MIE221 Group 11 Final Report:
High Volume Automatic Chair Caster Assembly System

April 14 2022

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1.0 Basic Overview of System:

This proposal presents a modular and automated assembly line for a 2-inch chair caster. The assembly line was created in line with design goals and objectives set by the team, pertaining to minimizing the cost, lowering manufacturing error probability, etc. Based on these motivators, the entire system was created through three subsystems: The sorting and orienting system (SO), the feedtrack (FT), and the assembly system (AS). In the SO system, a wiper and pressure beak coupled with a vibratory bowl is used to orient components like the wheel, washer, nut, bolt and axles correctly. After this, the parts will pass through the FGM system, which is made to ensure the lowest probability of jamming. Each part will have its own subsystem in the AS system. Once the parts are fed through to their respective AS subsystem, they will be assembled fully. The AS system employs a mobile-wagon for parts to be assembled onto, making the process fully modular for geometrical changes to the design. In order to ensure the system flows, the team has process control systems in place, such as machine vision robots detecting physical defects in the assembly line to improve the process. The quality control system being used is the IOS 9001:2015 Quality Management System.

2.0 Design Goals and Objectives, Caster Dimensions

The objectives of the assembly line design are outlined in Table 1. These were the measures used to guide the decision making process regarding designs.

Table 1. Design Objectives and Metrics, Ranked by Implementation Priority

Objective	**Metric**	**Priority**
Design Simplicity	Combine components for simplification of design	Medium
Minimize Cost	Select parts and materials as to ensure final assembly system cost is under CAD 500 000, unless superseded by any other design objective	Low
Minimize Number of Assembly Stations	Combine assembly stations when it does interfere with objective 1, 4 or 5	Medium
Minimize use of complicated robots in design	Use simple positioning robots only when absolutely needed	Medium
Minimize Jamming Potential	Use simple gating systems, minimize probability parts can be attached incorrectly	High

4.1 Sorting, Orienting, Feedtrack, Gating, Metering Systems

Since assembly is entirely automatic, it is important to ensure that all individual components of the caster are properly oriented. It was selected that the orienting of all components would be achieved through the use of vibratory bowl feeders where parts are randomly oriented due to continuous vibration and only properly oriented parts pass through the delivery chute to the feed track. Vibratory bowls were selected as all components of the caster are not fragile and can withstand the repeated impact of rejection [1]. Each component uses a vibratory bowl feeder to accommodate its size with the main difference between feeders being the ending orienting track of the bowl to ensure properly oriented parts pass through and improperly oriented parts are rejected.

There are a few characteristics of orienting tracks that are common between all six caster parts. Each has a wiper, pressure break, and angled track. A wiper is used at the start of each orienting track and its purpose is to reject any parts improperly standing upright or any stacked parts [2]. The purpose of the pressure break is to ensure that parts are single filed before entering the delivery chute as only one part is able to maneuver around the pressure break at a time. For the orienting of axles, a wiper and pressure break ensure the axles are correctly oriented and they are funneled in their orientations to the delivery chute. For the bolt, again a wiper and pressure break are used to orient the bolts correctly and as they approach the exit the bolts are suspended by their heads through the use of two parallel rails across a slot in the track that is larger than the bolt's body diameter but smaller than the bolt's head diameter as seen in Figure 1 [3].

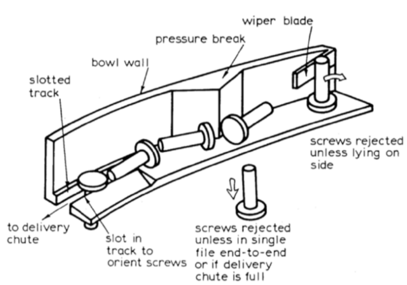


Figure 1. Orienting of bolts [3]

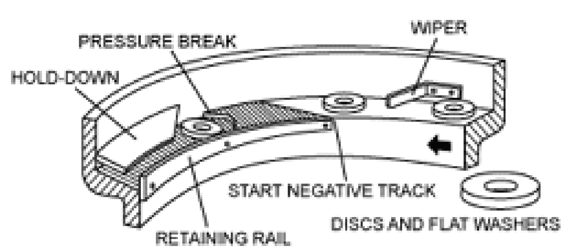


Figure 2. Orienting of washers (and nuts) [2]

Figure 2 shows the orienting track design for washers with the one for nuts using a similar approach. For washers and nuts, the end of the track has a negative angle with a retaining ledge with a height that is smaller than the thickness of the washer or nut [2]. This ensures that the washer or nut is lying flat on its side and that it is ready to be fed.

The wheels are oriented in a similar manner to rounded cups. Along with a pressure break and wiper, scallops are used on the track to ensure only one orientation can pass through by rejecting the wheels with the open side facing down with the help of a slight negative angle beneath the scallops to help carry off these rejected parts. The scallops allow the wheels with the open end up to pass while those with the open end down will fall over the scallops and return to the bowl [2]. Figure 3 shows the concept of the orienting track for the caster wheels.

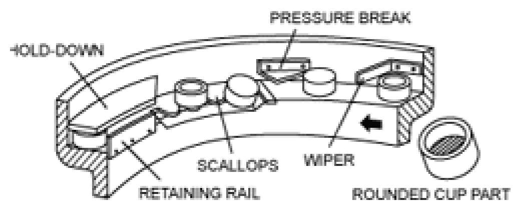


Figure 3. Orienting track for wheels [2]

To orient the housing, a pressure break, wiper, and dish-out are used as well as a secondary wiper blade. The purpose of the dish-out is to ensure that only housings with the rounded section facing the wall of the bowl pass through. The secondary wiper blade rejects housings that are leading with the side that has the hole for the bolt and only accepts those with the hole trailing.

This process is also accompanied by the feeding, gating, and metering system. The machinery within this section are vital to the assembly process, as they guide each component along the line and control the overall flow of product. Feeding consists of how components will move within the system, specifically into the actual assembly process, and along the line. This part of the assembly process mainly involved using gravity tracks along with vibratory feeder bowls as stated before, in order to sort and orient each piece and send them down in a position that could be attached to the workcell correctly [3][4].

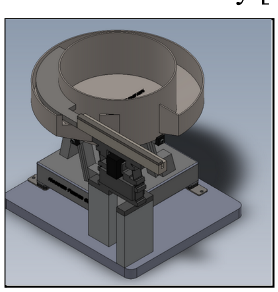
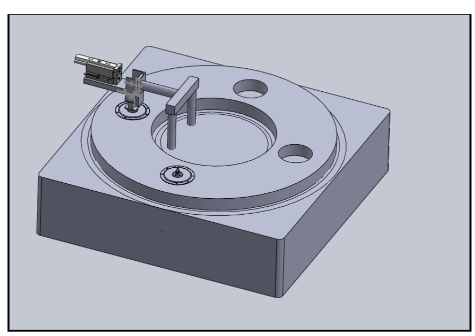



Figure 4 & 5:. Vibratory feeder (left), Work table (right)

Each gravity track is also attached to a motor for vibrational support to negate friction along the feeding process. Each station contains this configuration of having the component go through a vibratory feeder then sent through a gravity track. The actual assembly line containing the work cells uses an automated conveyor track, since a gravity fed option would be unable to operate due to the arrangement of the work table [5] (parallel to the ground, therefore no potential for vertical momentum).

Gating and metering refers to how the flow of components are controlled throughout the feeding system, as well as how they are metered to ensure a smooth flow process. This stage consisted of using two components: linear escapements and sliders. Linear escapements act as the main gating and metering machinery since they control the flow of the product and prevent jamming from happening throughout the feeding process. Borth duel timed and single non-rotating type escapements with a stroke of 1-inch will be used for each section [6][7]. The use of linear positioning slides also with a stroke of 1-inch, will also be used to guide components out of the feeding tracks.

4.3 Assembly System (AS) Overview - Indexing, Work carrier

The work carrier is designed to allow linear inputs for the bolt, wheels and axle by propping the housing up from the ring extrude around the axle hole. The wagon has also been designed to allow the pancake motor to rotate due to having the motor's shaft press fitted into the bottom of it. Furthermore, the work carrier's wall designs ensure that the housing will fall into the correct orientation due to their sloped tops that guide the housing towards the center of the work cell.

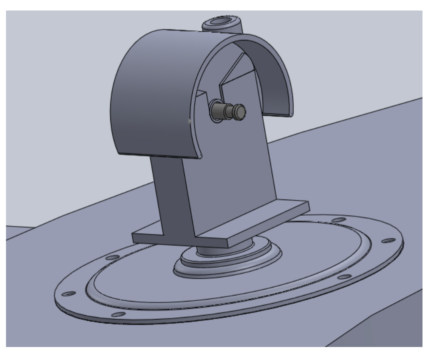


Figure 6**:** Image of the CAD for the caster, work cell and pancake motor.

4.3.1 Housing Input

The general process for inputting the housing onto the wagon is as follows. The workcell will arrive at the housing input station with the hole for the axle facing the perimeter of the rotary table. The feeding system for the housing will meter one to the platform directly in front of the pneumatic 1-inch stroke pusher in the orientations seen in the Figure [6] with the help of a simple gating system. The pusher will then push the housing onto the retractable platform right in front of it. The pusher will continue pushing the housing until just before it presses against the rigid wall on the opposite side of the caster. Next, the retractable platform will retract and the housing will fall flat onto the wagon. The housing falls onto the wagon without any slant due to the pusher and the rigid wall acting as guide rails by being directly next to it. Similarly, the rigid wall and flaps help prevent the housing from diverging from its intended position on the wagon. The workcell is then rotated slightly in such a way that the flat motor does not come into contact with the rigid wall when the rotary table rotates the workcell to the next station.

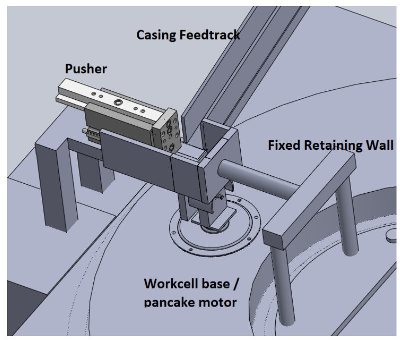
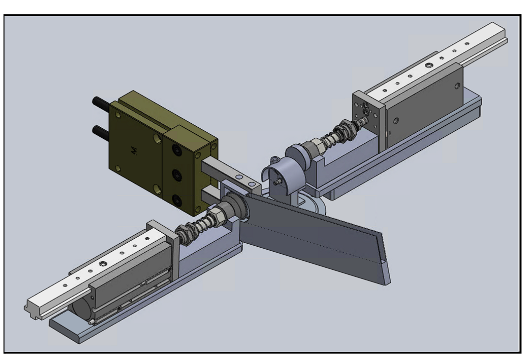
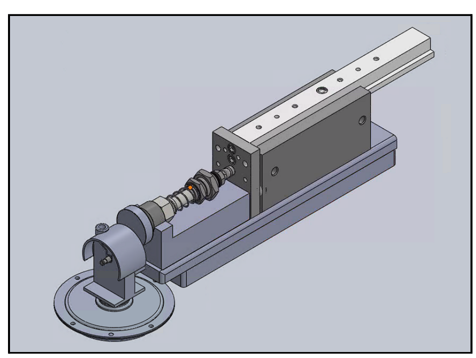


Figure 7: Image of CAD for the housing assembly process.

4.3.2 Axle and Wheel Inputs 1 and 2

The general process for inputting the wheel and axle is as follows. The workcell arrives at the axle and wheel station with the axle hole in the housing pointing towards the perimeter of the rotary table. The feeding system for the axle will meter one directly in front of the pneumatic 1-inch stroke pusher with an extended pusher attachment. Here the axle will be pushed into the axle hole in the housing with the help of a retractable platform which will close the gap between the hole and the axle. The axle is then pushed into its position in the housing and held there until the first wheel is pushed onto it on the opposite side. Once the wheel is in place, the pusher and retractable platform will retract and reset for the next axle. The CAD for this system can be seen in figure 9.





Figures 8 & 9: CAD of the axle and wheel input process (left) and a closer image of the axle input process.

The feeding system for the wheel guides a component to be directly in front of the pneumatic linear pusher with a vacuum gripper, as its pusher's tip and directly behind a feed escapement. The system is oriented in such a way that the wheel is concentric with its final position on the caster. In addition, the pneumatic gripper has a wall attached to the side of its pusher. The purpose of this wall is to act as a metering system for the wheels which will save the cost of adding another feed escapement device. To achieve this, the wall is oriented in such a way that when the pusher extends, the wall replaces the space the wheel being inputted was in before the extension. From here the vacuum gripper will press against the wheel which is constrained by the fully extended feed escapement gate. Once the vacuum is created on the wheel, the feed escapement gate will retract, allowing the pusher to push the wheel onto the axle. The axle is constrained from sliding towards the opposite side as the pusher for the axle is still constraining the axle from sliding out the opposite side. Once the first wheel is placed on the axle, the axle pusher will retract and the rotary platform will rotate 180^{o}. The axle pusher will then extend again and constrain the first wheel from sliding out when the second wheel is imputed. The CAD for this system can be seen in figure 8.

4.3.3 Bolt, Washer, Nut Assembly and Input

The bolt, washer and nut assembly (BWN) must occur before the bolt unit is attached into the castor casing. This is done through an elevated rotary table that first is inputted with upright bolts, before an elevated pusher pushes a washer through the bolt from underneath. A railing underneath the rotary table allows for the washer to travel alongside with the bolt without falling down, until the 3rd station, where the nut is pushed up via an elevated pusher and rotated in via a torque wrench above. The exit leads to another feed that ends above the clamped casing, where another torque wrench rotates the bolt assembly into it.

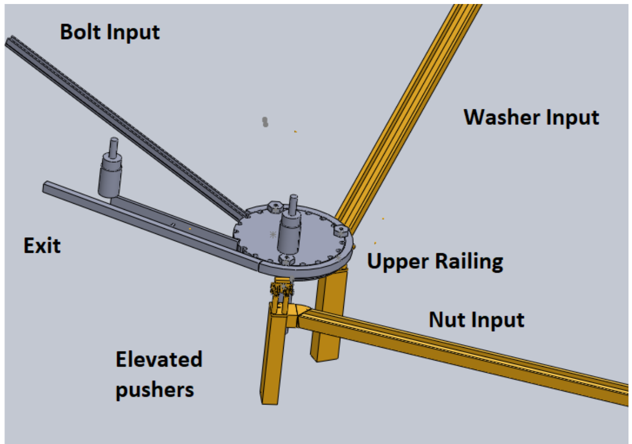
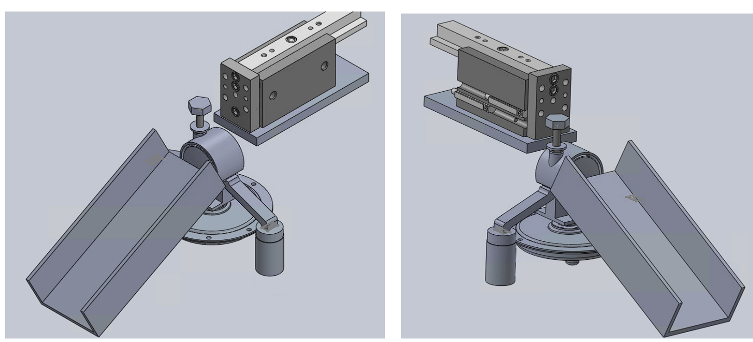


Figure 10: Nut, Bolt, Washer Assembly Station

4.3.4 Ejection

The general process for the ejection of the caster from the workcell into the collection bank is as follows. The workcell arrives at the ejection station with the wheels perpendicular to the perimeter of the rotary table from the bolt, washer and nut input**.** The caster is then lifted by linear actuators off of the workcell. These linear actuators are situated on the base of the rotary table and lift the caster from the gap between its two wheels as seen in figure []. The caster is then raised up to a pusher and a slide which leads to the collection bank. Here, the pusher pushes the caster off the linear actuators and onto the slide. The caster will slide down and into a collection bank.



Figures 11 & 12: Ejection System for Caster Wheel

5.0 Detailed Part Sourcing and Cost Analysis

Table 2 below highlights key parts that have been sourced that are included in the design along with an estimate of the price (detailed explanation in Appendix A) and the quantity needed.

Combining the total with the estimated cost of the custom included, the expected cost of the assembly system design is between $55000 and $75000.

Table 2. Part sourcing and Cost Analysis Table (Explanation of cost in Appendix A)

Part	Notes	Specificity and Source	Cost (USD)	Qty
Wheel Grip	Pneumatic gripper used for assembly of caster wheels	GrabCad originally from Aliexpress [7]	$120	1
Pushers (Horizontal Actuator)	1 inch stroke air cylinders used for all horizontal pushing	AGMS 1-2 Single Finger from AGI Automation [8]	$332	7
Pancake Motors	Used to rotate workcell	Printed Motor Works GPM9LR from TraceParts [9]	$120	4
Feeding Systems	Vibratory Bowls for orienting of all parts with feedtracks and hoppers included with custom orienting tracks	Automation Devices Inc. [10] and Hoosier Feeder Company [11]	$10000	5
Camera	Camera installed for quality control	a2A1920-51gmPRO - Basler ace 2 from Basler [5]	$479	1
Vertical Linear Actuator	Dual optical rod system for vertical actuation in NWB assembly	410-RC Dual Rod System from Newport [12]	$810	2
Total			$55023	

6.0 Quality & Process Control

The main objective of quality control is to plan for production of the design, control the assembly and flow of products within a manufacturing facility, then improve on every factor that could be corrected or refined in order to create a product that will satisfy consumer needs and continuously thrive as the market continues to change, as well as grow from its previous states.

Planning: The goal of this stage is to determine what the customer truly desires. In order to achieve a high quality control system as well, the "IOS 9001:2015 Quality management systems

- requirements” [4] manual will be incorporated into the manufacturing process. This will ensure that a set of metrics can be followed when the manufacturing process is taking place.
Control: Control focuses on managing the assembly line as well as monitoring, maintaining and correcting the flow of product as it’s being made. This process mainly involves using technology to detect anything out of place or incorrect within the assembly process. This could be damages to the product, geometric inaccuracies, improper assembly, etc. anything that will reduce the quality or value of the final product. The main instrument that will be used for this section will be the a2A1920-51gmPRO - Basler ace 2 machine vision camera at a price point of $479.00 [5] which detects physical defects along the line. If the camera detects any defects, a signal will be sent to the filtration systems of the assembly process, which will dispose of the part hastily. Information will also be sent from the camera to a database, so that improvements can be made based on what happens along the assembly line.
Improvements: In terms of improving the overall design, certain steps and precautions will be taken in order to ensure that some sort of refinement or correction can be made to the design. This includes offering and providing workers with the opportunity to learn and obtain a lean six sigma certification [6], so that they are capable of analyzing and processing information in order to create a solution geared towards improving production rates, decreasing defects, or other aspects of manufacturing that would be desirable from a business standpoint.

7.0 Optimisation for Multiple Caster Geometries

While the design of the automated assembly design is intended for only one size and shape of chair caster, there is a high degree of modularity within the assembly system as a whole allowing future improvements or changes within the assembly line design to accommodate a slightly different caster design. The assembly line is divided well into various modules which can be independently manipulated to satisfy any new necessary conditions. All feeding systems are independent and orienting and feed tracks can be changed, assembly stations can be slightly modified by changing grippers or certain positioners and pushers that would perhaps be more efficient for a different caster design. The workcell would be one of the most important aspects and an improvement to the workcell could allow multiple caster designs to be used with the same workcell. Overall, the modular design of the assembly system allows it to be optimized if necessary.

8.0 Conclusion

After analyzing and processing each aspect of an industrial manufacturing process, a thorough assembly system has been developed in order to maximize production, and improve on any aspects that can be changed for the future. Each decision was made to optimize various aspects of the manufacturing process such as cost & part sourcing, production, assembly, as well as a variety of others. A pre as well as post assembly system has been established for quality control, in order to improve and refine the quality of the product being produced, which will aid in improving production value, reduce any possibility for defects, and further optimize any other possibilities (for caster geometry).

References

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Appendix A. Cost Analysis Explanation

Part	**Specificity and Source**	**Cost (USD)**	**Cost Explanation**
Wheel Grip	GrabCad originally from Aliexpress [7]	$120	A similar model was found on Aliexpress for $60. A ‘safety factor’ of two was applied making the estimated price $120
Pushers (Horizontal Actuator)	AGMS 1-2 Single Finger from AGI Automation [8]	$332	Direct from source [8]
Pancake Motors	Printed Motor Works GPM9LR from TraceParts [9]	$120	By taking the average of five different similar flat motors the result was $120 USD
Feeding Systems	Automation Devices Inc. [10] and Hoosier Feeder Company [11]	$10,000	Based on market research and a live chat with Automation Devices Inc. [10] in which a feeding system for six parts was roughly estimated to be $60K, meaning that for each system is approximately $10K.
Camera	a2A1920-51gmPRO - Basler ace 2 from Basler [5]	$479	Directly from source [5]
Vertical Linear Actuator	410-RC Dual Rod System from Newport [12]	$810	Directly from source [12]

Appendix B. Engineering Drawings of Custom Parts

This appendix contains all two dimensional engineering drawings of custom parts used in the design.

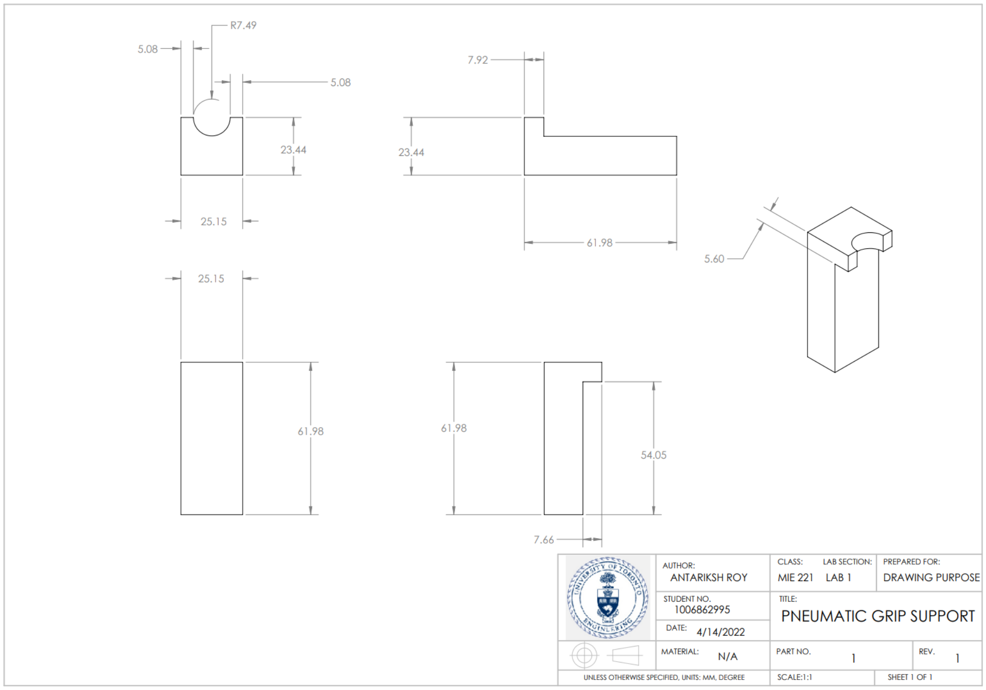

Figure D1. Pneumatic grip support

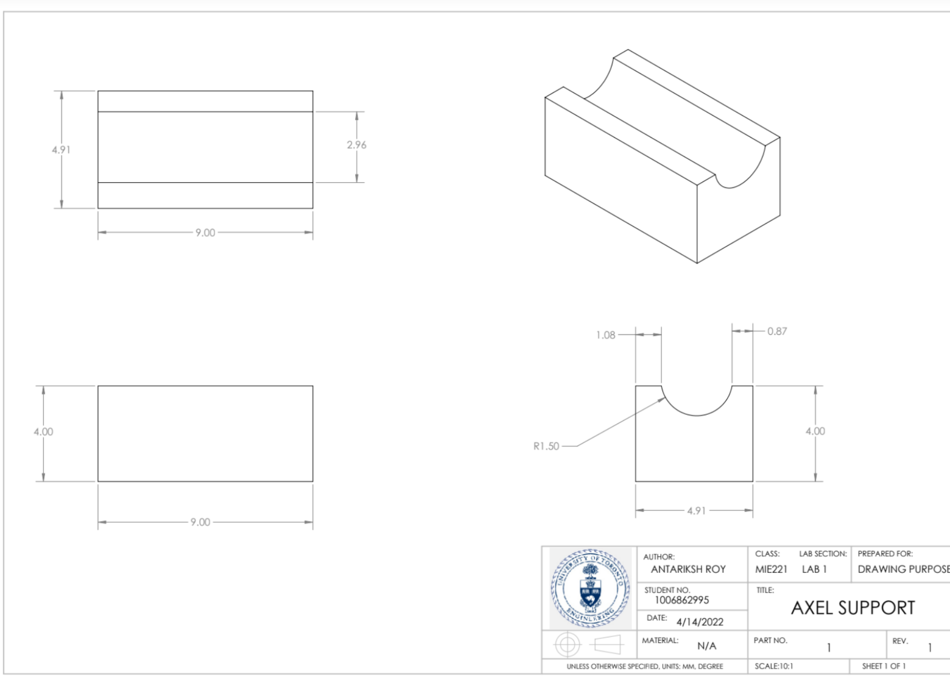

Figure D2. Axel Support

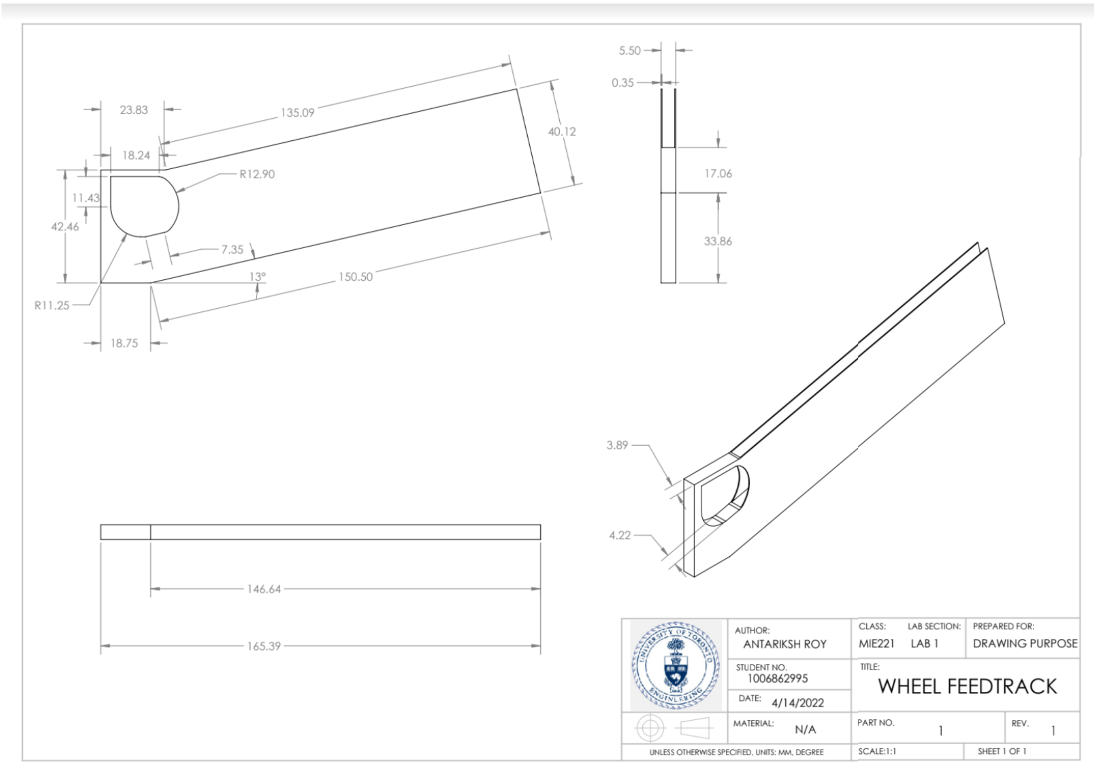

Figure D3. Wheel Feedtrack

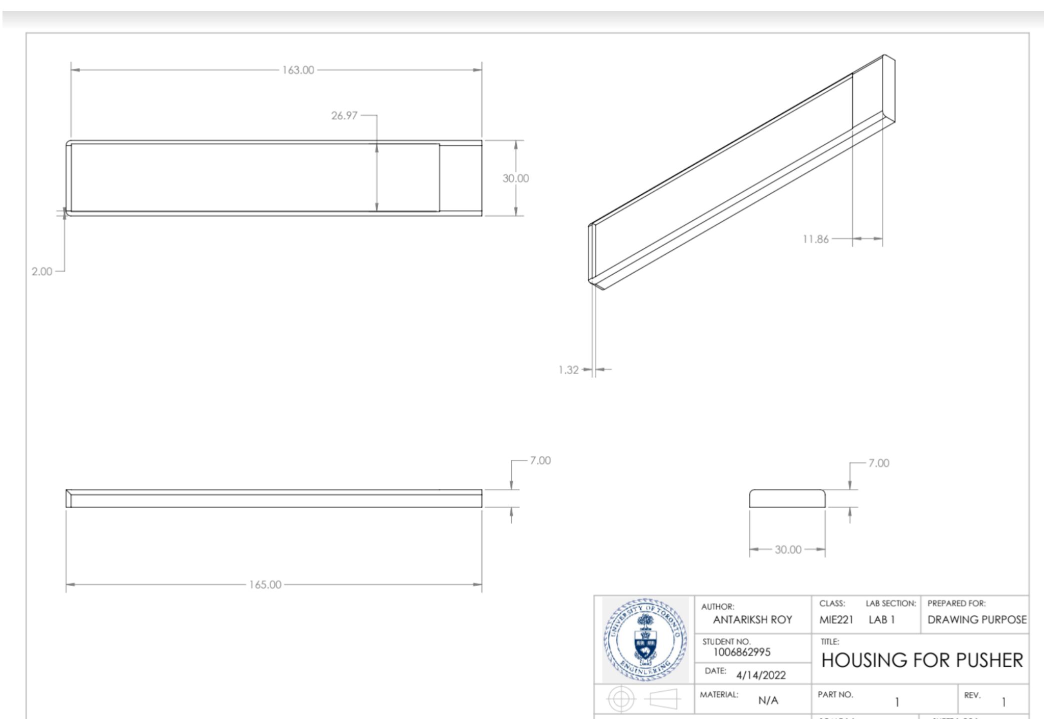

Figure D4. Housing for pusher

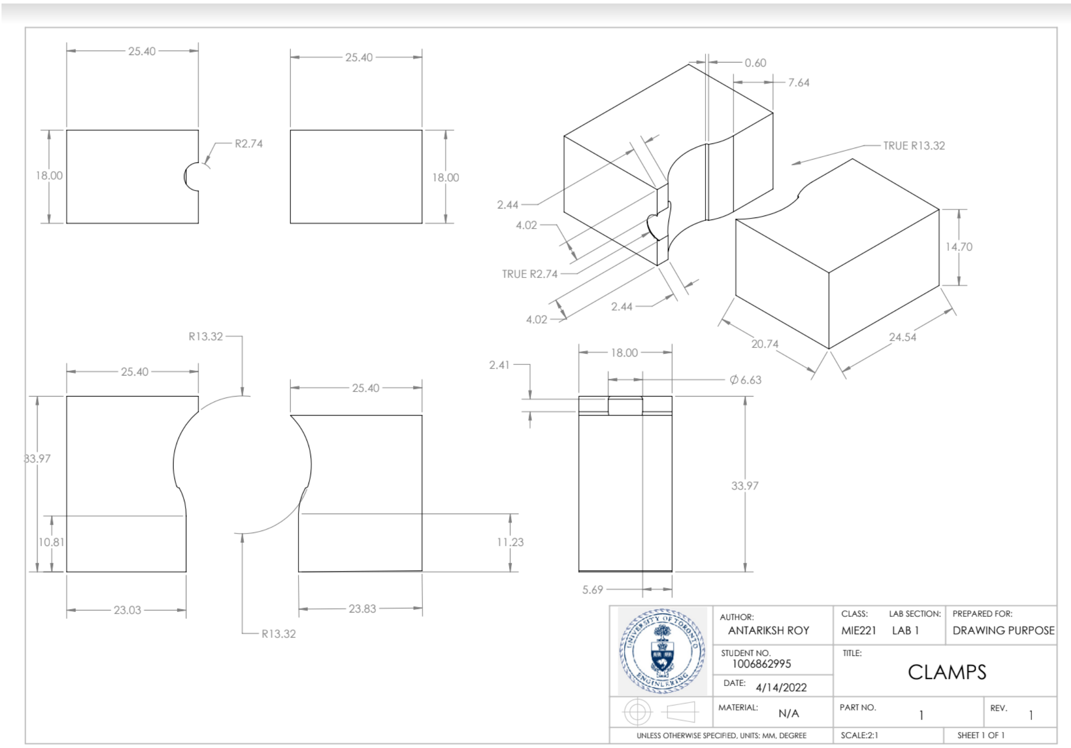

Figure D5. Clamps

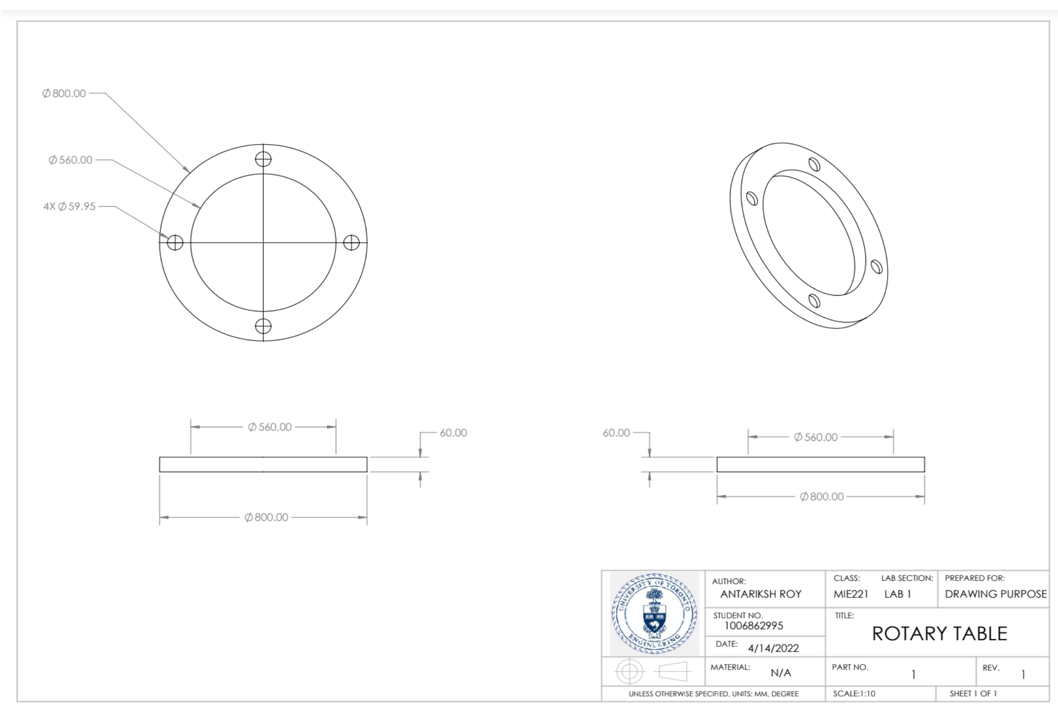

Figure D6. Rotary Table

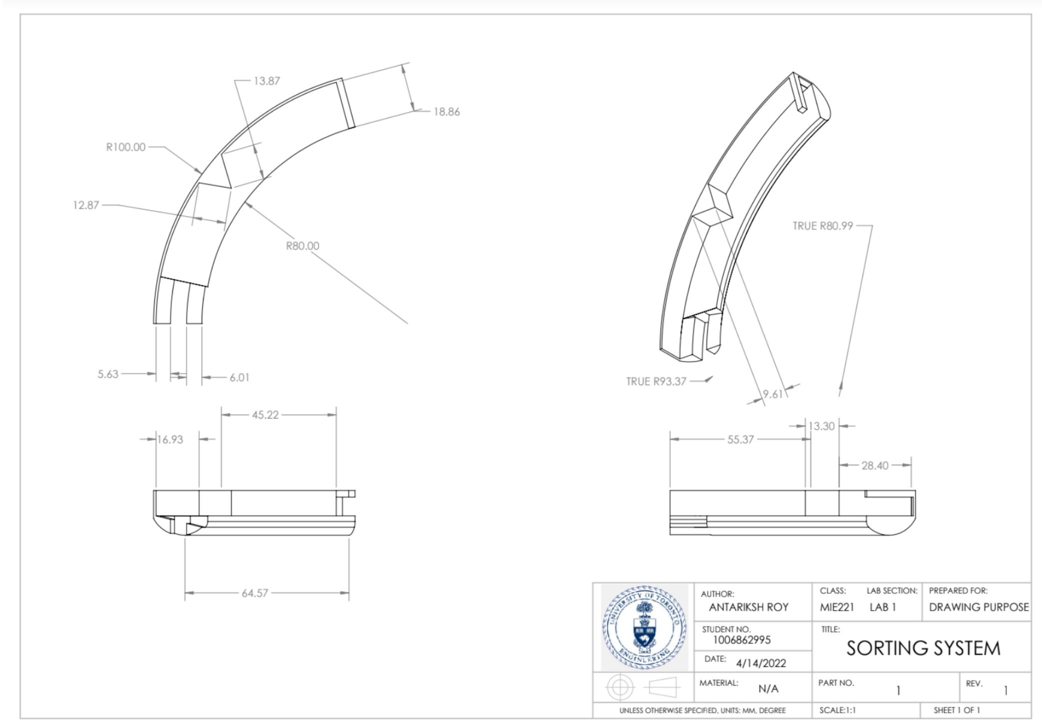

Figure D7. Sorting System

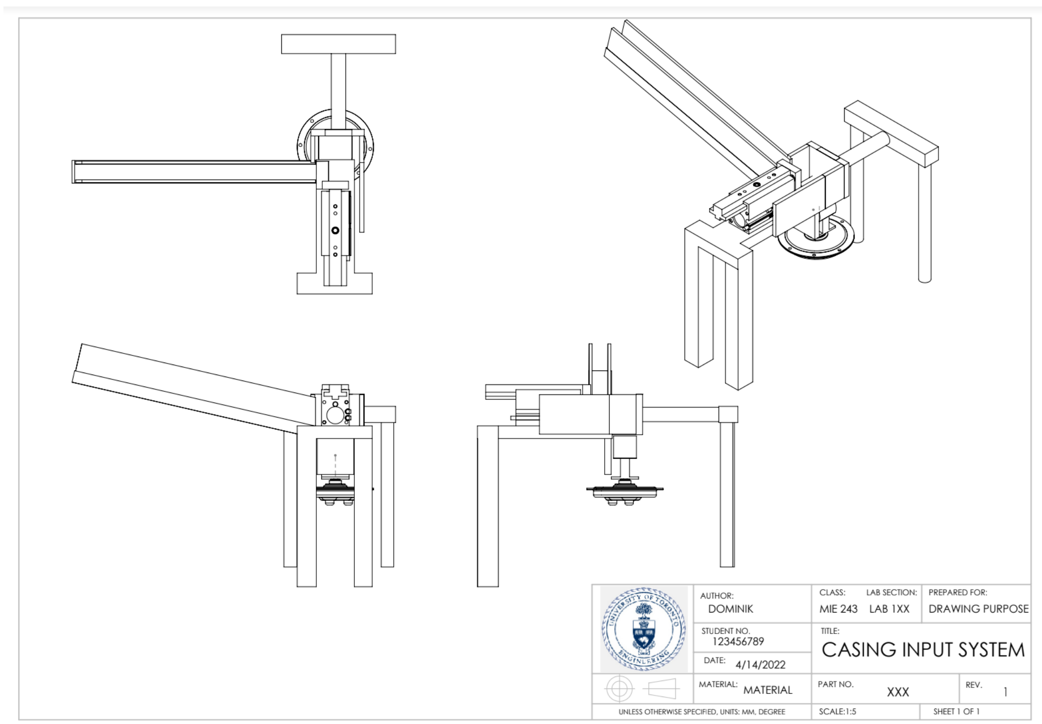

Figure D8. Casing Input System