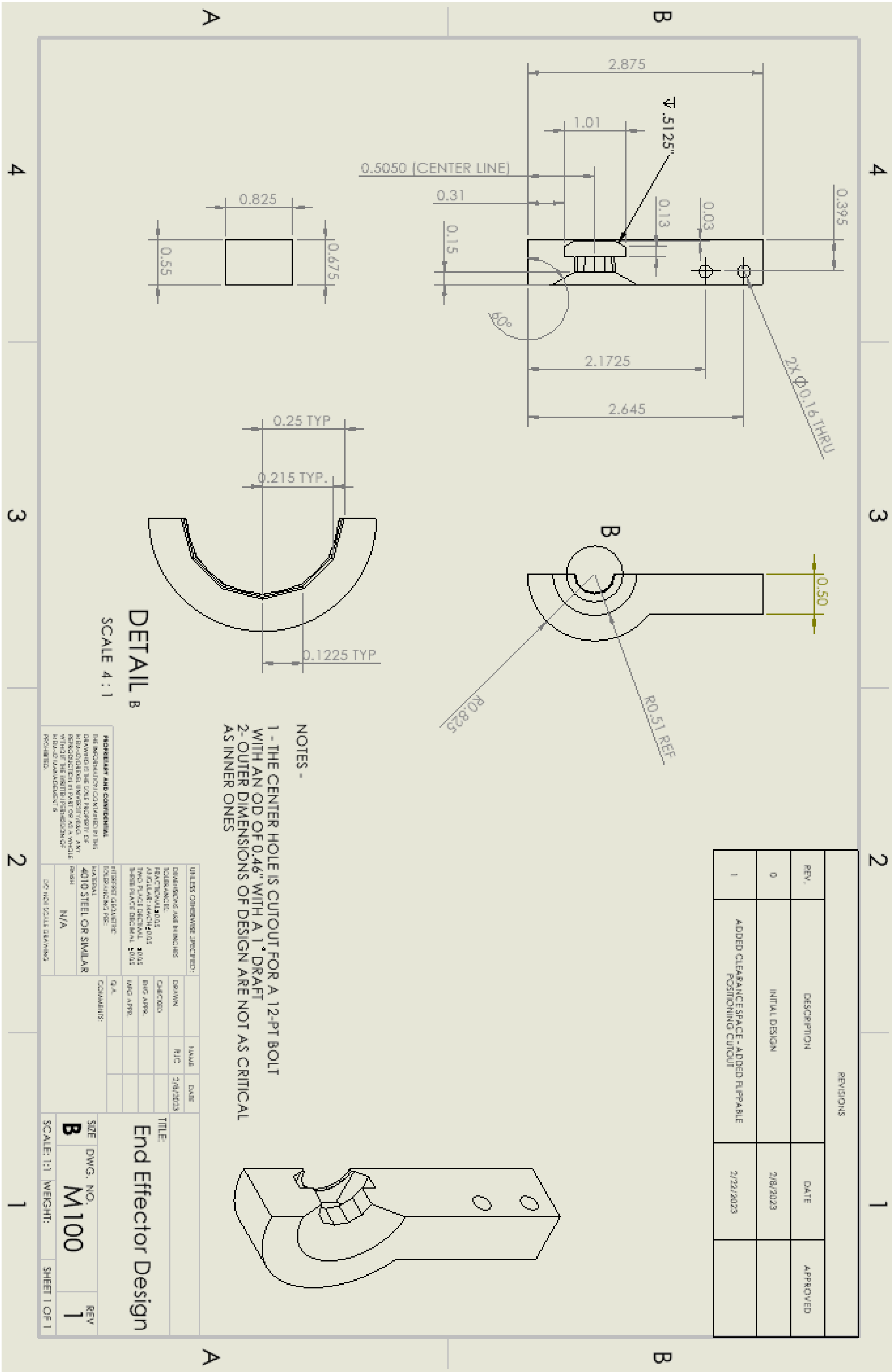
Wolfsteiner, P, & Pfeiffer, F. "Dynamics of a Vibratory Feeder." *Proceedings of the ASME 1997 Design Engineering Technical Conferences*. *Volume 1C: 16th Biennial Conference on Mechanical Vibration and Noise*. Sacramento, California, USA. September 14–17, 1997. V01CT15A011. ASME

11. Appendix

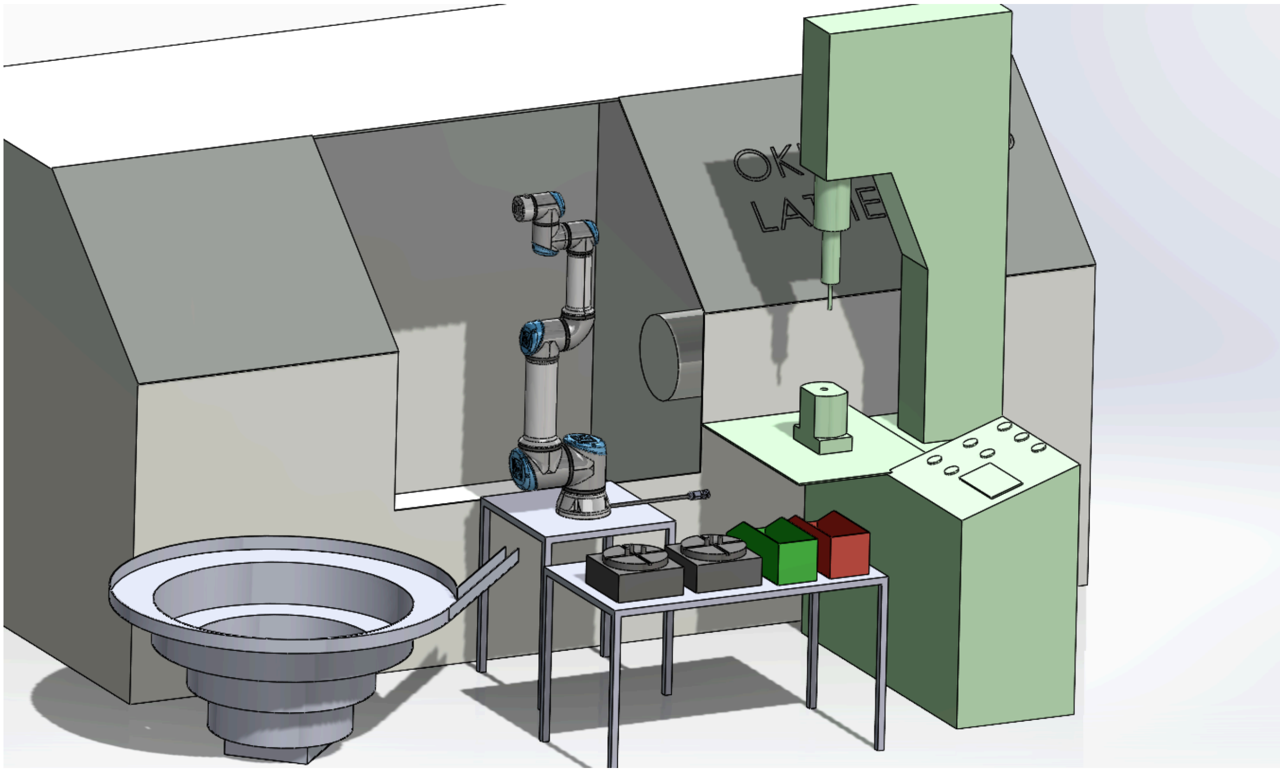
Appendix A. - Process Flow Chart

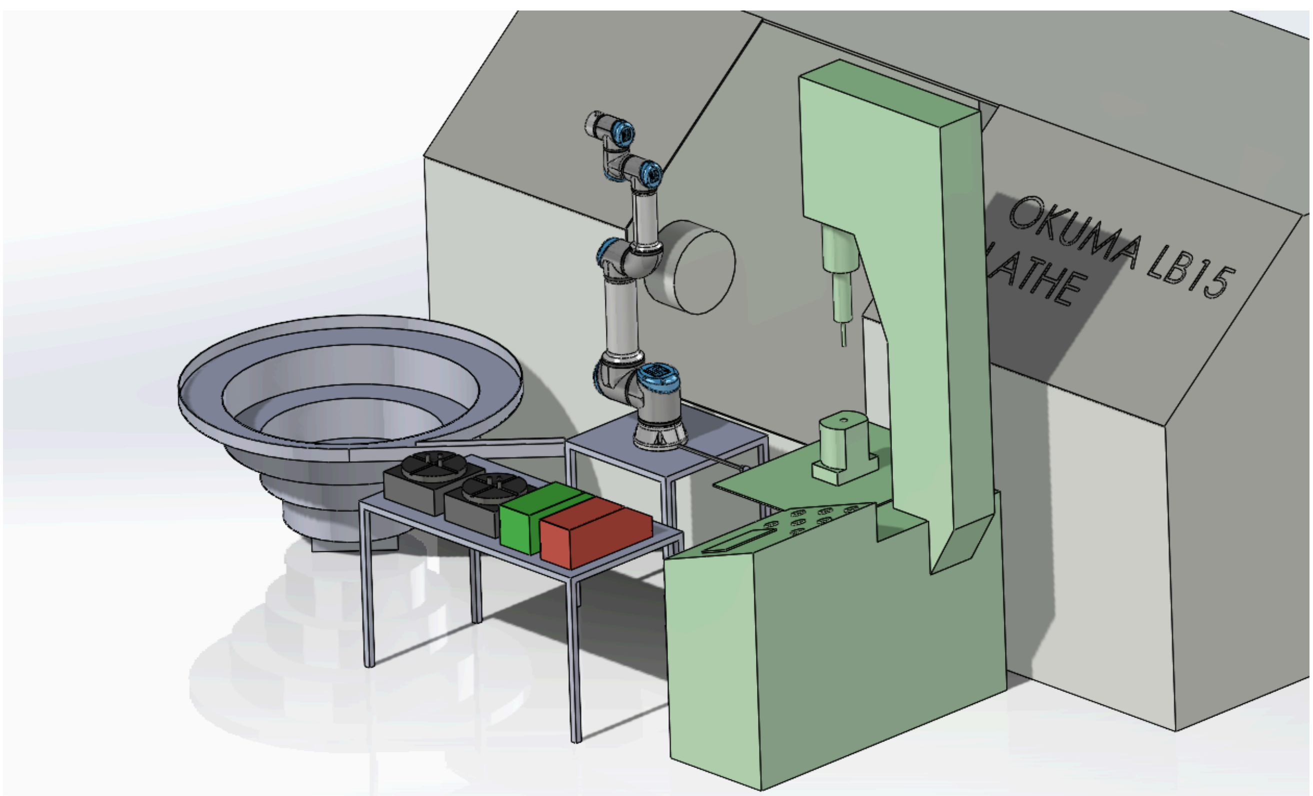


Appendix B. - End Effector Drawing



Appendix C. - Complete Cell 3D Design





Appendix D. - Bill of Materials

Bill of Materials (BOM)		
Company	**Item**	**Cost**
Universal Robot	UR-20 Collaborative Robot	$59,000.00
On-robot	Robotic Gripper	$4,963.00
Hoosier Feeder	Vibratory Feeder/Tumbler	$9,995.00
McMaster Carr	24V/DC Solenoid 1/8" NPT	$111.96
McMaster Carr	1/8" OD Air Tubing - 50ft	$14.50
McMaster Carr	1/8" Muffler	$2.33
McMaster Carr	1/8" NPT Air Fitting	$5.26
McMaster Carr	Arduino Mega 2560	$51.86
Overture Filament	PLA - easy space grey filament	$19.99
McMaster Carr	Low Carbon - A36 Steel (3" x 3" x 2")	$49.57
McMaster Carr	M5-0.8mm Steel Screws - 50 pack	$17.65
McMaster Carr	M5-0.8mm Steel Nuts - 100 pack	$4.05
McMaster Carr	Air Cylinder with 3" stroke - 15LB @100psi	$43.46
McMaster Carr	Proximity Sensor - 6mm Sensing Distance	$128.30
	Total Cost	$74,406.93

Appendix E. Customer/Stakeholders Needs and Specifications

Metric No.	Metric	Units	Impact	Marginal Value	Ideal Value
1	Total Bot Travel Distance	Inches	5	19.7" - 68.9"	60"
2	Measurement Accuracy	Thousandths of an Inch	5	.0005" - .0001"	.00005" - .00001"
3	Efficiency	Parts per hour	3	20-100%	60-100%
4	Weight of Part	Oz	1	1oz - 2lb	Current Part - 2oz
5	Overall Length/Height of Part	Inches	2	0.5" - 2"	Current Part - 1.01" , 0.675”
6	Weight of Bot	Lbs	1	24.7 lb - 141.1 lb	141 lb
7	Accessibility Time	minutes	2	5 - 10 minutes	less than 1 - 2 minutes
8	Payload	lbs	1	6.6 lb - 44.1 lb	44.1 lb