Final Project Documentation: All-Purpose Modular Base

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Section 1.0: Introduction

1.1 Executive Summary

The primary objective of this project is to design, manufacture, and assemble an all-purpose modular base. The final product will be designed to encompass the user's requirements while providing optimal performance. The device's performance will be measured in the base's ability to accomplish the system requirements and to the degree of satisfaction of the user. This project will be carried out in partnership with Dr. Robert Allison. Aside from the main goal, the secondary objective of this project is to provide a cheaper alternative to medical bases that are currently on the market.

The use for this device will be in medical centers, hospitals, nursing homes, and more. This device is important as it addresses the market need for a cheaper, functional medical base for medical uses. An example of where this device can be used would be in an old age home where one device is needed to act as a blood pressure machine as well as a table. First off, the modular base would be adjusted to the patient's sitting arrangement (chair, wheelchair, bed). Next, an upper module would be attached using the universal attachment mechanism (in this case it would be a blood pressure machine). Once the patient has finished using the blood pressure attachment, a nurse or a medical aid will remove the upper attachment from the lower attachment and place it off to the side. Next, an upper attachment with a tabletop will be located and attached to the base using the universal locking mechanism. After the patient is done with the table attachment, the upper module can be unattached, and both the upper and lower modules can be stored away for later use. As evident, this device provides the patients as well as the medical staff with a customizable, storage-friendly, and cost-effective alternative to current market modular bases.

To accomplish these objectives as well as manage the project easier, the device can be divided into subsystems being the upper and lower module. The focus of this project is to focus on the lower module (modular base) only. However, mock-ups for potential upper modules are provided in the project to demonstrate potential uses for the devices. The lower modular base can be further divided into subsystems; mechanical and electrical. The Mechanical system can analyze the structural integrity of the base, where the electrical will look at the electrical components of the base. Both systems must work in sync to provide an optimal end performance.

1.2 Problem Statement

A versatile, personalized, effective, and economical multipurpose table, needed for clinical, and medical use. This project will seek to address these issues by creating a Modular Base to meet these consumer needs.

1.3 Project Goal

The goal of this project is to create a multifunctional base that can support the attachment of various upper modules using an interface. This interface will allow the connection between the lower module (i.e. the base) and upper module (i.e. the attachment of choice). A secondary objective is to make this product competitive in the market by focusing on the design features such as portability, as well as cost effectiveness. Listed below are some of the other targeted objectives that this prototype will seek to achieve. Vibrations and noise caused by the machine are important factors that must be reduced when developing the prototype. Limiting how much the mechanical systems vibrate and how much noise is produced will increase the comfort level of the user. Furthermore, it is important to consider weight, and size of the device also. These two parameters need to be kept at a minimum so that the device is easily transportable.

Time will be a key component when carrying out this goal due to the difficulty in collaborating with one another with conflicting academic schedules. However, the time will be managed in order to achieve the sub-requirements and objectives stated below in the document. This report entails the sub-objectives, design methodology, and schedule that will be followed when carrying this project.

1.4 Progress Summary

The goal of the project has drastically changed from inception. Initially we had designed and begun prototyping a robotic arm for neurorehabilitation. This included automating the linear, rotational, and wrist flexion movements for the patient. After deliberation with course directors, this project was pivoted to create a modular base with a universal attachment piece to allow multiple upper modules. This pivot caused the timeline for the new project to be significantly delayed from other capstone projects. After approval from course directors, deliverable due dates for the TRR, TR, and Final Report were extended. Near the middle of February, we had finalized our design, parts needed, as well as a loose idea of how we will go about manufacturing and assembling all components. We had created work packages of individual tasks that needed to be completed and used the Work Breakdown Structure to help identify when these work packages should be carried out. The team had begun procuring the parts needed by the end of February and were expecting a delivery near the beginning/middle of March. Some of the parts had arrived early, although the key components such as the linear actuator and universal attachment piece did not arrive by the middle of March. Due to the on-going pandemic, we were no longer able to use York's facility to manufacture, assemble, and work on the physical prototype of the device. This affected our ability to test, and as a result we carried out simulations and predicted the result of the tests. We carried out stress simulations on the CAD models to see whether the current device would be able to sustain the predicted loads and carry out normal functions.

At this moment in the project we have made minor changes to our design based on the test results of the simulations. However, without carrying out physical tests it is difficult to determine whether this prototype will be fully functional when fabricated. As a result, the project is "complete" to the best of our ability given the current circumstance, however this is not the most optimal prototype we would have liked at the inception of the project.

If there had not been interruptions due to the pandemic, we expect our project to have been fully manufactured and assembled and completed the testing phases. We expected a few tests to not go as planned, however, we would've corrected these mishaps with the additional remaining time. Another goal of ours was to make the device aesthetically pleasing, this could have been achieved by painting the device. Moreover, covers could have been manufactured using PMMA plastic to cover the interior workings of the device such as the linear actuator, and wiring.

1.5 Project Importance

This project will be very beneficial for the medical environment. This prototype offers possibilities that can provide the patient with a more comfortable product. To further elaborate, the objectives of our project is to minimize the physical vibrations, noise of the prototype as the device will be operational in a quiet setting. The device must also have dimensions so that it is easily transportable, and storable without compromising the structural or functional integrity.

As a team, we noticed that current products in the markets lacked the functionality of a modular base. The devices online would only have one functional use such as an overbed table, or blood pressure machine (see Figure 1 and Figure 2). Our project provides an innovative solution by keeping the base and having a removeable upper attachment function. This would require a universal attachment point where the base would contain the female component, and the upper attachment would contain the corresponding male component. As a result, only upper attachments with the corresponding male component can be used with the base. Furthermore, we noticed that these current market devices lack customizability. These devices might offer the patients hindrances when being used which can provide an uncomfortable experience. Thus, we opted to make our device customizable for varying patient's height. We further wanted to customize the product for the user, and decided to make the device operational for wheelchairs, normal chairs, as well as medical beds. This factor was important as many of these devices can only be operational for certain seating arrangements. Due to this, we made our base modular in the sense that the legs would be able to extendable to accommodate various seating arrangements.

This project would be very beneficial for businesses as this prototype offers a low-cost solution to general problems faced in medical centres. If a company was interested, they could use the main requirements/objectives from this project to mass produce this device for the consumer market. The total cost for prototyping was nearly $800, however if this device were to be mass produced, then the cost would come substantially down. The price for this device is low compared to buying multiple devices where our device can be multi-functional.

The outcomes of this project are also very beneficial for patients. As aforementioned, current medical equipment lacks the customizability at the expense of the patient's comfort. This proposed prototype provides the patient with a more comfortable user experience. Furthermore, as this one device is multi-functional, it would require less space than multiple single-functioning equipment. If this device were to be operational in an old age home, then the patient would have an additional amount of room which they could use for their personal belongings.

Figure 1: Overbed table.

Figure 2: Blood pressure device.

Section 2.0: Technical Volume

2.1 Requirements Review

In this section, we will list how each requirement is validated based on testing procedures.

2.1.1 Requirement Validation for Electrical Tests

Test ID	ET 1.0: Power Source: Single-Cycle Lifespan
Requirement Ref.	PRF 4.11 The power source should last for a minimum time of roughly 5 hours per full charge cycle.
Test Purpose	To have a power source that lasts for a specified period of time.
Success Criteria	To pass: Both the ammeter and voltmeter displays values near zero after a 6-hour period.
Verification Status	Verified
Requirement Validation	The power source is used to supply power to all electrical components used by the device. Therefore, it is necessary that the source supplies a constant current output for a specific period of time. The power source we are using is a 12V-7.2AH battery; so it would take approximately 6 hours to go from 100% to 0% when connected to a 10 Ω load. Because this is a simple circuit test, we predict that there would be no challenges in this test and that all test results would be as expected (i.e. the ammeter and voltmeter readings are near zero after a 6-hour period).

Test ID	ET 1.1: Power Source: Rechargeability
Requirement Ref.	INT 3.5 The product shall have a rechargeable power source. PRF 4.9 The power source shall take no longer than 5 hours to recharge.
Test Purpose	To have a power source that can be recharged, rather than replaced.
Success Criteria	To pass: By step 8, the power source is fully charged and contains at least 12 V. The time to charge is less than 5 hours in duration.
Verification Status	Verified
Requirement Validation	The charger is used to re-supply power to the power source. The batter should be charged while not being used (i.e. during the device’s downtime), and it should be done in a timely manner. Since this is a test in which we connect to devices together and let them sit for a period of time, we expect to encounter no challenges and that all test results would be as expected (i.e. the battery is fully charged from zero to 12V within a 2-hour timeframe).

Test ID	ET 1.2: Linear Actuator
Requirement Ref.	FNC 1.6 The base shall contain a central actuator that controls the linear movement of the upper module (i.e. the height is adjustable). PRC 2.2 The time for the linear actuator to reach its maximum height from minimum will take no more than 30 seconds (and vice-versa).
Test Purpose	To see if the linear actuator reaches maximum and minimum stroke lengths.
Success Criteria	To pass: The linear actuator is capable of fully extending and retracting and is within the timeframe of 30s.
Verification Status	Verified
Requirement Validation	The linear actuator is used to control the vertical movement of the upper module. By connecting it to the battery, we can verify that the actuator extends; reversing the polarity of the connections should return the opposite result. Since this is a test in which we connected two devices directly together, we expect there to be no challenges and that all results would be as expected (i.e. the linear actuator is capable of extending and retracting within the specified timeframe).

Test ID	ET 1.3: ON/OFF Switch
Requirement Ref.	FNC 1.9
Test Purpose	To have a functional switch that opens and closes the power source supply voltage to the actuator and upper module.
Success Criteria	To pass: By step 5, 12V must be read by the voltmeter; and by the final step, the voltmeter must display 0V.
Verification Status	Verified
Requirement Validation	The ON/OFF functions by physically breaking the circuit, preventing any current flow from flowing throughout the system. This will permanently halt all electrical functionality no matter how much or little power is being delivered to the circuit. When connected properly in series with our circuit and assuming there are no faults with the switch itself, the resulting test will succeed.

Test ID	ET 1.4: Rocker Switch
Requirement Ref.	FNC 1.9 The lower module shall have an ON/OFF switch for the power unit.
Test Purpose	To have a functional switch that opens and closes the power source supply voltage to the actuator and upper module.
Success Criteria	To pass: By step 5, 12V must be read by the voltmeter; and by the final step, the voltmeter must display 0V.
Verification Status	Verified
Requirement Validation	The rocker switch functions by physically breaking the circuit when in NEUTRAL, while providing power to the circuit when in UP/DOWN. The test involves some connections between multiple electrical components in the device, but we do not expect to

	encounter any challenge; we expect all test results are as specified (i.e. there is voltage supplied to the actuator when the rocker switch is in the specified position).

Test ID	ET 1.5: Power Source: Output Wattage
Requirement Ref.	PRF 4.1 The product shall be energy efficient, using power up to a maximum of 100 W.
Test Purpose	To have a functional power source that supplies enough power to the entire system (i.e. to the actuator and to the upper module).
Success Criteria	To pass: By step 13, the calculated power consumption must be less than 100 W.
Verification Status	Verified
Requirement Validation	Under max draw the current would reach approximately 4 amps when the actuator is in use. With the top module attachment (although not built) in theory the smaller electronic components would be around 1-amp usage. This brings power consumption to a total of 60W when both top module electronics and the actuator are in use. The 60W value is an estimation due to the fact the upper module components are not being produced and would mostly consist of small electronic screens and other small electrical features.

Test ID	ET 1.6: Power Source: Heat
Requirement Ref.	PRF 4.10 The power source should not exceed a maximum operating temperature of 35 degrees.
Test Purpose	To have an efficient power source that does not produce a heat hazard to the user and surrounding equipment (i.e. not too hot to the touch).
Success Criteria	To pass: By step 10, the thermometer reading must be less than 35° C.
Verification Status	Verified
Requirement Validation	The current drawn from the battery would not be consistently high. We plan on allowing top module attachments to use the battery powering the actuator so there would be consistent current draw, but they would be small amounts which would not produce noticeable heat from the battery. However, depending on the load on top of the actuator it will affect current drawn when moving the actuator up/down resulting in heat changes. Since the battery would only be in stressful operation (actuator movement) for approximately a minute and a half based on our tests the heat generated should not overcome the threshold. However, in case of heat exceeding allowable temperatures during tests, improving ventilation of the battery should allow it to still run safe and cool quicker when used in its recommended environment.

Test ID	ET 1.7: Emergency Stop Button
Requirement Ref.	FNC 1.8 The lower module shall contain an emergency stop button. REG 5.5 The product shall have an emergency stop button in accordance to (CSA). REG 5.6 The product shall abide by the Canadian Medical Device Regulations (1998).
Test Purpose	To have a functional “full-stop” mechanism that can override all subsystems in the device and cut power to them.
Success Criteria	To pass: By step 6, 12V must be read by the voltmeter; and by the final step, the voltmeter must display 0V.
Verification Status	Verified
Requirement Validation	The emergency stop button functions by physically breaking the circuit, preventing any current flow from flowing throughout the system. This will permanently halt all electrical functionality no matter how much or little power is being delivered to the circuit. When connected properly in series with our circuit and assuming there are no faults with the button itself, the resulting test will succeed.

2.1.2 Requirement Validation for Mechanical Tests

Test ID	MT 2.0: Base Plate Strength
Requirement Ref.	PRF 4.6 The product shall be stable such that a small impact force will not knock over the system.
Test Purpose	The base plate must be able to support the weight of the pillar, the attached apparatus, and any external force applied to the system. The plate will be tested for deflection and possible fracture due to the operating loading conditions.
Success Criteria	The base plate will not have significant deflection after the experiment is completed.
Verification Status	Verified
Requirement Validation	Testing whether the base plate supports the weight of the pillar and upper module. The base plate will be securely fastened and loaded with a 240 lb load for an hour. The load represents the weight of the pillar and any apparatus mounted atop of it. We predict the base plate purchased will not significantly deflect due to the load and will remain stable when the height adjustable pillar is fixed to it.

Test ID	MT 2.1: Pillar Strength
Requirement Ref.	PRF 4.6 The product shall be stable such that a small impact force will not knock over the system. PRF 4.3 The run-to-break time shall be no lower than 1000 hours.

Test Purpose	The pillar will be heavily involved in handling the load of the varying modules. The pillar will be made of an aluminum square tube. Since the base will involve different uses depending on the module that is mounted, weight will vary. The most weight that could be placed on top would be the weight of the varying attachment and the load placed on the member. The pillar's strength will be tested with static weights at different locations of the plate to test the pillar's strength from different angles of loads. The weight of the varying attachment would be a maximum of 40 lbs and the maximum load would be 50 lbs.
Success Criteria	The pillar should show no signs of deflection or deformation from the load at each load point.
Verification Status	Verified
Requirement Validation	Testing the pillar's strength and durability. The pillar will be securely fastened and loaded with 90 lbs at different locations and configurations for an hour each. The different load configurations will represent the different apparatuses and the different loads that are associated with them. We predict the pillar will not show significant signs of deflection or deformation from the loadings and will remain stable and functioning.

Test ID	MT 2.2: Base Leg Extension
Requirement Ref.	PRC 2.1 The time-to-setup for the system shall be a maximum of 1 minute. PRF 4.2 All movement shall occur in a smooth manner; there shall be no sudden stops during movement.
Test Purpose	The width of the base must be easy and quick to set up while maintaining the system's stability. The base legs should have minimal friction with the outer tube and extension should be smooth.
Success Criteria	Each base leg can be set up within 10 seconds with little to no difficulty.
Verification Status	Verified
Requirement Validation	Testing whether the legs extend and contract quickly and in a smooth manner. The extending legs will have a lubricant added in high friction areas to improve the smoothness of extending and contracting. We predicted the legs would successfully pass this test, so the legs would take less than 10 seconds to set up. The quick leg setup and the addition of lubrication helps meet the two requirements by minimizing the setup time and smoothening the motion.

Test ID	MT 2.3: Base Stability
Requirement Ref.	PRF 4.6 The product shall be stable such that a small impact force will not knock over the system.
Test Purpose	Based on functional requirements, the base must be stable so that when forces are applied to the system, the base does not allow the apparatus to tip over. This force normally would be applied by external means at the outer edges of the apparatus.
Success Criteria	The base remains stable and does not tip over during the experiment.

Verification Status	Verified
Requirement Validation	Testing the base stability while under operating conditions. The stability of the base is critical to its durability and usability. This test makes the base endure the worst case scenario which is to have a large load at the outer limits of its workspace. We predicted the base will successfully pass this test and not tip over due to the large load. This test helps meet the requirement by ensuring it can withstand the load.

Test ID	MT 2.4: Wheel Strength
Requirement Ref.	PRF 4.2 All movement shall occur in a smooth manner; there shall be no sudden stops during movement.
Test Purpose	The whole system will be moved by pushing it on wheels hence they (5 wheels) must be strong enough to hold the weight of the entire base and still function with minimal resistance. The test will be carried out to inspect the wheels in operational conditions.
Success Criteria	The base will be able to be moved using the wheels with the least amount of force.
Verification Status	Verified
Requirement Validation	Testing the functionality and usefulness of the wheels purchased. The five wheels need to withstand the load from operational use and still move the base and apparatus with minimal effort. We predicted the wheels to pass this test because they are of industrial strength and are designed for heavier loads. The test helps meet the requirement by providing smooth motion while transporting the device.

Test ID	MT 2.5: Leg Extension Locking Mechanism
Requirement Ref.	FNC 1.11 The extending legs will have a locking mechanism.
Test Purpose	The purpose of this test is to test whether the leg extension locking mechanism is working properly. Once the locking mechanism is engaged, the leg extensions should no longer move.
Success Criteria	A successful test would mean that the pin is able to withstand a strongly applied human force without the pin breaking.
Verification Status	Verified
Requirement Validation	Testing whether the extending legs locking mechanism can securely lock the legs. The locking mechanism is a pin and hole design. We predict the locking mechanism will be successful due its simplicity and practicality. This test helps fulfil the requirement because it will lock the legs securely in place.

Test ID	MT 2.6: Actuator Strength
Requirement Ref.	FNC 1.6 The base shall contain a central actuator that controls the linear movement of the upper module (i.e. the height is adjustable)
Test Purpose	The actuator must safely support the weight of the apparatus it is attached to. The weight of an apparatus can change depending on its purpose. Apparatuses are likely to weigh between 10 to 50 kilograms (20-110 lb). The linear actuator will be loaded with 30 and 150 lb.
Success Criteria	The linear actuator will move the weight in both scenarios securely without breaking or malfunctioning
Verification Status	Verified
Requirement Validation	Testing the strength and movement of the linear actuator under operating conditions. The actuator is vital to our design because it will be providing the vertical motion for the height adjusting pillar. We predicted the actuator will pass this test because the loadings we are applying to it are less than it is designed to withstand. The actuator strength test helps meet the requirement by ensuring a stable and adequate actuator is used.

Test ID	MT 2.7: Base Portability
Requirement Ref.	PRF 4.8 The product shall be compact and portable, to a maximum size of 1.5m x 1.5m x 1.5m. FNC 1.12 The lower module should be easily portable.
Test Purpose	The width of the legs should be able to contract enough so it is easy to move between different locations.
Success Criteria	A successful system will move smoothly and maneuver to the individual's intentions.
Verification Status	Verified
Requirement Validation	Testing the portability of the base module. The base should be able to pass through doorways and hallways easily without struggle. We predicted the base module will successfully pass this test because of the wheels purchased and its geometry which will allow it to maneuver through tight corners. The test helps validate the requirements because it ensures the base is compact enough to be easily portable.

Test ID	MT 2.8: Interface
Requirement Ref.	FNC 1.1 The product shall be composed of two parts: a lower module (i.e. the base) and an upper module (i.e. the attachment). FNC 1.2 The base shall have an interface by which any upper module can be attached. FNC 1.3 All upper modules shall have an interface by which the base can be attached. INT 3.2 The interface shall have a secure connection and can only be attached/detached manually.
Test Purpose	To ensure that the device possesses two major components before assembly. The base structure which is mainly for compatibility with diverse seating arrangement and

	the attachment interface which will be used for connecting various devices for different purposes e.g. table for eating, blood pressure device.
Success Criteria	Both parts are fully built, and the attachment interface can be mounted on the base structure. The possibility of connecting multiple devices is seen on the attachment interface.
Verification Status	Verified
Requirement Validation	Testing whether the base module and the attachments are independent of each other while still being able to be securely attached to one another. The base module is designed to be compatible with any module that has the correct interface connection, but it must also be able to stand on its own. We predicted to pass this test because the base and attachments will be made separately and will have a male and female interface connection. The test helps validate the requirements by ensuring the base and attachments are independent and can be securely connected to each other.

Test ID	MT 2.9: Module Motions
Requirement Ref.	FNC 1.4 The base shall allow the upper module to have a free rotational movement (i.e. 360-degree movement about a pivot). FNC 1.5 The base shall allow the upper module to have a “seesaw” motion (i.e. tilting motion on the axis parallel to ground).
Test Purpose	To confirm that the product can rotate fully and be locked in place to stop rotation and confirm that the attachment interface allows for see-saw motion and adjustments when desired module is attached on top.
Success Criteria	The attachment interface rotates freely about the base structure and the interface is stable when locked in a see-saw position.
Verification Status	Verified
Requirement Validation	Testing the rotational motion in two directions. The upper modules can vary in function, so the base module will be able to rotate to adjust to the upper modules needs. We predicted the base module to pass the test due to its interface design and implementation. The test will validate the requirements by allowing rotation in both the indicated directions.

Test ID	MT 2.10: Joint Connections
Requirement Ref.	PRF 4.6 The product shall be stable such that a small impact force will not knock over the system.
Test Purpose	To ensure every joint connection within the frame by each fastener is secure and rigid. Guarantees any moment or load put on the connecting pieces during operational use will not dislodge the joint connections.
Success Criteria	All connecting joints are rigid and can withstand appropriate moments or loads applied to the frame
Verification Status	Verified

Requirement Validation	Testing the strength of the connecting joints. The base module will be subjected to many kinds of loadings due to the upper modules. The joints must be able to withstand the forces from the upper module to keep the base stable. We predicted the base module to pass this test at every joint location. The test helps validify the requirement by aiding the base structure to be stable.

Test ID	MT 2.11: Product Weight
Requirement Ref.	PRF 4.5 The lower module shall weigh no more than 50 kg.
Test Purpose	To ensure the weight of the device does not exceed 50kg based on the requirement.
Success Criteria	The weight of the device does not exceed 50kg
Verification Status	Verified
Requirement Validation	Testing whether the base module weighs less than 50 kg. We predicted the base will be less than 50 kg due to the size and components purchased. The test validates the requirement by ensuring the base module weighs less than 50 kg.

2.1.3 Requirement Validation for Other Tests

Test ID	OT 3.0: Lower Module Dimensions
Requirement Ref.	PRF 4.8 The product shall be compact and portable, to a maximum size of 1.5m x 1.5m x 1.5m.
Test Purpose	To see whether the base is small and compact, as specified.
Success Criteria	To pass: The measured (length x width x height) is less than (1.5m x 1.5m x 1.5m).
Verification Status	Verified
Requirement Validation	The base module needs to be compact to be easily portable. We predicted the base module to pass the test because it is within the limits. The test validates the requirement by having the measurement limits

Test ID	OT 3.1: Compatibility with Chairs
Requirement Ref.	INT 3.1 The product shall be compatible with existing chairs, wheelchairs, and beds.
Test Purpose	This is an important feature that makes our product so unique. It should be workable with a normal 4-legged chair, a wheelchair, and a hospital bed.
Success Criteria	To pass, the average adult user should be able to manipulate the top part of the device in all viable directions at a relaxed arm length.
Verification Status	Verified
Requirement Validation	The base module will have many upper modules, some of which will be designated to use chairs or other sitting devices. We predict the base will pass this test due to the extending legs that can adjust to many if not most chairs and beds. The test validates

	the requirement because it ensures the base is compatible with different chairs and beds.

Test ID	OT 3.2: Sound Output
Requirement Ref.	PRF 4.4 The product shall be quiet, to a maximum of 50 dB.
Test Purpose	To see whether any sound produced by the product is not too loud.
Success Criteria	To pass: The total sound output should be less than 50dB.
Verification Status	Verified
Requirement Validation	To test the loudness of the base module. We predicted the base module to pass this test because of the calculations and information from each component. The test validates the requirement by ensuring the base module is not louder than 50dB.

Test ID	OT 3.3: Power Unit Dimensions
Requirement Ref.	PRF 4.7 The product shall have a small, compact power unit, to a maximum size of 0.25m x 0.25m x 0.15m.
Test Purpose	To see whether the power unit is small and compact, as specified.
Success Criteria	To pass: The measured (length x width x height) is less than (0.25m x 0.25m x 0.15m).
Verification Status	Verified
Requirement Validation	To keep the base module small and compact we also chose small and compact components. The test was passed by purchasing a power unit that is within the measurement limits. The test validates the requirement by ensuring the power unit is small and compact to fit on the small and compact base module.

Test ID	OT 3.4: Device Aesthetics
Requirement Ref.	INT 3.6 The product shall be aesthetically pleasing; it shall be appropriate for a medical environment.
Test Purpose	Our product needs to be aesthetically appropriate in a medical environment. This promotes confidence in the integrity of the product.
Success Criteria	Average response must score at least 75-80%
Verification Status	Verified
Requirement Validation	Making the product aesthetically pleasing increases the chances of customers purchasing our product and promotes the integrity of it. Also, making it able to be used in medical practice opens a new market that can order the base module by the thousands. The test validates the requirement by asking the general public for their opinion on the products aesthetics.

Test ID	OT 3.5: Comprehensive Sealing and Labeling
Requirement Ref.	REG 5.2 The product shall have labels that identify risks/hazards in the device following Canadian Medical Device Regulations (SOR/98-282). REG 5.4 The product shall be sealed without exposing any unsafe/uncovered parts in accordance to the Canadian Standards Association (CSA) - Canadian Electrical Code (CE)
Test Purpose	Ensure the exterior of the device is well-sealed and appropriately labeled in order to maximize user confidence in operating the device and minimize risk of injury to them or to the device.
Success Criteria	Checklist completed
Verification Status	Verified
Requirement Validation	The base module would be a regulated device since it will be marketed to in the medical field. The labels that identify the risks/hazards are necessary to comply with the Canadian Medical Device Regulations. The coverage of unsafe/uncovered parts is also necessary under the CSA and CE code. The test validates the requirement by ensuring the two regulations are met.

Test ID	OT 3.6: Canadian Medical Device Regulations Adherence
Requirement Ref.	REG 5.6 The product shall abide by the Canadian Medical Device Regulations (1998).
Test Purpose	Our device is meant to be used in medical environments as auxiliary and therefore should abide by the current medical devices' regulations; this protects the users and us, the creators.
Success Criteria	The application satisfies the authorization section
Verification Status	Verified
Requirement Validation	To sell the base module to the medical field, it must abide by the Canadian Medical Device Regulations. The test validates the requirement by ensuring the base module adheres to the necessary regulations.

Test ID	OT 3.7: EPD Adherence
Requirement Ref.	REG 5.1 The product shall be composed of environmentally friendly materials according to the International Environmental Product Declarations (EPD). REG 5.3 The product shall not deteriorate under daily use such that the health or safety of the user is affected according to EPD regulations.
Test Purpose	We wish to abide by the Environmental Product Declaration (EPD) because it gives our product a competitive edge.
Success Criteria	All material can be found in the pre-verified material stage or the second checking stage.
Verification Status	Verified

Requirement Validation	To give our product a competitive edge we chose to make it adhere to the International Environmental Product Declarations regulations for environmentally friendliness and durability. The test validates the requirement to ensure the base module adheres to the necessary regulations.

Test ID	OT 3.8: Budget Evaluation
Requirement Ref.	PRC 2.6
Test Purpose	To see whether the total cost is less than the designated budget.
Success Criteria	To pass: The total cost of all expenses is less than $1000 CAD.
Verification Status	Verified
Requirement Validation	The project had a budget constraint which would allow the product to be manufactured or re-developed at a practical cost. It is important that the device would not be too expensive as no client would integrate the device in their network if it is too costly. Based on the current completed design the calculated cost was under $1000 CAD.

2.2 Mechanical Design

2.2.1 Description

Our prototype is attempting to be comfortable, affordable, and customizable in today's current market. As displayed by the model, as well as CAD drawings below, our prototype contains a customizable height, as well as an extendable leg feature. Since we are only focusing on the modular base of the design, we have only shown the dimensions, features, and functionally of the base. The main mechanical components of the modular base consist of; legs, wheels, a pillar, and an upper module connection interface.

Out of the four legs, the two legs that are more spread from one another are extendable to accommodate different seating arrangements. This can include but not limited to hospital beds, wheelchairs, and regular chairs. It was only necessary to allow half of the legs to be extendable in order to allow the system to accommodate most seating arrangements. Furthermore, as displayed by the legs extending video (see Section 2.2.3: Leg Extension), it shows only one side of the prototype extending. On this same side is where the seat/bed will be. For example, in an operation use of a bed; the legs will extend in a certain length where the legs will not interfere with objects underneath the bed. The dimensions of the legs, as well as the extension lengths are shown below in the CAD drawing file (see Section 2.2.3: Leg Extension).

The wheels were added in the system to verify the transportability requirement. Having legs on all four corners allows the entire prototype to be easily rolled in and out of the room that the prototype is being used in. Also, a fifth wheel was placed under the pillar to help support the weight as there is a large stress concentration at that point. When purchased, the wheels come with a locking mechanism.

The pillar is a key component of the mechanical design. The pillar is what connects the legs, to the interface which connects the upper modules. Below the pillar is the aluminum plate that is meant to be welded to the legs and the pillar. The role of that plate is to provide structural support for the pillar and the upper attachment. The pillar consists of two concentric square tubes with different sizes so that they are able to slide in and out of one another. Housed within the pillar is the linear actuator which provides the linear movement of the pillar to raise and lower the upper attachment. The linear actuator receives its power from a battery source, which is provided in detail in the electrical design portion of the report.

The interface system is responsible for combining the modular base to the upper modules. The modular base consists of the male connector of the interface whereas the upper module holds the female connector. The interface is similar to the male end of a tripod system (see Figure 8). The male tripod head would slide into and finally lock into the female end of the upper module.

2.2.2 CAD Drawings and Design

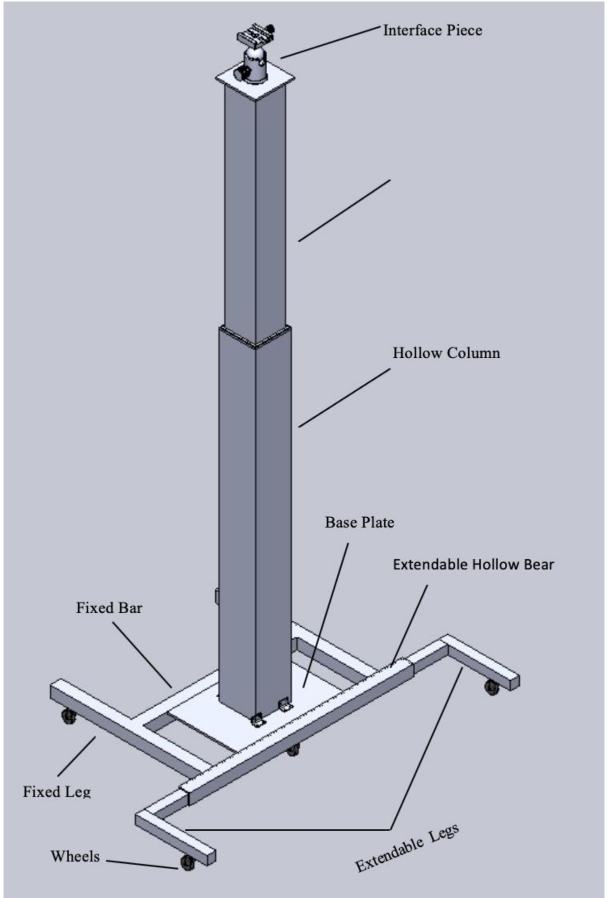


Figure 3: Labelled lower module.

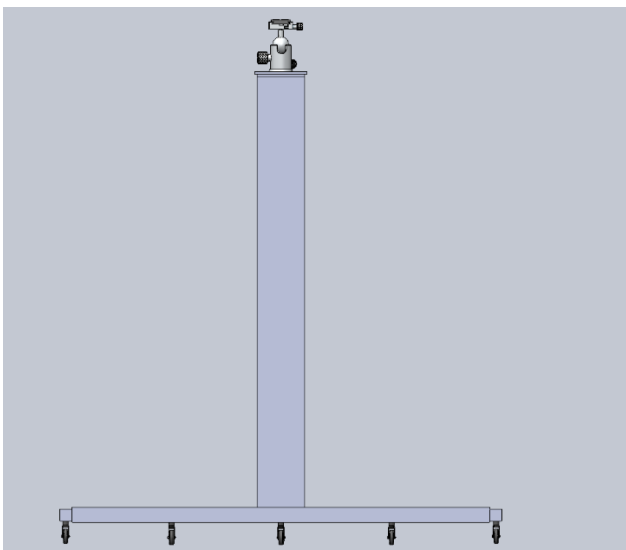


Figure 4: Side-view of lower module.

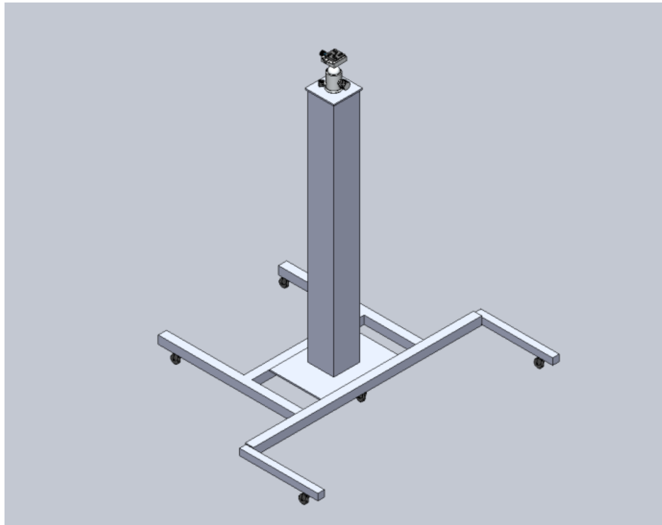


Figure 5: Isometric view of design.

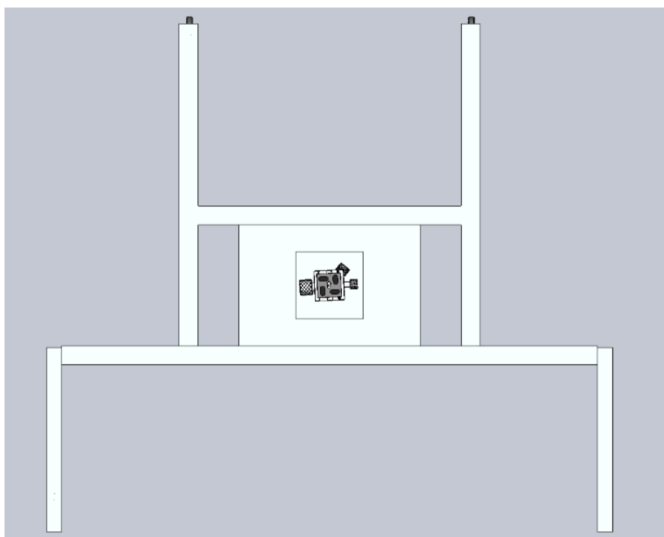


Figure 6: Top-view of legs (retracted).

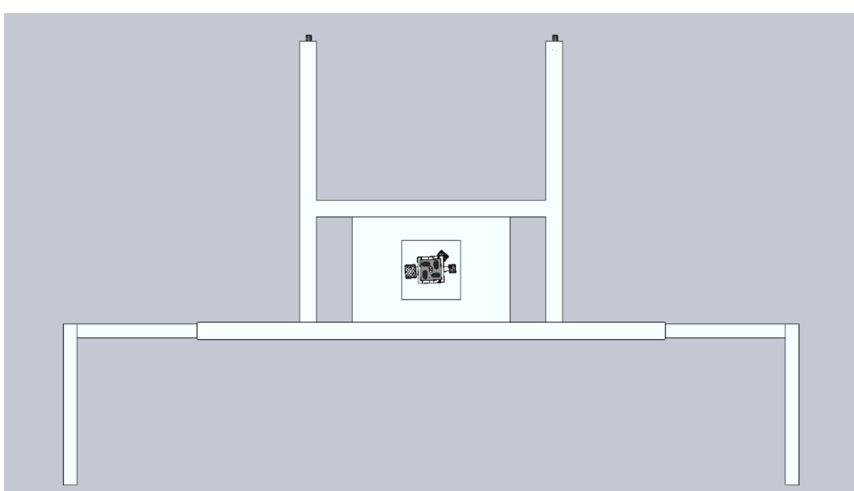


Figure 7: Top-view of legs (extended).

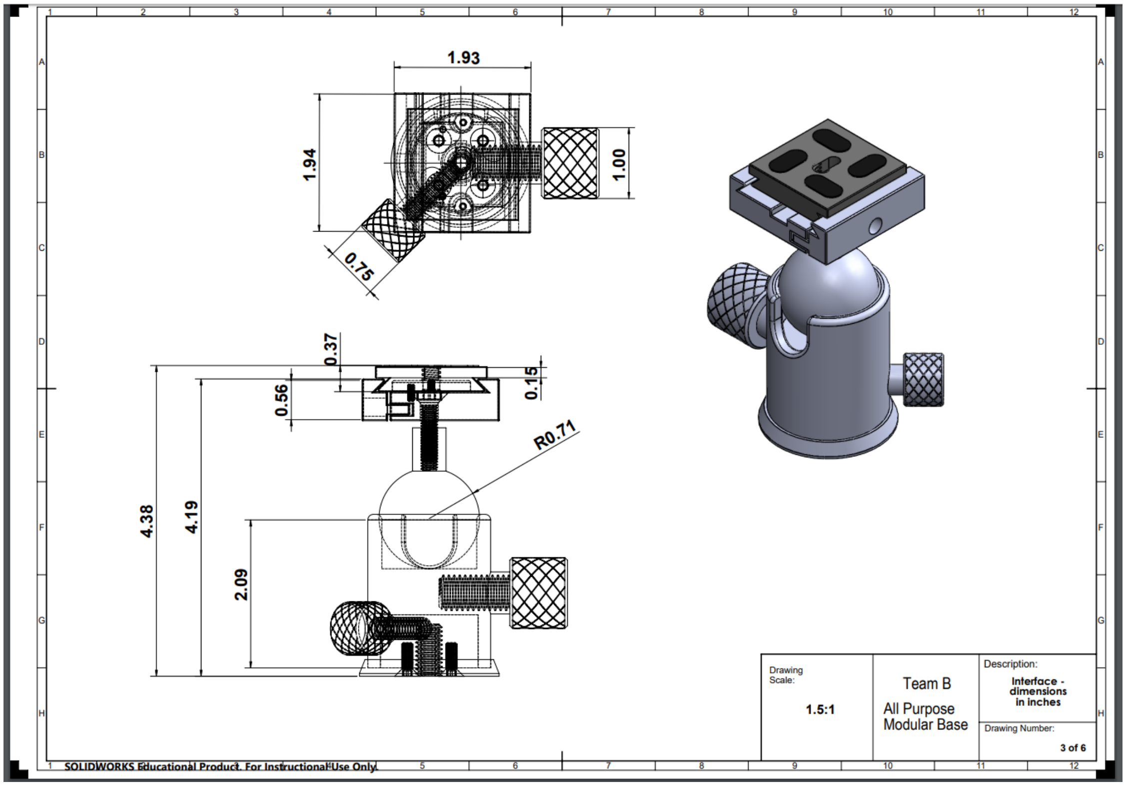


Figure 8: Dimensions of connecting interface.

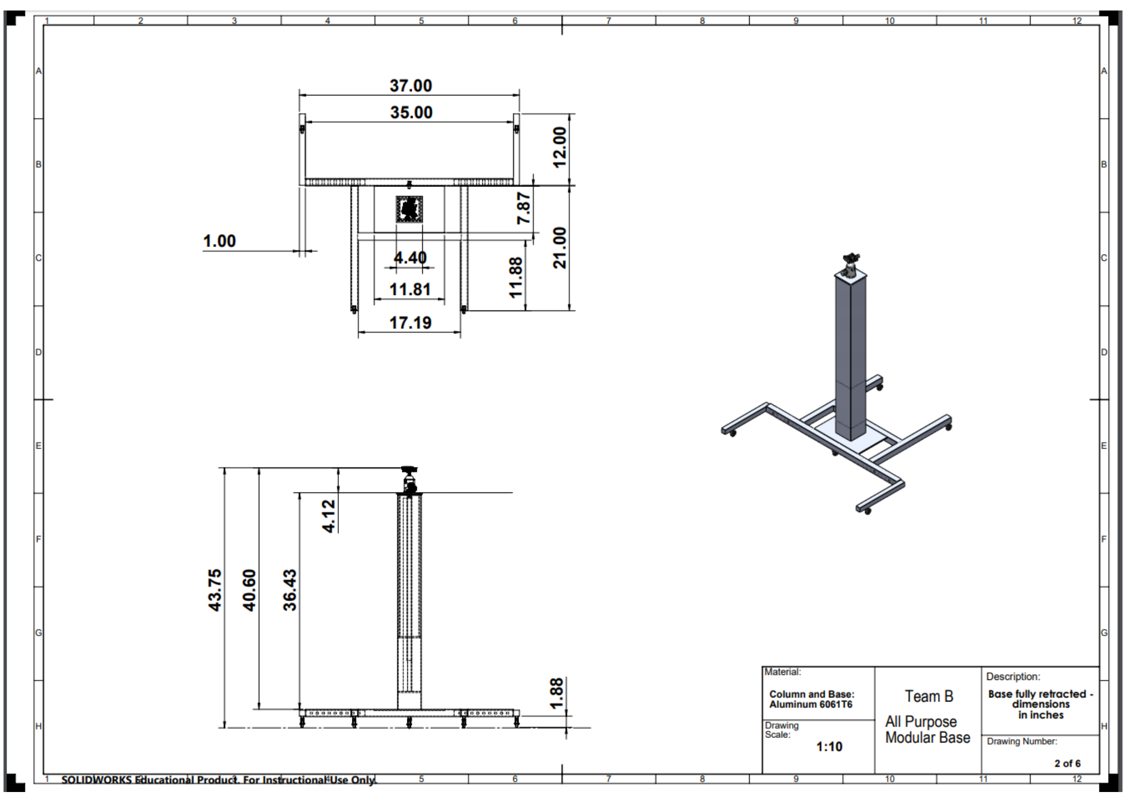


Figure 9: Base design (retracted legs).

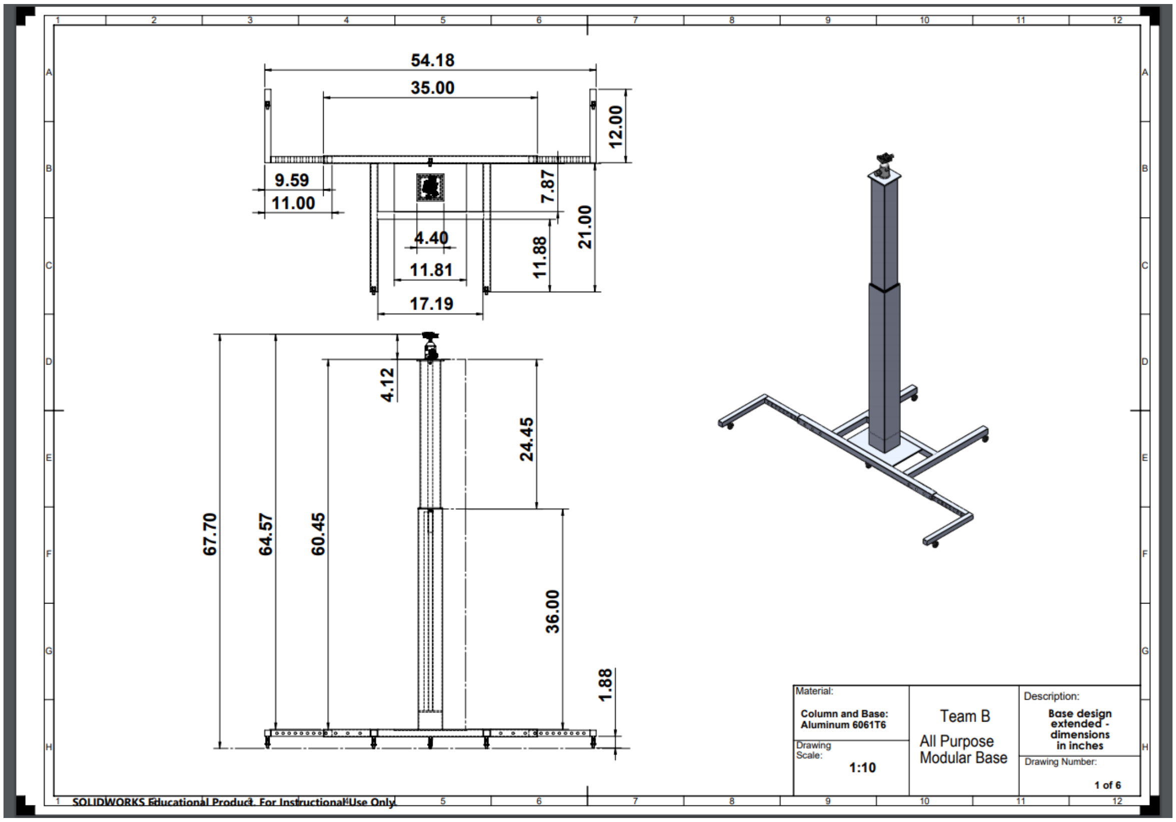


Figure 10: Base design (extended legs).

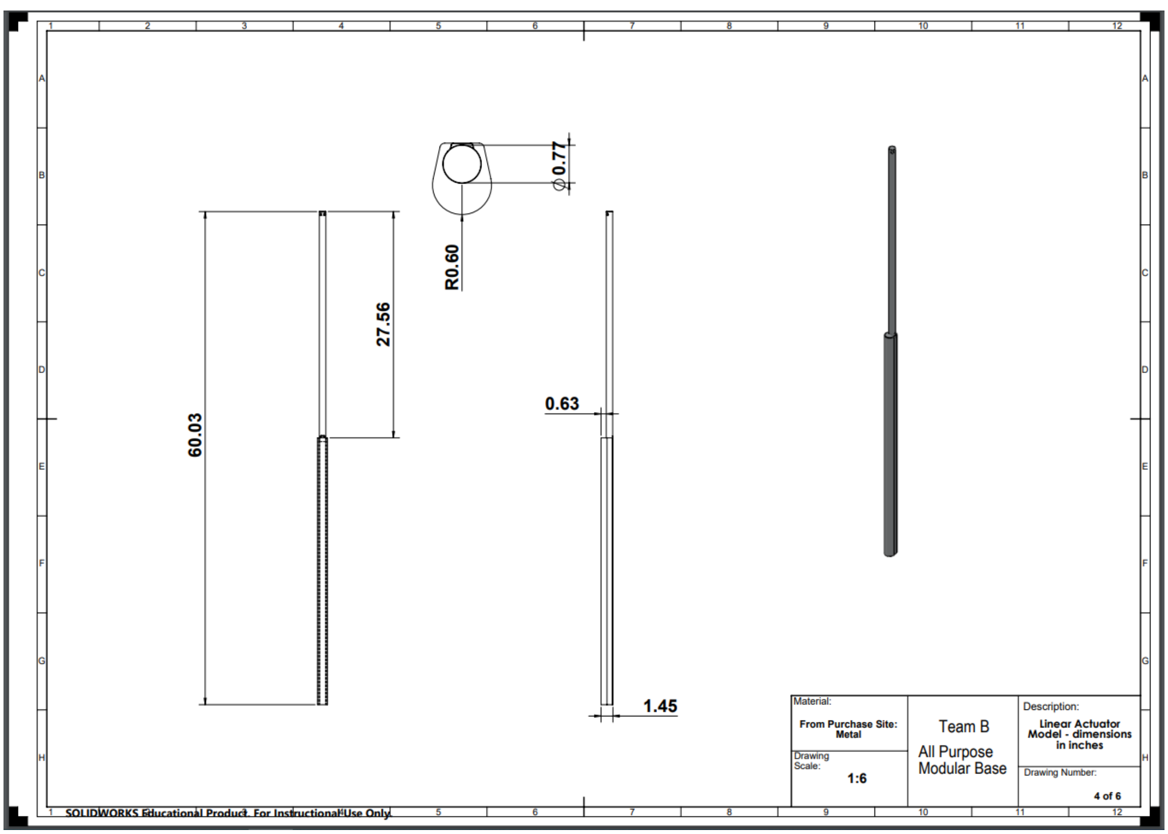


Figure 11: Dimensions of linear actuator.

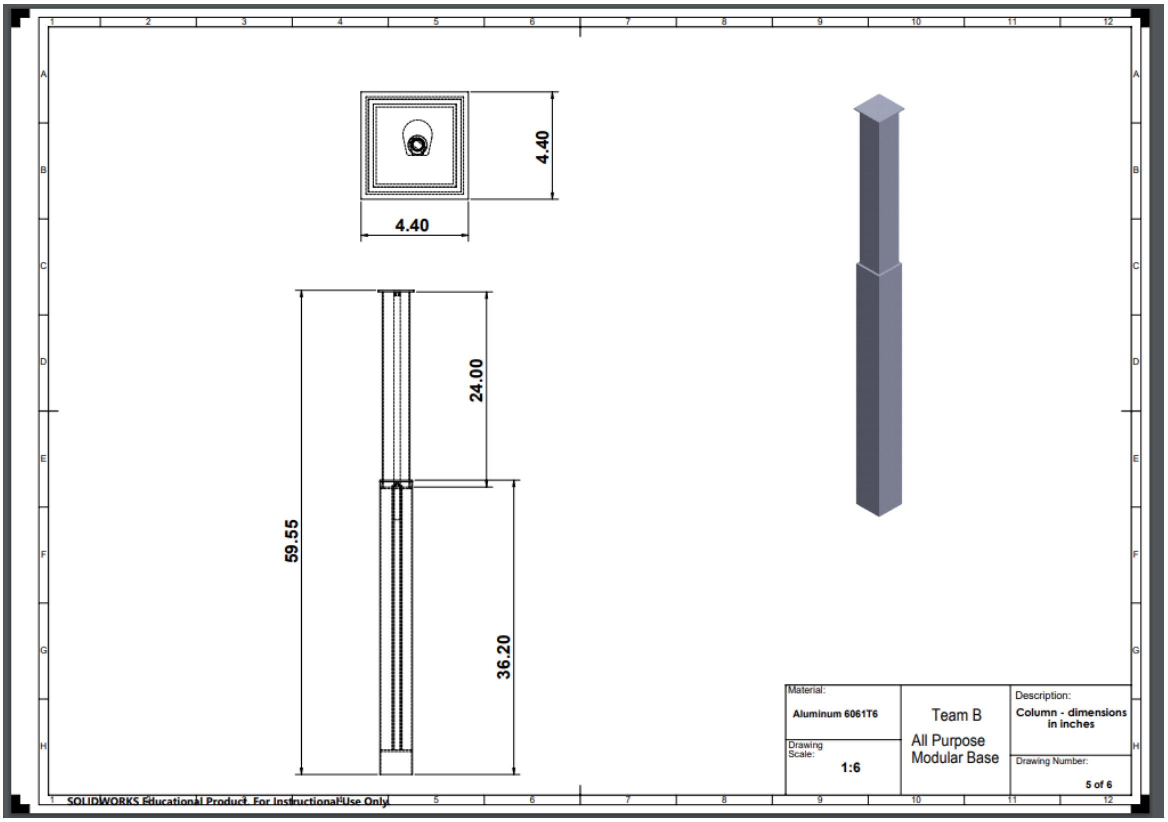


Figure 12: Dimensions of center column.

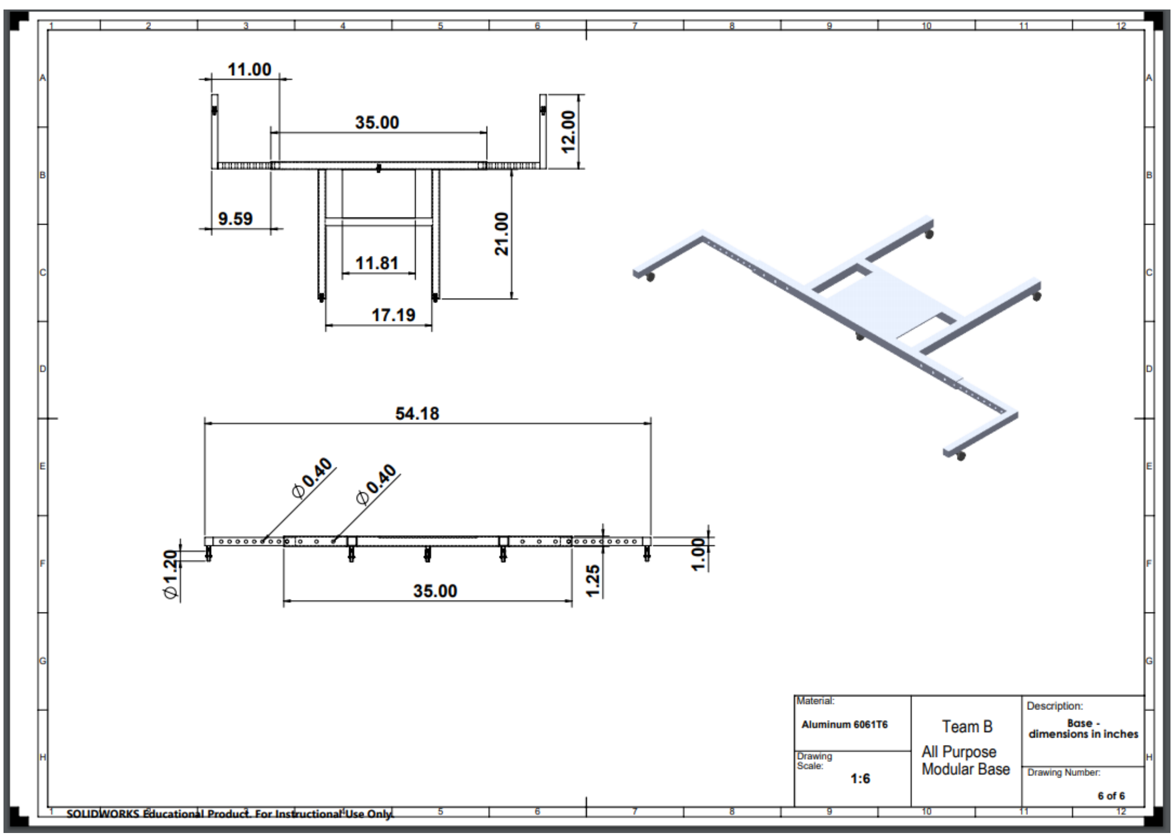


Figure 13: Dimensions of the base.

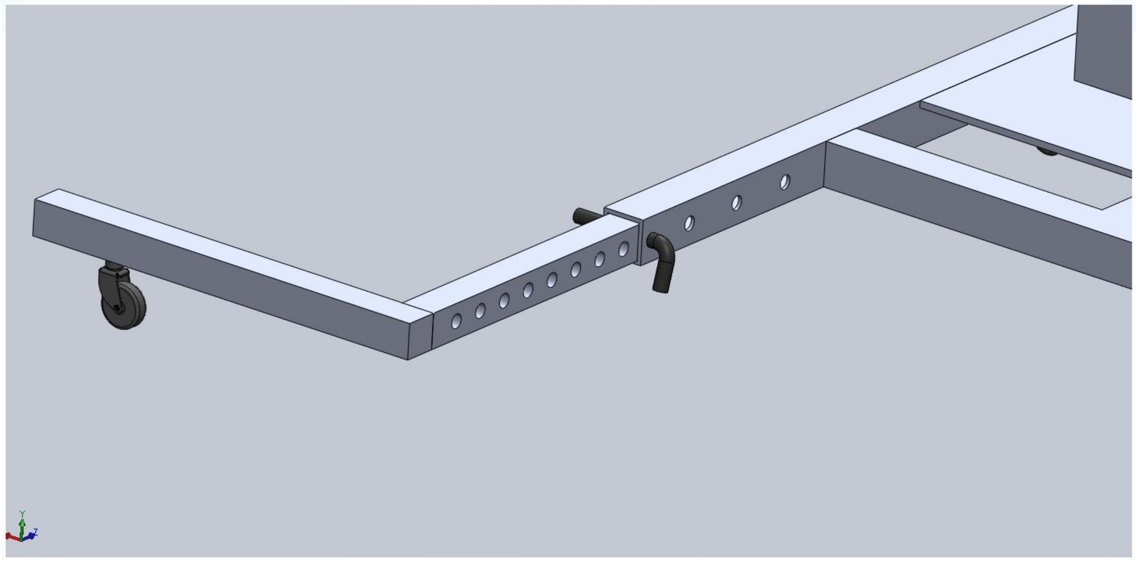


Figure 14: Base locking mechanism.

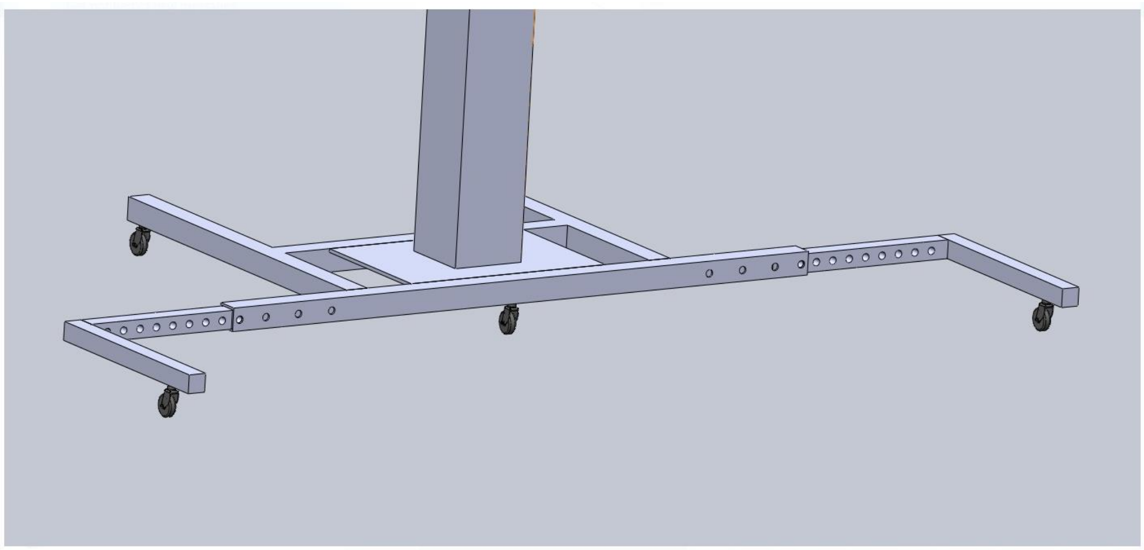


Figure 15: Base locking mechanism (wide).

2.2.3 Clips

Wheels:	https://youtu.be/3gUcC-zCycE
Tripod Interface:	https://youtu.be/9mGIQgriJVM
T-Module:	https://youtu.be/dYRNOfoZq1Y
Leg Extension:	https://youtu.be/qz8SJWBQExY
Column Extension:	https://youtu.be/CJnoQFXcbAU
BP Module:	https://youtu.be/8Aj0vpvW02Q
Base Lock:	https://youtu.be/JcraXLgnSes

2.3 Electrical Design

The overall electrical design for the device is shown in Figure 16 below. The main power source consists of a 12VDC, 7.2AH sealed lead-acid battery. The battery connects to a charger which when plugged into a standard North American* wall outlet, converts 120VAC, 60Hz to 12VDC at a current of 1A to recharge the battery. The battery is connected to the emergency stop button and then to a three-way rocker switch in a series connection. This ensures the emergency button must be released for the circuit to function as a safety precaution. The potential top module would be supplied power even if the actuator is forced to stop moving. As an example, this prevents important data recording tools from the upper modules from being lost if the base were to be forcibly shut down. Rather it would be more practical to have a breaker to prevent any electrical failure towards the upper module. This would be an improvement in the design but out of the scope of the project since upper modules are only theorized and not practically implemented. The rocker switch determines whether the actuator moves up, down or stays in its current position. Under no load (based on actuator manual) the current drawn is approximately 3.5A and under maximum load (150 lbs) it uses approximately 7A.

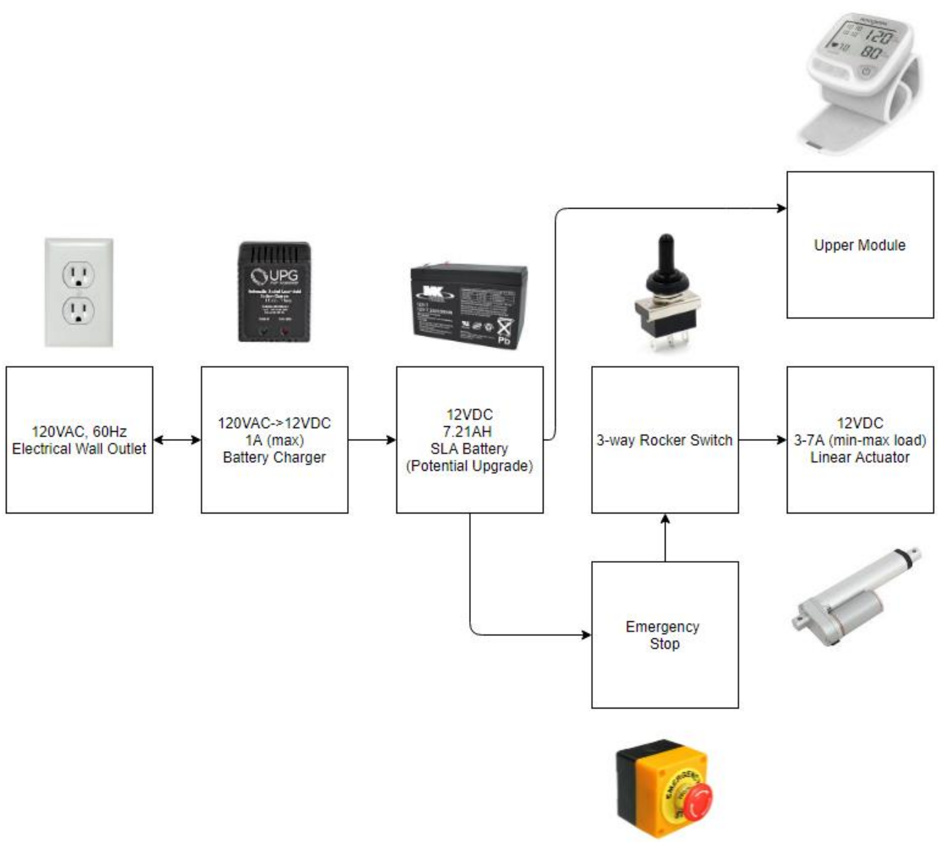


Figure 16: Overall electrical design.

*Note: It is more efficient if the group focuses on one electrical region and purchase relevant parts for North American standards since the project is being conducted there and would start in that region if further development ensues.

The circuit used to control the actuator is shown in Figure 17 below. The design consists of two 12V relays, a rocker switch, an emergency stop button, a battery, and an actuator. When there is no connection in the circuit, the rocker switch is in its OFF position (centered), the relays are not energized, and so only positive voltage is applied to both ends of the actuator causing a lock and preventing movement. The actuator will also not move if there is no voltage applied, if for example the emergency stop button is pushed. When the rocker switch is flipped one of the relays flip its connection and completes the entire circuit. Depending on which relay is powered, a positive voltage is either applied to the positive or negative terminal of the actuator. If the voltage is applied to the positive terminal of the actuator, then it will rise otherwise it would retract if a positive voltage is applied to the negative terminal.

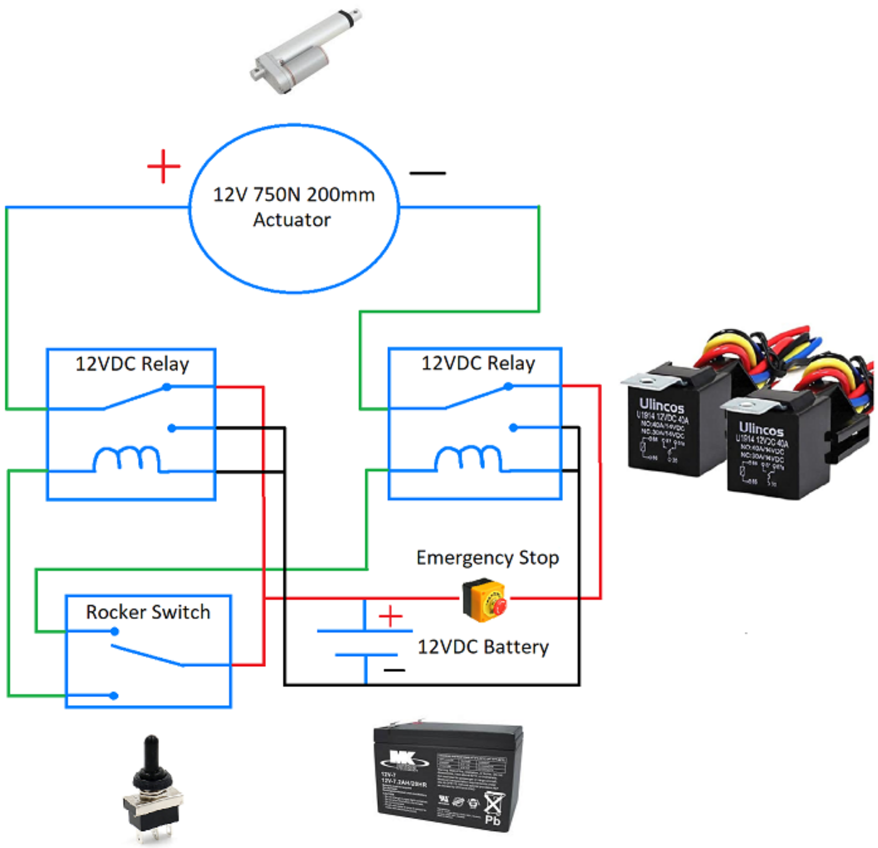


Figure 17: Actuator circuit.

2.4 Compliance Analysis

2.4.1 Specifications

- Width (X-Axis): 0.5 m
- Width (Y-Axis): 0.6 - 0.8 m [0.2m for expansion of legs]
- Height (Z-Axis): 0.8 - 1.0 m [0.2m for actuator extension]
- Mass: 50 kg
- Power: 48-384 W

2.4.2 Requirement Compliance

Requirement ID	Requirement Description	Verification Status
FNC 1.1	The product shall be composed of two parts: a lower module (i.e. the base) and an upper module (i.e. the attachment).	Verified
FNC 1.2	The base shall have an interface by which any upper module can be attached	Verified
FNC 1.3	All upper modules shall have an interface by which the base can be attached	Verified
FNC 1.4	The base shall allow the upper module to have a free rotational movement (i.e. 360-degree movement about a pivot).	Verified
FNC 1.5	The base shall allow the upper module to have a “seesaw” motion (i.e. tilting motion on the axis parallel to ground).	Verified
FNC 1.6	The base shall contain a central actuator that controls the linear movement of the upper module (i.e. the height is adjustable).	Verified
FNC 1.7	The base shall contain a power source to supply power to the actuator and upper module.	Verified
FNC 1.8	The lower module shall contain an emergency stop button.	Verified
FNC 1.9	The lower module shall have an ON/OFF switch for the power unit.	Verified
FNC 1.10	The lower module shall have a switch by which the actuator can be moved.	Verified
FNC 1.11	The extending legs will have a locking mechanism	Verified
FNC 1.12	The lower module should be easily portable.	Verified
PRC 2.1	The time-to-setup for the system shall be a maximum of 1 minute.	Verified

PRC 2.2	The time for the linear actuator to reach its maximum height from minimum will take no more than 30 seconds (and vice-versa).	Verified
PRC 2.3	The product shall be finalized by December 2019.	Verified
PRC 2.4	A product prototype shall be developed by March 2020.	Verified
PRC 2.5	All product components adjustments shall be logged on a document	Verified
PRC 2.6	All product components shall cost no more than $1000 CAD combined.	Verified
INT 3.1	The product shall be compatible with existing chairs, wheelchairs, and beds.	Verified
INT 3.2	The interface shall have a secure connection and can only be attached/detached manually.	Verified
INT 3.3	The product shall have a modular power source.	Verified
INT 3.4	The product shall have a wireless power source.	Verified
INT 3.5	The product shall have a rechargeable power source.	Verified
INT 3.6	The product shall be aesthetically pleasing; it shall be appropriate for a medical environment.	Verified
PRF 4.1	The product shall be energy efficient, using power up to a maximum of 100 W.	Verified
PRF 4.2	All movement shall occur in a smooth manner; there shall be no sudden stops during movement	Verified
PRF 4.3	The run-to-break time shall be no lower than 1000 hours.	Verified
PRF 4.4	The product shall be quiet, to a maximum of 50 dB.	Verified
PRF 4.5	The lower module shall weigh no more than 50 kg.	Verified
PRF 4.6	The product shall be stable such that a small impact force will not knock over the system.	Verified
PRF 4.7	The product shall have a small, compact power unit, to a maximum size of 0.25m x 0.25m x 0.15m.	Verified
PRF 4.8	The product shall be compact and portable, to a maximum size of 1.5m x 1.5m x 1.5m	Verified
PRF 4.9	The power source shall take no longer than 5 hours to recharge.	Verified
PRF 4.10	The power source should not exceed a maximum operating temperature of 35 degrees.	Verified
PRF 4.11	The power source should last for a minimum time of roughly 5 hours per full charge cycle.	Verified

REG 5.1	The product shall be composed of environmentally friendly materials according to the International Environmental Product Declarations (EPD).	Verified
REG 5.2	The product shall have labels that identify risks/hazards in the device following Canadian Medical Device Regulations (SOR/98-282).	Verified
REG 5.3	The product shall not deteriorate under daily use such that the health or safety of the user is affected according to EPD regulations.	Verified
REG 5.4	The product shall be sealed without exposing any unsafe/uncovered parts in accordance to the Canadian Standards Association (CSA) - Canadian Electrical Code (CE).	Verified
REG 5.5	The product shall have an emergency stop button in accordance to (CSA).	Verified
REG 5.6	The product shall abide by the Canadian Medical Device Regulations (1998).	Verified

2.4.3 Mass Limitations

In the conceptual phase of the design we set a constraint to ensure the lower module will weigh no more than 50kg to enable a lightweight system for easy transportation as well as being heavy enough to support a large upper module. In order to achieve our goal, we chose aluminum tubes for the legs as oppose to solid tubes to reduce weight and kept this same material most of the lower module to avoid complexity during the welding process. The table below will provide masses of each component of the lower module.

Components	No of parts	Weight per part (Kg)	Total weight of components
Wheels	5	1.92	9.6
Extendable Legs	2	0.45	0.9
Extendable hollow bar	1	1.1	1.1
Fixed Legs	2	0.51	1.02
Fixed Bar	1	0.51	0.51
Base Plate	1	4.31	4.31
Hollow Column	1	8.88	8.88
Inner Column	1	19.48	19.48
Linear actuator	1	2.5	2.5
Interface piece	1	0.81	0.8
Charger	1	0.95	0.95
Battery	1	0.63	0.7
Emergency stop button	1	0.03	0.03
Rocker switch	1	*Negligible*	*N/A*
		Total	**50.753**

Our design components sum up to slightly exceed our weight constraint of 50kg but most of the masses were achieved from manually weighing the components on a scale which could lead to various human errors in the measurement. The design is still operational because the 0.753kg can be neglected compared to 50kg

2.4.4 Power Consumption

The device under no load with no top module attached would consume (12Vx 4A = 48W). Under full load with no module attached the device would consume (12V x 7A = 84W). Under full load with a top module, infant incubator estimated at 100-300W, running would consume approximately 184-384W. Other modules could use less or more power depending on the device.

2.4.5 Simulations

The upper attachment, which could be a table for example, was removed for the finite element analysis and replaced with a block. We can assume a maximum load of 500N at the end of the block. We are assuming a much larger force than we would see during operational use for safety reasons. We assumed an upper attachment would have a length of 50 (cm) from the center of the pillar. Therefore, the maximum moment on the block would be the 500 N load acting 50 (cm) from the center of the pillar. In the simulation was generated and the proper initializations were made; the block was subjected to a load of 500 N. The force direction is down towards the ground. As the largest moments yields the largest deflections, and stress concentration on the pillar, we can assume this is the worst-case scenario.

2.4.6 Stress Analysis

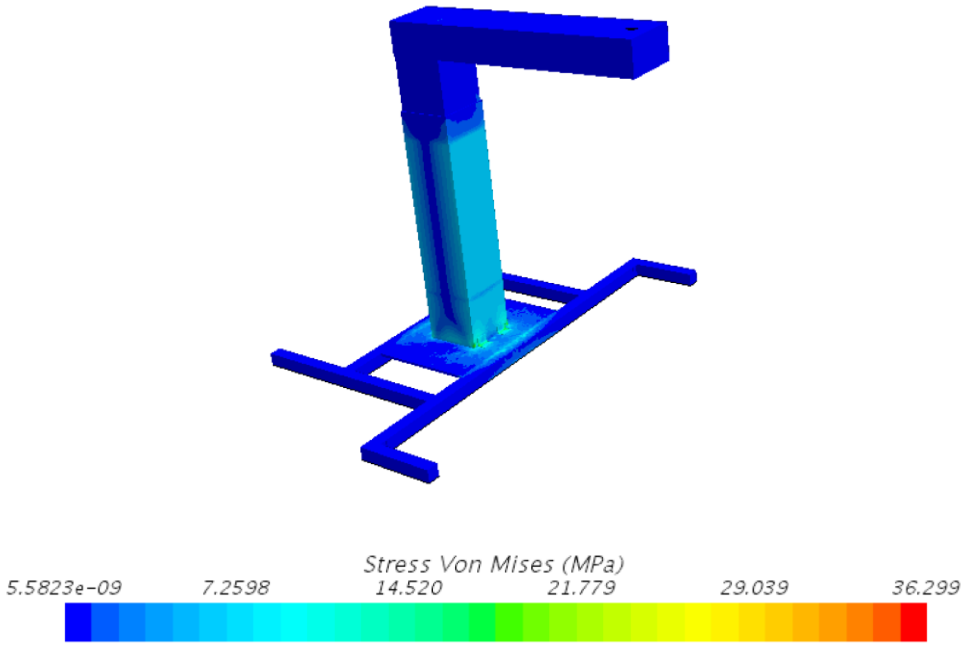


Figure 18: Stress Analysis

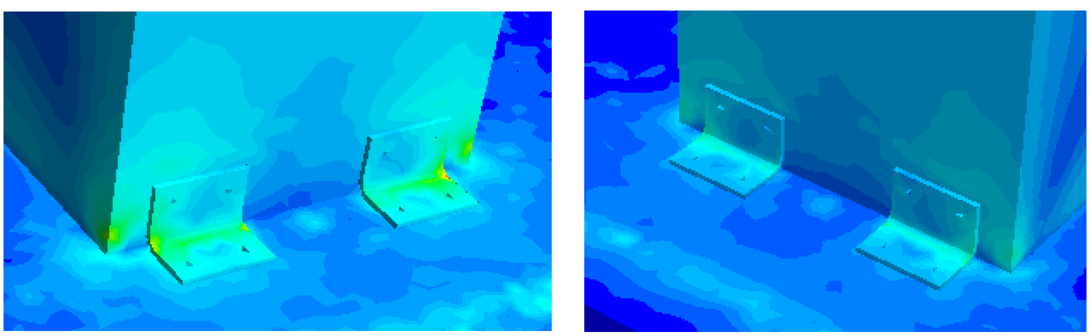


Figure 19: Stress Analysis – L Brackets

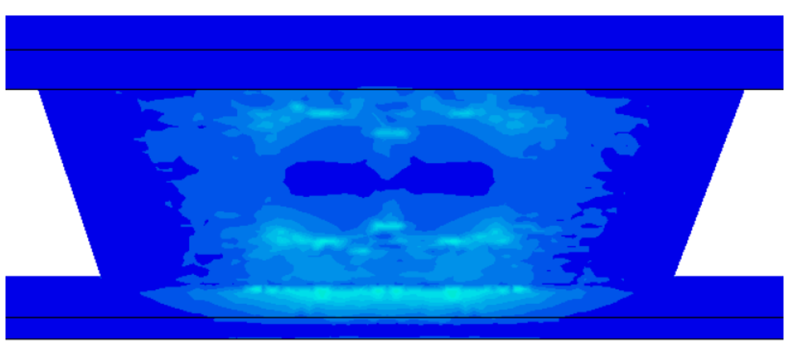


Figure 20: Stress Analysis – Bottom

From Figure 18, the base column experiences the largest amount of stress. The mesh was refined on the column, the L Brackets that keep it vertical, and the flat plate under it. Figure 18 shows the column experiencing a Von Mises stress of 7 – 10 MPa while under the 500 N load. Figure 19 shows a close-up of the L Brackets where the left picture it the front two L Brackets and the right is of the back two L brackets. The L Brackets show the most variation of stress. The brackets undergo a von Mises stress of 12 – 36 MPa. The front two L Brackets undergo the most stress. Figure 20 is the underneath of the flat plate that the column is on. The flat plate is shown to undergo a von Mises stress of 5 – 12 MPa. The stresses experienced in the column, L Brackets, and flat plate, were lower than the max yield stress of their respective material, so the device can endure the worst-case scenario.

2.4.7 Deflection Analysis

After applying a load on 500N in the negative y-direction, analysis was done on the base to see what part may deflect due to the force acting on the device. The result is shown in Figure 21.

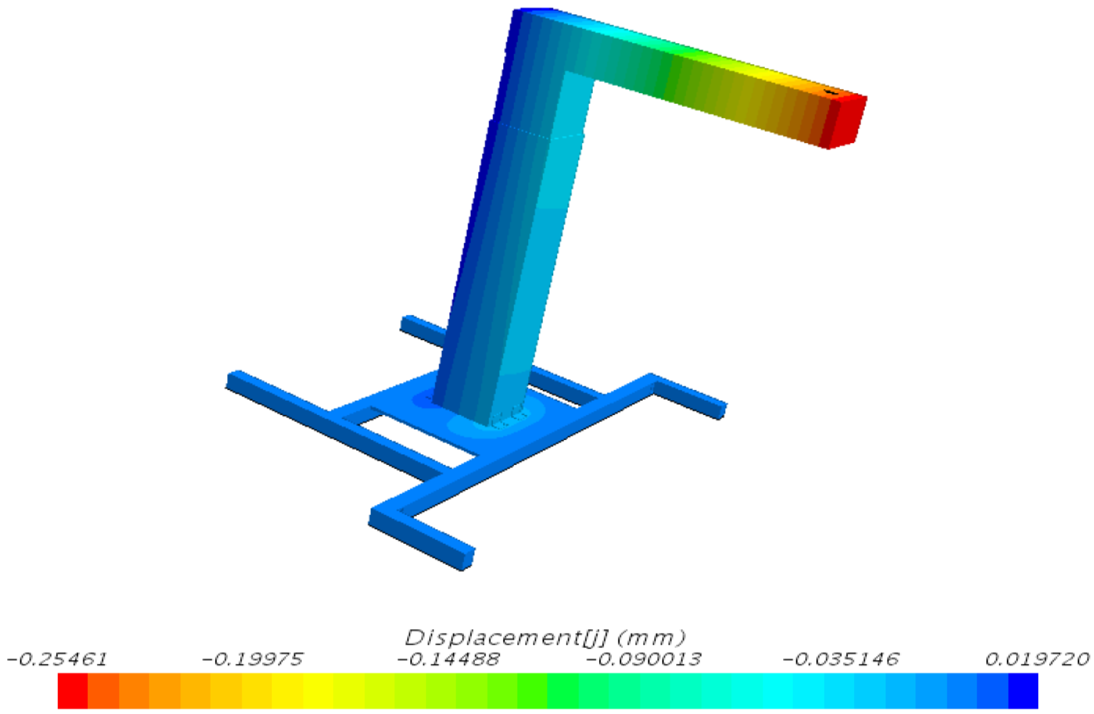


Figure 21: Displacement Y-Direction

From Figure 21, it is seen that the maximum deflection occurs at the point where the load is being applied. It is seen that the block will deflect about 0.02mm during the worst-case scenario. The rack deflecting 0.02mm is good news as this is relatively small and tells us that the system is strong enough to withstand even the worst-case scenario.

2.4.8 Strengths and Limitations of Design

Some of the strengths of our design:

- It is lightweight due to material selection, and dimensioning. We did not select thick material so that the weight would be reduced without compromising the structural integrity.
- It is customizable for various seats (e.g. wheelchair), and the height can be adjusted in accordance with the operation needed.
- It is safe to use.

Some of the limitations of our design:

- Transportability was taken into consideration, but it was not our highest priority. This could've been improved by making the stand legs fold; however, this may pose a structural issue (i.e. stability).
- We intended to decrease the weight of the design by using aluminum, however, we were constrained by the budget.
- Difficulty in mass production; this device cannot be easily mass produced since all the parts are custom made (e.g. drawer fitted inside the legs).
- The base/stand is not as compact as we had liked. However, we wanted to optimize customizability and safety over the overall size.

2.4.9 Mechanical NCRs

Throughout the manufacturing, and assembly process, we expect to encounter some mechanical errors. Specifically, welding comes with great risk. None of our team members has experience welding, and because of that, it could affect our ability to precisely weld joints together. The pillar, and the base plate must be welded properly to ensure the structural rigidity of the prototype. If the parts are not welded at a desired angle, this can also cause the base to be unstable, and pose a safety issue. Another error we expect is the stress concentration at the interface connection. Both the upper and lower modules are connected at a single point (the interface), and thus the stress caused by the weight of the upper attachment and operational use, will create a point of high stress concentration. Having a high stress concentration in a mechanical system is very dangerous because the system can typically yield at that spot. This would pose a severe danger to the patient, and nurse/medical technician. In order to resolve this issue, a stronger material than aluminum could be replaced for the current interface. Furthermore, the geometry of the current interface design could be changed to reduce the stress concentration. One last technical error we are predicting is the lack of secureness the pillar poses for multiple operational uses. As we are welding and using L-brackets, any sudden impact (impulse) poses a risk to the integrity of the pillar joints, and stability. The pillar has very minimal room for error due to the fact that it houses the linear actuator within. Therefore, the pillar poses significant room for errors that may arise during the assembly phase that must be acknowledged beforehand.

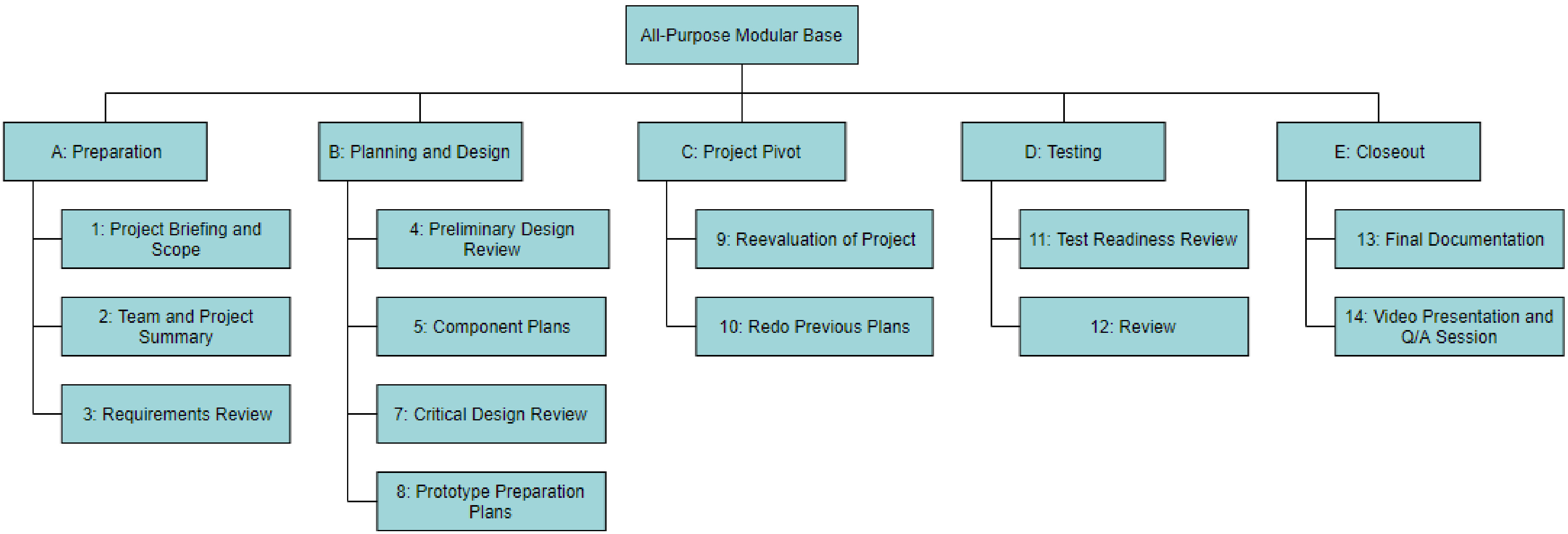
2.4.10 Electrical NCRs

An electrical failure would occur if we were to use an upper module with too high a power draw. For example, many devices such as the nebulizer, generally come with their own power chords which transform the wall voltage to its desired rating. Since our pivot was late in the design process, we understood that we would not be able to accommodate all types of solutions. We planned on having a “receptacle” connection on the device itself which would allow a top module to get power from the base. Then that new receptacle would wire through the base and out near the bottom where the charger would be placed. It would take power from a wall outlet and split the power between the battery charger and the ‘’new receptacle". This would then provide enough power for the charger and any other top module which uses 120VAC. It would also hide the physical charger as we could internally put it on the base and use a generic three prong plug to connect to the wall. Another note is that the charger only works with 120VAC, 60Hz receptacle outlets so eastern continents and some south-western parts of the globe would not be able to use the charging function. The group wanted to focus on local boundaries and then we could potentially research expansions for future endeavors.

Section 3.0: Project Management

In the following sections, we present the Work Breakdown Structure (WBS), Work Package Descriptions (WPD), Resource Allocation Matrix (RAM), and the Project Schedule (Gantt) as-run. Any changes from previous iterations are discussed in Section 3.5.

3.1 Work Breakdown Structure



3.2 Work Package Descriptions

WP ID	1	**WP Name**	Project Briefing and Scope
WP Dates	Sept 7 - Sept 13	**Expected Hours**	23
Manager	Maruti, Michael		
Support	Adam, Aya, Kishor, Lemuel, Pavel		
Inputs Needed	- Initiation email from course directors with company contact information		
Tasks to be Done	- Functional/component summary of the existing product - Demo of the existing product - Discussion of the scope of the project - Decide on method of communication between the company representative and the group		
Outputs Generated	- Idea of how the product functions - Basic ideas to improve the product - Scope of project		

WP ID	2	**WP Name**	Team and Project Summary
WP Dates	Sept 14 - Sept 20	**Expected Hours**	46.5
Manager	Kishor, Lemuel		
Support	Adam, Aya, Maruti, Michael, Pavel		
Inputs Needed	- Outputs of WP 1: Project Briefing and Scope		
Tasks to be Done	- Write a brief statement of the goal/objective of the project - Create a table of all stakeholders in the project - Each member creates a table containing their skillset and their goals for the project - All members decide/assign roles for the duration of the project, based on their personal qualification statements - Research into existing alternatives of the product - Pros/cons of the alternatives - A group evaluation of the document - Rubric evaluation of the Team and Project Summary document		
Outputs Generated	- Team and Project Summary Document - Feedback from course directors, supervisor, and company representative		

WP ID	3	**WP Name**	Requirements Review
WP Dates	Sept 21 - Oct 4	**Expected Hours**	93
Manager	Kishor, Maruti, Michael		
Support	Adam, Aya, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 2: Team and Project Summary		
Tasks to be Done	- Each member creates a list of requirements for the product based on the given company requirements, and their understanding of the product - Create a method of validating each requirement - A group evaluation of the document - Rubric evaluation of the Requirements Review document		
Outputs Generated	- Requirements Review Document - Feedback from course directors, supervisor, and company representative		

WP ID	4	**WP Name**	Preliminary Design Review
WP Dates	Oct 5 - Nov 4	**Expected Hours**	174
Manager	Adam, Lemuel, Pavel		
Support	Aya, Kishor, Maruti, Michael		
Inputs Needed	- Outputs of WP 3: Requirements Review		
Tasks to be Done	- Update statement of the goal/objective of the project - Update the requirements table using the feedback from stakeholders - A group evaluation of the document - Rubric evaluation of the Preliminary Design Review document - WP 4.1 to WP 4.3		
Outputs Generated	- Preliminary Design Review Document - Feedback from course directors, supervisor, and company representative		

WP ID	4.1	**WP Name**	Design Concepts and Analyses
WP Dates	Oct 5 - Nov 4	**Expected Hours**	50
Manager	Adam, Lemuel, Pavel		
Support	Maruti		
Inputs Needed	- Outputs of WP 3: Requirements Review		
Tasks to be Done	- System breakdown into key functions - System-level interfaces explained (e.g. use-case diagram, black box) - Design principles - Create multiple design solutions - Manufacturability guidelines		
Outputs Generated	- Morphological chart and Black Box diagram - Explanations of key parts in the product - Multiple design solutions with explanations - Explanation of design principles - Explanation for design based on manufacturability guidelines		

WP ID	4.2	**WP Name**	Work Breakdown and Scheduling
WP Dates	Oct 5 - Nov 4	**Expected Hours**	64
Manager	Kishor, Maruti, Michael		
Support	Adam, Aya, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 3: Requirements Review		
Tasks to be Done	- Create a chart, organizing the work needed to be done in the project - Create descriptions, with names and identifiers, for all work needed to be done in the project - Create a table showing each team members hours broken down by project month and by work package - Create a Gantt chart, showing the project schedule to completion		
Outputs Generated	- Work Breakdown Structure - Work Package Descriptions - Resource Allocation Matrix - Project Schedule Plan		

WP ID	4.3	**WP Name**	Expenses, Risks, Trade Study
WP Dates	Oct 5 - Nov 4	**Expected Hours**	31
Manager	Aya		
Support	Maruti, Michael, Pavel		
Inputs Needed	- Outputs of WP 3: Requirements Review		
Tasks to be Done	- Technical design budgets, based on project constraints - List of possible risks - Risk Matrix showing the risks by likelihood and consequence - Risk mitigation strategies - Create trade study metrics, criteria and weightings - Evaluate other approaches for functions of the product		
Outputs Generated	- Rough estimation of expenses - Risk Matrix - Risk mitigation strategies - A table that evaluates possible alternatives for certain functions of the product, using the created weightings/criteria		

WP ID	5	**WP Name**	Design-Specific Component Plans
WP Dates	Nov 5 - Nov 15	**Expected Hours**	43
Manager	Aya, Lemuel, Pavel		
Support	Adam, Kishor, Maruti, Michael		
Inputs Needed	- Outputs of WP 4: Preliminary Design Review		
Tasks to be Done	- WP 5.1 to WP 5.2		
Outputs Generated	- Design-Specific Component Plans (i.e. material lists, and explanations) - Feedback from supervisor, and company representative		

WP ID	5.1	**WP Name**	Material List and Research
WP Dates	Nov 5 - Nov 15	**Expected Hours**	33
Manager	Adam, Maruti		
Support	Kishor, Michael, Pavel		
Inputs Needed	- Outputs of WP 4: Preliminary Design Review		
Tasks to be Done	- Create a list explaining the possible materials to be used in prototyping - Research all materials in the Material List		
Outputs Generated	- Material List - Detailed research and explanations on materials		

WP ID	5.2	**WP Name**	Updating Schedule and Work Plan
WP Dates	Nov 5 - Nov 15	**Expected Hours**	10
Manager	Kishor, Michael		
Support	Maruti		
Inputs Needed	- Outputs of WP 4: Preliminary Design Review		
Tasks to be Done	- Update schedules and work plans based on feedback from stakeholders		
Outputs Generated	- Updated Schedule and Work Plan		

WP ID	6	**WP Name**	Design-Specific Test Plans
WP Dates	Nov 9 - Nov 15	**Expected Hours**	53
Manager	Kishor, Maruti, Michael		
Support	Adam, Aya, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 5: Design-Specific Component Plans		
Tasks to be Done	- WP 6.1 to WP 6.3		
Outputs Generated	- Design-Specific Test Plans (i.e. how to test prototype) - Feedback from supervisor, and company representative		

WP ID	6.1	**WP Name**	Test Planning
WP Dates	Nov 9 - Nov 15	**Expected Hours**	14
Manager	Adam, Michael		
Support	Lemuel, Maruti		
Inputs Needed	- Outputs of WP 5: Design-Specific Component Plans		
Tasks to be Done	- Create a plan for testing the chosen design		
Outputs Generated	- Test Plan		

WP ID	6.2	**WP Name**	Requirement Document Check
WP Dates	Nov 9 - Nov 15	**Expected Hours**	10
Manager	Kishor		
Support	Aya, Pavel		
Inputs Needed	- Outputs of WP 5: Design-Specific Component Plans		
Tasks to be Done	- Cross-check updated requirements from WP 4 with the design		
Outputs Generated	- All non-conformances with the design are identified		

WP ID	6.3	**WP Name**	Non-Conformance Plans
WP Dates	Nov 9 - Nov 15	**Expected Hours**	19
Manager	Aya, Maruti		
Support	Adam, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 6.1 to 6.2		
Tasks to be Done	- Create a plan to deal with unintended consequences of design		
Outputs Generated	- Non-Conformance Plan		

WP ID	7	**WP Name**	Critical Design Review
WP Dates	Nov 16 - Dec 21	**Expected Hours**	112
Manager	Adam, Aya, Maruti		
Support	Kishor, Lemuel, Michael, Pavel		
Inputs Needed	- Outputs of WP 5: Design-Specific Component Plans		
Tasks to be Done	- Describe project objective, work to be done in the project, key deliverables and risks - Updated Requirements Review - A group evaluation of the document - Rubric evaluation of the Critical Design Review document - WP 7.1 to WP 7.3		
Outputs Generated	- Critical Design Review Document - Feedback from course directors, supervisor, and company representative		

WP ID	7.1	**WP Name**	Baseline Design
WP Dates	Nov 16 - Dec 21	**Expected Hours**	26
Manager	Adam, Lemuel, Pavel		
Support	Maruti		
Inputs Needed	- Outputs of WP 5: Design-Specific Component Plans		
Tasks to be Done	- Present design that conforms to the Requirements Document - Identify performance metrics and design interfaces - Illustrate design use cases		
Outputs Generated	- Baseline Design		

WP ID	7.2	**WP Name**	Upd. Work Breakdown and Scheduling
WP Dates	Nov 16 - Dec 21	**Expected Hours**	64
Manager	Kishor, Maruti, Michael		
Support	Adam, Aya, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 5: Design-Specific Component Plans		
Tasks to be Done	- Update the existing chart, organizing the work needed to be done - Updated descriptions, with names and identifiers, for all work needed to be done in the project - Update existing table showing each team members hours broken down by project month and by work package - Update existing Gantt chart, showing the project schedule to completion		
Outputs Generated	- Updated Work Breakdown Structure - Updated Work Package Descriptions - Updated Resource Allocation Matrix - Updated Project Schedule Plan		

WP ID	7.3	**WP Name**	Upd. Expenses, Risks, Trade Study
WP Dates	Nov 16 - Dec 21	**Expected Hours**	31
Manager	Aya		
Support	Maruti, Michael, Pavel		
Inputs Needed	- Outputs of WP 5: Design-Specific Component Plans		
Tasks to be Done	- Updated design budgets, based on project constraints - Update list of possible risks - Update Risk Matrix showing the risks by likelihood and consequence - Update Risk mitigation strategies - Updated trade study metrics, criteria and weightings		
Outputs Generated	- Closer approximation for expenses - Updated Risk Matrix - Updated Risk mitigation strategies - Updated Trade Study		

WP ID	8	**WP Name**	Prototype Preparation Plan
WP Dates	Dec 21 - Jan 17	**Expected Hours**	65
Manager	Lemuel, Maruti, Pavel		
Support	Adam, Aya, Kishor, Michael		
Inputs Needed	- Outputs of WP 7: Critical Design Review		
Tasks to be Done	- Book/schedule rooms dedicated to team for prototyping and testing - WP 8.1 to WP 8.4		
Outputs Generated	- Rooms are scheduled for team throughout building and testing phases - Prototype Preparation Plan - Feedback from supervisor, and company representative		

WP ID	8.1	**WP Name**	Updated Material List and Research
WP Dates	Dec 21 - Jan 17	**Expected Hours**	33
Manager	Adam, Maruti		
Support	Kishor, Michael, Pavel		
Inputs Needed	- Outputs of WP 7: Critical Design Review		
Tasks to be Done	- Update existing list explaing the materials to be used in prototyping - Updated research on all materials in the Material List		
Outputs Generated	- Updated Material List - Updated research and explanations on materials		

WP ID	8.2	**WP Name**	Electrical Component Ordering
WP Dates	Dec 21 - Jan 17	**Expected Hours**	8
Manager	Kishor, Michael		
Support	Maruti		
Inputs Needed	- Outputs of WP 8.1		
Tasks to be Done	- Order all required electrical components from design documents		
Outputs Generated	- All electrical components are scheduled to arrive in time for prototyping		

WP ID	8.3	**WP Name**	Mechanical Material Ordering
WP Dates	Dec 21 - Jan 17	**Expected Hours**	8
Manager	Lemuel, Pavel		
Support	Aya		
Inputs Needed	- Outputs of WP 8.1		
Tasks to be Done	- Order all required mechanical components from design documents		
Outputs Generated	- All mechanical components are scheduled to arrive in time for prototyping.		

WP ID	8.4	**WP Name**	Updating Schedule and Work Plan
WP Dates	Dec 21 - Jan 17	**Expected Hours**	10
Manager	Kishor, Michael		
Support	Maruti		
Inputs Needed	- Outputs of WP 7: Critical Design Review		
Tasks to be Done	- Update schedules and work plans based on feedback from stakeholders		
Outputs Generated	- Updated Schedule and Work Plan		

WP ID	9	**WP Name**	Revaluation of Project
WP Dates	Jan 18 - Jan 31	**Expected Hours**	140
Manager	Lemuel, Maruti		
Support	Adam, Aya, Kishor, Michael, Pavel		
Inputs Needed	- Feedback from course directors		
Tasks to be Done	- Pivot the project in its current state; think of alternatives - Reschedule project components - Confirmation of plans with course directors		
Outputs Generated	- Approval from supervisor, and course directors		

WP ID	10	**WP Name**	Test Readiness Review
WP Dates	Feb 1 - Feb 19	**Expected Hours**	100
Manager	Adam, Aya, Lemuel		
Support	Kishor, Maruti, Michael, Pavel		
Inputs Needed	- Outputs of WP 9: Revaluation of Project		
Tasks to be Done	- Capture state of development of the system; its readiness for testing - Create sequence of testing planned for the system - Step-by-step procedure to conduct/assess if a test was successful or not - Create process to track/account for test failures (e.g. address failures through design modification, re-testing, etc.) - A group evaluation of the document - Rubric evaluation of the Test Readiness Review document		
Outputs Generated	- Test Readiness Review Document - Feedback from course directors and supervisor		

WP ID	11	**WP Name**	Redo Prototype Preparation Plan
WP Dates	Feb 20 - Mar 13	**Expected Hours**	65
Manager	Lemuel, Maruti, Pavel		
Support	Adam, Aya, Kishor, Michael		
Inputs Needed	- Outputs of WP 9: Revaluation of Project		
Tasks to be Done	- Book/schedule rooms dedicated to team for prototyping and testing - WP 8.1 to WP 8.4		
Outputs Generated	- Rooms are scheduled for team throughout building and testing phases - Prototype Preparation Plan - Feedback from supervisor, and company representative		

WP ID	11.1	**WP Name**	Updated Material List and Research
WP Dates	Feb 20 - Mar 13	**Expected Hours**	33
Manager	Adam, Maruti		
Support	Kishor, Michael, Pavel		
Inputs Needed	- Outputs of WP 9: Revaluation of Project		
Tasks to be Done	- Update existing list explaining the materials to be used in prototyping - Updated research on all materials in the Material List		
Outputs Generated	- Updated Material List - Updated research and explanations on materials		

WP ID	11.2	**WP Name**	Electrical Component Ordering
WP Dates	Feb 20 - Mar 13	**Expected Hours**	8
Manager	Kishor, Michael		
Support	Maruti		
Inputs Needed	- Outputs of WP 11.1		
Tasks to be Done	- Order all required electrical components from design documents		
Outputs Generated	- All electrical components are scheduled to arrive in time for prototyping		

WP ID	11.3	**WP Name**	Mechanical Material Ordering
WP Dates	Feb 20 - Mar 13	**Expected Hours**	8
Manager	Lemuel, Pavel		
Support	Aya		
Inputs Needed	- Outputs of WP 11.1		
Tasks to be Done	- Order all required mechanical components from design documents		
Outputs Generated	- All mechanical components are scheduled to arrive in time for prototyping		

WP ID	11.4	**WP Name**	Updating Schedule and Work Plan
WP Dates	Feb 20 - Mar 13	**Expected Hours**	10
Manager	Kishor, Michael		
Support	Maruti		
Inputs Needed	- Outputs of WP 9: Revaluation of Project		
Tasks to be Done	- Update schedules and work plans based on feedback from stakeholders		
Outputs Generated	- Updated Schedule and Work Plan		

WP ID	12	**WP Name**	Test Review
WP Dates	Mar 14 - Mar 27	**Expected Hours**	141
Manager	Adam, Aya, Michael		
Support	Kishor, Lemuel, Maruti, Pavel		
Inputs Needed	- Outputs of WP 11: Redo Prototype Preparation Plan		
Tasks to be Done	- Create a matrix, verifying testing methods created in WP 3: Req. Review - Create short summary of remaining non-conformances; explain plan to address these before project completion - Create summary of all expenses - Update Test Procedures from WP 10.3; add all procedures used during testing - A group evaluation of the document - Rubric evaluation of the Test Review document		
Outputs Generated	- Test Review Document - Feedback from course directors and supervisor		

WP ID	13	**WP Name**	Final Documentation
WP Dates	Mar 28 - Apr 24	**Expected Hours**	172
Manager	Kishor, Maruti, Michael		
Support	Adam, Aya, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Each member describes their overall experience during this project - Create a finalized compilation of all other smaller documents - A group evaluation of the document - Rubric evaluation of the Test Review document - WP 13.1 to WP 13.6		
Outputs Generated	- Final Documentation - Feedback from course directors and supervisor		

WP ID	13.1	**WP Name**	Executive Summary
WP Dates	Mar 28 - Apr 24	**Expected Hours**	10
Manager	Maruti		
Support	Aya		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Finalize statement of project objective		
Outputs Generated	- Final Executive Summary		

WP ID	13.2	**WP Name**	Requirements Document
WP Dates	Mar 28 - Apr 24	**Expected Hours**	12
Manager	Kishor, Michael		
Support	Maruti		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Review of requirements and how system has been validated for each		
Outputs Generated	- Requirements Review		

WP ID	13.3	**WP Name**	Design Documents
WP Dates	Mar 28 - Apr 24	**Expected Hours**	20
Manager	Adam, Lemuel, Pavel		
Support	Maruti		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Finalize all design documents with weightings and explanations - Finalize design budgets, and technical aspects of design		
Outputs Generated	- Final Design Documents - Design Compliance Analysis		

WP ID	13.4	**WP Name**	Work Plan Documents
WP Dates	Mar 28 - Apr 24	**Expected Hours**	64
Manager	Kishor, Maruti, Michael		
Support	Adam, Aya, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Finalize the existing chart, organizing the work needed to be done - Finalize descriptions, with names and identifiers, for all work needed to be done in the project - Finalize existing table showing each team members hours broken down by project month and by work package - Finalize existing Gantt chart, showing the project schedule to completion		
Outputs Generated	- Final Work Breakdown Structure - Final Work Package Descriptions - Final Work Package Descriptions - Final Project Schedule Plan		

WP ID	13.5	**WP Name**	Expenses, Risks, Trade Documents
WP Dates	Mar 28 - Apr 24	**Expected Hours**	31
Manager	Aya		
Support	Maruti, Michael, Pavel		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Finalize design budgets, based on project constraints - Finalize list of possible risks - Finalize Risk Matrix showing the risks by likelihood and consequence - Finalize Risk mitigation strategies - Finalize trade study metrics, criteria and weightings		
Outputs Generated	- Final Expense List - Final Risk Matrix - Final Risk mitigation strategies - Final Trade Study		

WP ID	13.6	**WP Name**	Test Documents
WP Dates	Mar 28 - Apr 24	**Expected Hours**	20
Manager	Aya, Pavel		
Support	Adam, Lemuel		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Compilation report of all test documents		
Outputs Generated	- Final Test Document		

WP ID	14	**WP Name**	Video Presentation & Q/A Session
WP Dates	Mar 28 - Apr 30	**Expected Hours**	56
Manager	Maruti, Michael		
Support	Adam, Aya, Kishor, Lemuel, Pavel		
Inputs Needed	- Outputs of WP 12: Test Review		
Tasks to be Done	- Each member reviews all project documents - Each member prepares for presentation of final product		
Outputs Generated	- Presentation video of final product to course directors and supervisor		

3.3 Resource Allocation Matrix

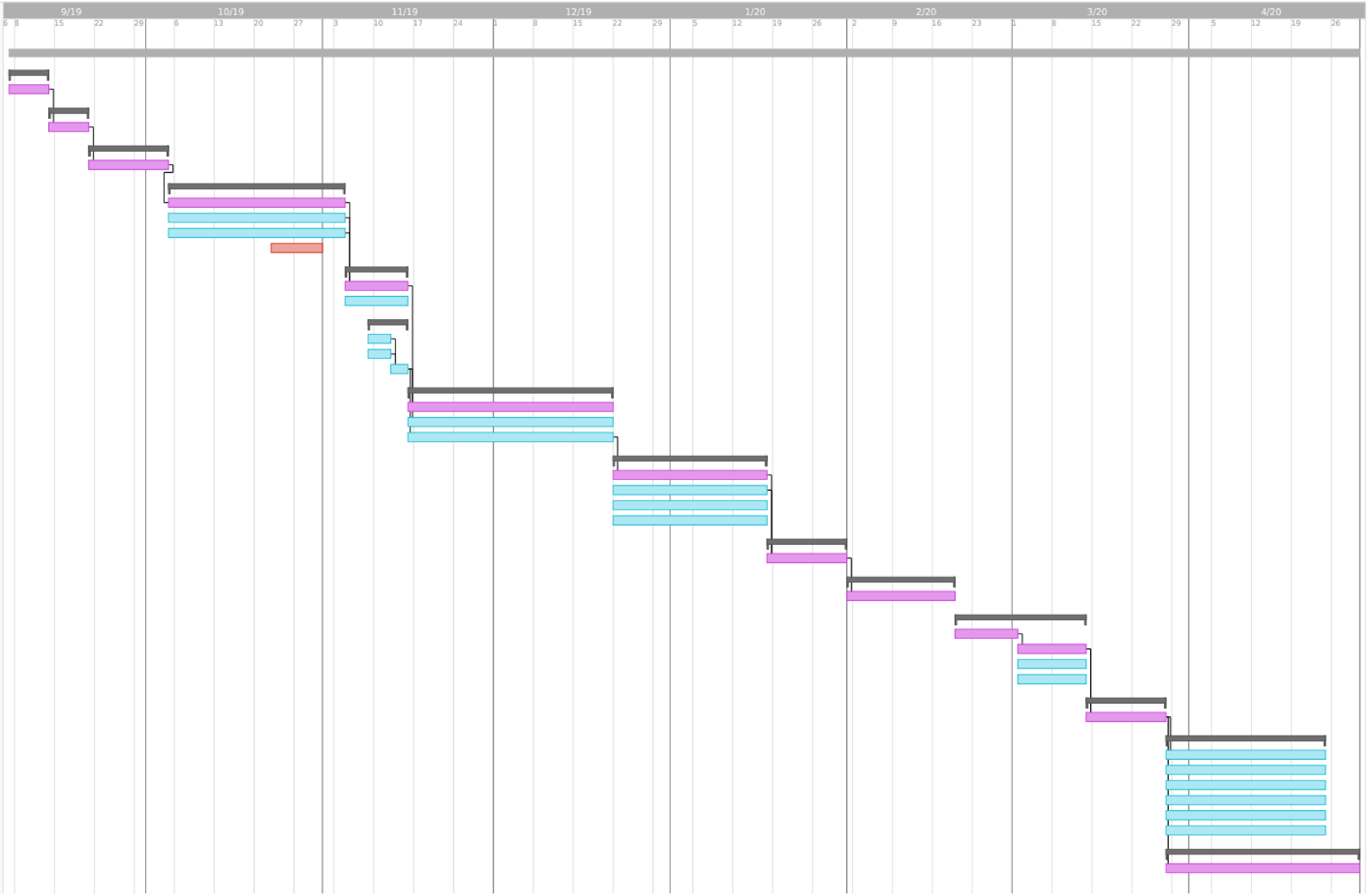
<table>
<tr><th rowspan="2">Month</th><th rowspan="2">Week</th><th rowspan="2">Package ID</th><th rowspan="2">Package Name</th><th colspan="7">Hours per Person [by Package]</th><th rowspan="2">Total Hours</th><th colspan="7">Hours per Person [by Month]</th></tr>
<tr><th>Adam</th><th>Aya</th><th>Kishor</th><th>Lemuel</th><th>Maruti</th><th>Michael</th><th>Pavel</th><th>Adam</th><th>Aya</th><th>Kishor</th><th>Lemuel</th><th>Maruti</th><th>Michael</th><th>Pavel</th></tr>
<tr><td rowspan="3">September</td><td>Sept 7 - Sept 13</td><td>1</td><td>Project Briefing and Scope</td><td>3</td><td>3</td><td>3</td><td>3</td><td>4</td><td>4</td><td>3</td><td>23</td><td rowspan="3">24</td><td rowspan="3">24</td><td rowspan="3">24</td><td rowspan="3">24</td><td rowspan="3">21.5</td><td rowspan="3">22.5</td><td rowspan="3">22.5</td></tr>
<tr><td>Sept 14 - Sept 20</td><td>2</td><td>Team and Project Summary</td><td>7</td><td>7</td><td>8</td><td>8</td><td>5.5</td><td>5.5</td><td>5.5</td><td>46.5</td></tr>
<tr><td>Sept 21 - Sept 27,
Sept 28 - Oct 4</td><td>3</td><td>Requirements Review</td><td>14</td><td>14</td><td>13</td><td>13</td><td>12</td><td>13</td><td>14</td><td>93</td></tr>
<tr><td rowspan="4">October</td><td rowspan="4">Oct 5 - Oct 11,
Oct 12 - Oct 18,
Oct 19 - Oct 25,
Oct 26 - Nov 4</td><td>4</td><td>Preliminary Design Review</td><td>24</td><td>25</td><td>28</td><td>24</td><td>24</td><td>23</td><td>26</td><td rowspan="4">174</td><td rowspan="4">24</td><td rowspan="4">25</td><td rowspan="4">28</td><td rowspan="4">24</td><td rowspan="4">24</td><td rowspan="4">23</td><td rowspan="4">26</td></tr>
<tr><td>4.1</td><td>Design Concepts and Analyses</td><td>15</td><td>0</td><td>0</td><td>15</td><td>5</td><td>0</td><td>15</td></tr>
<tr><td>4.2</td><td>Work Breakdown and Scheduling</td><td>2</td><td>10</td><td>20</td><td>3</td><td>8</td><td>19</td><td>2</td></tr>
<tr><td>4.3</td><td>Expenses, Risks, Trade Study</td><td>4</td><td>12</td><td>0</td><td>4</td><td>3</td><td>1</td><td>7</td></tr>
<tr><td rowspan="11">November
&
December</td><td rowspan="3">Nov 5 - Nov 15</td><td>5</td><td>Design-Specific Component Plans</td><td>4</td><td>7</td><td>6</td><td>7</td><td>6</td><td>6</td><td>7</td><td rowspan="3">43</td><td rowspan="11">27</td><td rowspan="11">31</td><td rowspan="11">30</td><td rowspan="11">29</td><td rowspan="11">30</td><td rowspan="11">30</td><td rowspan="11">31</td></tr>
<tr><td>5.1</td><td>Material List and Research</td><td>4</td><td>7</td><td>2</td><td>7</td><td>4</td><td>2</td><td>7</td></tr>
<tr><td>5.2</td><td>Updating Schedule and Work Plan</td><td>0</td><td>0</td><td>4</td><td>0</td><td>2</td><td>4</td><td>0</td></tr>
<tr><td rowspan="8">Nov 16 - Nov 22,
Nov 23 - Dec 2,
Dec 3 - Dec 6,
Dec 7 - Dec 13,
Dec 14 - Dec 20,
Dec 21 - Dec 27</td><td>6</td><td>Design-Specific Test Plans</td><td>7</td><td>8</td><td>8</td><td>6</td><td>8</td><td>8</td><td>8</td><td rowspan="4">53</td></tr>
<tr><td>6.1</td><td>Test Planning</td><td>4</td><td>0</td><td>0</td><td>3</td><td>3</td><td>4</td><td>0</td></tr>
<tr><td>6.2</td><td>Requirement Document Check</td><td>0</td><td>3</td><td>4</td><td>0</td><td>0</td><td>0</td><td>3</td></tr>
<tr><td>6.3</td><td>Non-Conformance Plans</td><td>3</td><td>5</td><td>0</td><td>3</td><td>5</td><td>0</td><td>3</td></tr>
<tr><td>7</td><td>Critical Design Review</td><td>16</td><td>16</td><td>16</td><td>16</td><td>16</td><td>16</td><td>16</td><td rowspan="4">112</td></tr>
<tr><td>7.1</td><td>Baseline Design</td><td>8</td><td>0</td><td>0</td><td>8</td><td>4</td><td>0</td><td>6</td></tr>
<tr><td>7.2</td><td>Upd. Work Breakdown and Scheduling</td><td>2</td><td>10</td><td>20</td><td>3</td><td>8</td><td>19</td><td>2</td></tr>
<tr><td>7.3</td><td>Upd. Expenses, Risks, Trade Study</td><td>4</td><td>12</td><td>0</td><td>4</td><td>3</td><td>1</td><td>7</td></tr>
<tr><td rowspan="4">December
&
January</td><td rowspan="4">Dec 28 - Jan 3,
Jan 4 - Jan 10,
Jan 11 - Jan 17</td><td>8</td><td>Prototype Preparation Plan</td><td>8</td><td>9</td><td>9</td><td>10</td><td>10</td><td>9</td><td>10</td><td rowspan="4">65</td><td rowspan="4">28</td><td rowspan="4">29</td><td rowspan="4">29</td><td rowspan="4">30</td><td rowspan="4">30</td><td rowspan="4">29</td><td rowspan="4">30</td></tr>
<tr><td>8.1</td><td>Updated Material List and Research</td><td>4</td><td>7</td><td>2</td><td>7</td><td>4</td><td>2</td><td>7</td></tr>
<tr><td>8.2</td><td>Electrical Component Ordering</td><td>0</td><td>0</td><td>3</td><td>0</td><td>2</td><td>3</td><td>0</td></tr>
<tr><td>8.3</td><td>Mechanical Material Ordering</td><td>0</td><td>2</td><td>0</td><td>3</td><td>0</td><td>0</td><td>3</td></tr>
</table>

		8.4	Updating Schedule and Work Plan	0	0	4	0	2	4	0								
	Jan 18 - Jan 24, Jan 25 - Jan 31	**9**	**Re-evaluation of Project**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	140							
February & March	Feb 1 - Feb 7, Feb 8 - Feb 14, Feb 15 - Feb 21	**10**	**Test Readiness Review**	**15**	**16**	**13**	**13**	**14**	**15**	**14**	100	44	45	42	40	46	44	45
	Feb 22 - Feb 28, Feb 29 - Mar 6, Mar 7 - Mar 13	**11**	**Redo Prototype Preparation Plan**	**8**	**9**	**9**	**10**	**10**	**9**	**10**	65							
		11.1	Updated Material List and Research	4	7	2	7	4	2	7								
		11.2	Electrical Component Ordering	0	0	3	0	2	3	0								
		11.3	Mechanical Material Ordering	0	2	0	3	0	0	3								
		11.4	Updating Schedule and Work Plan	0	0	4	0	2	4	0								
	Mar 14 - Mar 20, Mar 21 - Mar 27	**12**	**Test Review**	**21**	**20**	**20**	**17**	**22**	**20**	**21**	141							
March & April	Mar 28 - Apr 3, Apr 4 - Apr 10, Apr 11 - Apr 17, Apr 18 - Apr 24, Apr 25 - Apr 30	**13**	**Final Documentation**	**22**	**24**	**24**	**26**	**25**	**26**	**25**	172	30	32	32	34	33	34	33
		13.1	Executive Summary	0	3	0	0	7	0	0								
		13.2	Requirements Document	0	0	5	0	2	5	0								
		13.3	Design Documents	6	0	0	6	2	0	6								
		13.4	Work Plan Documents	2	10	20	3	8	19	2								
		13.5	Expenses, Risks, Trade Documents	4	12	0	4	3	1	7								
		13.6	Test Documents	3	7	0	3	0	0	7								
		14	**Video Presentation & Q/A Session**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	56							

Statistics	**Adam**	**Aya**	**Kishor**	**Lemuel**	**Maruti**	**Michael**	**Pavel**
Total Hours Spent [per Person]	177	186	185	181	184.5	182.5	187.5
Total Hours Spent [as Group]	1283.5						

3.4 Project Scheduling

Robotic Arm	start	end
Project Briefing and Scope	**09/07/19**	**09/13/19**
Project Briefing and Scope	09/07	09/13
Team and Project Summary	**09/14/19**	**09/20/19**
Team and Project Summary	09/14	09/20
Requirements Review	**09/21/19**	**10/04/19**
Requirements Review	09/21	10/04
Preliminary Design Review	**10/05/19**	**11/04/19**
Design Concepts and Analyses	10/05	11/04
Work Breakdown and Scheduling	10/05	11/04
Expenses, Risks, Trade Study	10/05	11/04
Mid Terms/Break (No Work)	10/23	10/31
Design-Specific Component Plans	**11/05/19**	**11/15/19**
Material List and Research	11/05	11/15
Updating Schedule and Work Plan	11/05	11/15
Design-Specific Test Plans	**11/09/19**	**11/15/19**
Test Planning	11/09	11/12
Requirement Document Check	11/09	11/12
Non-Conformance Plans	11/13	11/15
Critical Design Review	**11/16/19**	**12/21/19**
Baseline Design	11/16	12/21
Updated Work Breakdown & Schedul...	11/16	12/21
Updated Expenses, Risks, Trade Stu...	11/16	12/21
Prototype Preparation Plan	**12/22/19**	**01/17/20**
Updated Material List & Research	12/22	01/17
Mechanical Material Ordering	12/22	01/17
Electrical Component Ordering	12/22	01/17
Updating Schedule and Work Plan	12/22	01/17
Re-evaluation of Project	**01/18/20**	**01/31/20**
Re-evaluation of Project	01/18	01/31
Test Readiness Review	**02/01/20**	**02/19/20**
Test Readiness Review	02/01	02/19
Redo Prototype Preparation Plan	**02/20/20**	**03/13/20**
Updated Material List and Research	02/20	03/01
Electrical Component Ordering	03/02	03/13
Mechanical Material Ordering	03/02	03/13
Updating Schedule and Work Plan	03/02	03/13
Test Review	**03/14/20**	**03/27/20**
Test Review	03/14	03/27
Final Documentation	**03/28/20**	**04/24/20**
Executive Summary	03/28	04/24
Requirements Document	03/28	04/24
Design Documents	03/28	04/24
Work Plan Documents	03/28	04/24
Expenses, Risks, Trade Study Docum...	03/28	04/24
Test Documents	03/28	04/24
Video Presentation	**03/28/20**	**04/30/20**
Video Presentation & Q/A Session	03/28	04/30



3.5 Project Management Changelog

In reference to previous iterations (see Appendix: Section 5.3) of the Work Breakdown Structure (WBS), Work Package Descriptions (WPD), Resource Allocation Matrix (RAM), and Project Scheduling (Gantt), there have been some major changes

- The WPD were redone from WP 7.0 and onwards; this is because we went over the scheduled timing of completion on the CDR deliverable (we were given an extension on the CDR deliverable). So, this delayed the other work packages' start times.
- Due to a pivot in the project, we were forced to "re-evaluate our project," hence the replacement of old "WP 9: Build Prototype" with "WP 9: Re-evaluate Project".
- This pivot resulted in a series of changes to our timeline since we were allotted extensions for all deliverables after the pivot. Our TRR was extended to mid-February, TR to late-March, and Final Report to late-April.
- After we completed WP 10, we were forced to repurchase items and remake plans that we had made for the previous project, hence the addition of "WP 11: Redo Prototype Preparation Plan" rather than the old "WP 11: Prototype Testing."
- After WP 11, we were to begin building our prototype, but we were further delayed by COVID-19 events; therefore, we were never able to build a prototype at all in this project (due to lack of equipment). This led to us doing "predictive performance" tests on our design; but in terms of project scheduling, we were able to continue the project (virtually) with the previous obstacles.
- All the changes made in the WPD were to be reflected in the RAM, WBS, and the Gantt chart; therefore, all changes in the RAM, WBS, and Gantt chart have the same justification as the changes in the WPD.

3.6 Team Meetings Log

Title	Date	Duration (min)	Members Present	Purpose of Meeting
Meeting with Ilia	09/20/19	90	All	- Introduction - Project breakdown - Expected requirements
Meeting with Rob Allison	11/04/19	30	Adam, Maruti, Michael, Pavel	- PDR update, motor advice - Gearing constraints - Vertical motion for height change - Talk to Jas Paul for materials
Meeting with External Supervisor	11/08/19	120	All	- Introduction - Review of PDR - Background summary - Suggestion of useful resources
Mechanical Members Meeting	11/14/19	150	Adam, Maruti, Lemuel, Pavel	- Base design ideas - Research on linear actuators - Base sketch
General Group Meeting	11/15/19	180	All	- Finalizing the design of the base as well as discussing the CDR requirements
Meeting with Hossam	11/18/19	90	Adam, Maruti, Lemuel	- Discuss disagreements currently going on with client - Discuss available space to work on project in Bergeron Centre
General Group Meeting	11/19/19	210	Adam, Kishor, Maruti, Michael, Pavel	- Measurement of existing prototype as well as acquiring necessary pictures - Call Illia to discuss the base design
General Group Meeting	11/21/19	150	All	- Follow up with CDR, making sure everyone is okay with their assigned parts for the CDR - Call client for update - Conversation about stand design
Meeting with Rob Allison	11/22/19	60	Kishor, Lemuel, Maruti, Michael	- Update Rob on project's progress - Discussing relationship/disagreement with client - Go over Rob's comments for previous report - Find any potential flaws in our current design
Meeting with Franz	11/22/19	30	All	- Update on demands from clients, current level of the project - Breakdown of deliverables, CDR, PDR, and requirements list - Brainstorming on how we can move forward with client - Creating agendas before phone call meeting
Meeting with James	01/17/29	45	Adam, Maruti, Lemuel, Pavel	- Settle existing conflicts with client - Discuss a win-win situation for the team and client moving forward
Mechanical Members Meeting	01/17/29	30	Adam, Maruti, Lemuel, Pavel	- Discussing material log and setting updates to visiting metal stores to make purchases
General Group Meeting	01/21/20	150	All	- Discussing updates in design - Confirming materials and dimensions - Suggesting options for purchase of parts - Brainstorming ways to build joint as agreed with the client - Splitting up workload for upcoming test readiness report

Metal Supermarket	01/23/20	45	Adam, Maruti, Lemuel, Pavel	- To see products on the market and check for prices of potential materials
Meeting with Hossam	01/23/20	45	Adam, Maruti, Lemuel, Pavel	- Discuss ways to move forward with existing problems with client - Seeking possible route to follow moving forward with project
Meeting with Rob Allison	01/23/20	30	Adam, Maruti, Lemuel, Pavel	- Look for similar stuff out there, Avoid using designs from Ilia - Suggesting to pursue a completely different design - Or look at a similar design from a different company - Checking test required for the TRR - Weight on base plate - Moments arm calculation on the end of the rack - Testing to see if the actuator can lift a weight - Adjustable shaft – moving from position A to B to see if it works - Consider 3 different scenarios for the top design e.g. blood pressure machine, Optometry machine, rehab facility - Rob never disagreed with our design; approved of the functional design
Meeting with Claudia	01/23/20	60	Kishor, Lemuel, Maruti, Michael, Pavel	- Group discussion on current status of project - Brainstorming possible ways to tackle current situation with client - Claudia helped with setting up meeting with course instructors - Confirming that the crises will not affect our final grades
Meeting with Course Directors	01/24/20	45	All	- Next steps with project - Grades - Purpose of Project - Discussing how things could have been handled differently - Identifying the problem in the final report and reflecting on it - What to do next in the project regarding the top piece - We can stay within the field of rehabilitation if we have good reason - What problems can this device solve - Thinking about what can be attached to the stand - What makes our design special amongst other stands - Compare and contrast the prices of tables that exist already - Design Aesthetic - Schedule a timeline that works within the available time - Design process is the most important thing concerning our grades

General Group Meeting	01/25/20	120	All	- Every member was tasked with coming up with potential idea moving forward with our current project - Goal was to try and stay within the scope of our current idea for time efficiency - We decided to create a generic stand with a revolving top powered by motor - This will be useful as a generic stand in potential rehabilitation, it will allow for travel vertically and for rotation - Blood pressure machine interphase for the top piece
Meeting with Hossam	01/28/20	30	All	- To update profs on current progress with design to see what will be useful moving forward - 1st idea: How will you present your idea to avoid conflict with Ilia on capstone day - Can this device take multiple problems - Designing a stand that can be useful for awkward chairs - Make sure you have not used any IP from previous client so there can be no action towards you - Keep in mind that you will be questioned on what this base could be used for - Consider designing mock up table and mock up blood pressure machine that can be attached to your stand - Avoid problems with Ilia - Search up other devices needed for wheel chair settings - Think about your competition and what you need to do moving forward - Does your structure support your argument - Make a plan within schedule for deliverables - Think about capstone day and come up with a structure for your presentation
General Group Meeting	02/07/20	90	All	- Update on material selection - Confirmation on new top design - Brainstorm various ideas on top design - Design selection potential (tripod camera rotation device)
General Group Meeting	02/14/20	150	All	- Working on adjusting the requirements list to meet update design - Work on TRR report and split parts
General Group Meeting	02/28/20	45	All	- Parts procurement discussion - Tripod stand commercial use for interphase - Scheduling roles for purchase

3.7 Total Expenses

The final totals of the expenses are listed in the table below. We had ordered many items earlier on, however, the delivery time had extended due to the shutdown. Furthermore, as our design process was delayed due to the loss of our client, we had to rethink our new design, and this delayed us in creating a new parts list.

Item	Per Item Cost	Total Cost of Item
1x Step Down Converter	58.27	58.27
1x Stepper Motor	17.99	17.99
1x Auto Relay Wire Harness	12.48	12.48
1x Toggle Switch	8	8
2x Hardware Drawers	37.95	75.9
1x Linear Actuator	66.89	66.89
1x Tripod Head	142.91	142.91
Metal for Stand	128.38	128.38
1x Controller for stepper motor	9.19	9.19
5x Wheels	8.98	50.74
Total Cost:		**570.75**

Currently, the overall cost is $570.75. Majority of the cost went to the key components such as metal for the stand, and the tripod head, as expected. We also expected the electronic equipment to be relatively inexpensive aside from the linear actuator. The test was a success as the total cost of the expenses was below $1000. Due to the shutdown, we are unable to manufacture the prototype, as well as make purchases. Due to this, we expect the final expense to be higher than $570.75. There are many small nuances that must be accounted for in the cost that were not such as screws, bolts, etc. We can estimate these costs to be roughly $50. Furthermore, the portable battery pack and charger were not purchased and thus did not account into the expenses. From looking at online resources, the battery pack and charger are estimated to cost $37.99, and $12.95 respectively. The sum cost of these estimated additional costs is roughly $670 (see Appendix: Section 5.2 for receipts).

3.8 Preliminary Business Case

We perform a SWOT analysis to assess our current position and determine necessary steps to move forward.

Strengths	Weaknesses
• Modular design makes our product unique • Legs designed to expand, and contract as needed to fit in hospital or small clinic corridors • Low price point • Better alternative for clients considering purchasing specifically accessibility-friendly devices • Minimal training required to operate	• Untested prototype • As a company, we have a little to no market presence or reputation • Small team of staff with shallow experience • Unreliable cash flow in early stages • Unpatented
Opportunities	**Threats**
• Niche market is expanding with many future opportunity • Diverse client set including hospitals, clinics, in-home care businesses, and nursing homes	• Competitors may quickly develop their own design and mass produce it

Based on the results of this analysis we know that the current estimated price point and nature of design is what gives us our competitive edge. Also, our weaknesses seem to stem from our size. Therefore, we will invest in training our staff and developing relationships with others in this market. Since we’re operating in a small market but with clients of different sizes, we can solidify a foothold in the market with a small client and build our relationships upwards. The biggest threat to our product is if our competitors copy it considering they’ve been in the industry; they know the clients and have the resources to mass produce. We must consider patenting our product in order to circumvent such a threat. We will also perform a “features” study to assess what our initial clients like to see adapted into our product to maintain our status as unique.

Section 4.0: Lessons Learned

4.1 Deviations from Plan

Throughout the lifecycle of the project, we've encountered two major obstacles that demanded we change course. First, due to a possible miscommunication error, our initial client receded from the project. His company, VIBRAINT, brought us an arm rehabilitation robot project and provided us with some improvements he'd like to see applied. We were allowed to borrow his prototype for reverse-engineering and testing purposes. Despite reassuring us of the freedom to take this project in any direction we'd like, he was so dissatisfied of the concrete design we came up with that he pulled out of the project, taking his prototype with him. This forced us to deviate from said concrete design as we were no longer able to continue with the same project due to a Non-Disclosure Agreement we signed.

After much discussion with course directors, we figured that while we cannot pursue this specific design for the purposes of rehabilitation, we can still keep the unique aspects we designed and rework them to fit into a wider, yet medical, domain. First, our adjustable legs and concentric central column remained part of our design. This established our base for the device. We added a new interface for the top part that allows different devices to attach to our base, original VIBRAINT device as well.

The other obstacle that has effectively stunted further development of our product is the Covid-19 pandemic. Due to this worldwide shutdown, we were unable to buy items since shipping has been delayed/halted. We also lost access to the mechanical shop in the Bergeron Centre as the university had to shut down. We relied on many equipment in the shop to build and test our product. The team was advised to conduct as much testing as possible using Star CCM to demonstrate the potential of our product.

4.2 Failure Report

Considering we were not able to execute the project past ideation; this section will discuss anticipated mechanical and electrical failures. Our biggest manufacturing obstacle is the main column. The design consists of concentric aluminum tubes being manipulated by a linear actuator. Our team has minimal machine shop experience. To get that mechanism to operate smoothly, the tubes need to be cut out and attached expertly. To achieve such integrity would require multiple trials on our part.

One of our perceived failures include the miscommunication that led to our initial client to part ways with us. In the early design stages, we had a consistent open line with our client, the face of VIBRAINT, and all parties had a solid view on the project's direction. It was during the concrete design stage that our team took more time to dwell over the details that we got back to our client a little late. They didn't have any qualms with our design at that point however, by February they decided we're going in different directions and parted ways. Now we know that with this type of client, open communication is not sufficient. In the future, we'd practice proactive communication. The group would also pursue supervisor and course director input earlier into the discussions. This would allow solutions to be developed early in the project cycle allowing for easier timeline adjustments.

4.3 Lessons Learned

This project was very beneficial for our growth as future engineers as we had learned valuable lessons along the way. As we reflect on the methods, we used that worked well and ones that did not work well, we can discover ideas that should be repeated as well as some that should be avoided. By doing so, we can use this as a learning opportunity to strive for improvement for upcoming projects. It is important to distinguish whether the method was poor or if it was simply carried out incorrectly.

4.3.1 Working in an Interdisciplinary Team

This project allowed us to learn how to cohesively work together in an interdisciplinary team. Prior to this project, we did not have experience working alongside engineers of other disciplines. This project gave us valuable exposure into the teamwork, communication, and empathy skills it takes to work cohesively in a team. For instance, we had to communicate with one another about aspects of the project we did not understand. The mechanical team did not fully understand the linear actuator system and had to lean off of the electrical team, and vice-versa for the structural integrity of the system. Initially, bridging this knowledge gap was difficult, however, by communicating effectively and being empathetic to one another helped us overcome this difficulty and produce a successful project.

4.3.2 Team and Supervisor Meetings

At the beginning of the project we had underestimated the need to meet frequently with our team, as well as the supervisor. For the first couple deliverables, we had only met a week or so leading up to a deliverable and met with the supervisor infrequently. However, as the project schedule progressed, we found that we would have an easier time managing current tasks and goals had we met and communicated our ideas earlier on. An example of this was related to the linear actuator. If we had met earlier on and discussed the specifications of the linear actuator we needed for our system, it could have saved us time finding a vendor at a crucial time in the project. Furthermore, we could have leveraged our resources to help better discover unique ideas, specifically, our supervisor Dr. Rob Allison. We could have had bi-weekly progress report meetings with Dr. Rob Allison to discuss our trajectory of the project and potentially gain new insight from his experience. Dr. Allison’s expertise might have been able to help us create a plan of action that would deter us from potential failures. Furthermore, we could also discuss potential problems we are experiencing in the project such as the linear actuator. We found that having an open line of communication is very important as many issues, concerns, and ideas could have been addressed. In a real-world application, this project can teach us to reach out to our project managers, supervisors, or project leads if we have questions as they are meant to offer us guidance so that the overall project is successful. Finally, it taught us that frequently short meetings are effective as they help the team stay on the same page with one another.

4.3.3 Client Requirements and Design

One of the first lessons we learned was that it is very important to be clear and detailed when gathering the clients needs. When we had our initial client, we had arranged a meeting to go over the scope of the project. During the meeting, the client stated that he wanted to give us the reigns of the project, and said it was our discretion as to how we will conduct the project. We listed the main objectives/goals he wanted as well as a few secondary optional objectives. However, as the project progressed (near the CDR) phase, the client was attempting to take over the design to match his idea. This was very conflicting for our group as we had already set requirements, conducted design sketches, and begun searching for parts. We would not have been able to accept these design changes at this point in the project. As a result, the client backed out of the project, and we had to pivot to a new project all together. To solve this issue, we could have made it very clear from the beginning that based on the clients' objectives, we will develop a design that satisfies these requirements. Furthermore, a more specific approach could have been asking the client to list the top 3 objectives he wanted achieved, and then list a few sub-objectives that might be a good addition to the design. After generating these targets, it is clear that major changes cannot be made to the project as we have a strict schedule to maintain, and any additional changes prevent our group from moving forward. This would force the client to not make changes to a finalized design and thus prevent significant changes to our schedule.

4.3.4 Meetings with Clients

Another lesson we had learned was how to manage meetings with clients. During our project, the majority of our scheduled meetings would go off topic, and we would not achieve our desired outcome of the meeting. For instance, a meeting to double check a few requirements with the client, turned into a conversation about scrapping our current design plan and reinventing a new one. To prevent this from happening, we could send the client an agenda with time constraints of the topics the meeting will be discussing. After the points on the agenda have been achieved, then we would be able to discuss other ideas the client had for a short amount of time. This tactic would surely help keep meetings on track and help both parties save time. In the workplace, this direct tactic can also be used. For instance, if you are acting as a consultant for an engineering firm and meeting with a client, the client will attempt to push his ideas onto you, however it is the engineers job to be organized and provide them with the best engineering results (even if it may not agree with what they had envisioned).

4.4 Next Steps and Path Forward

The current Capstone project has come to an end; however, this is not the ending result we had imagined in September 2019. We had initially envisioned carrying out the design, testing, and simulation phase properly and built a working prototype. However, due to unforeseen circumstances, we were only able to design, and simulate our model and not test and build as we had hoped to. The next step, if the project were to continue, is to procure parts that were unobtainable during the shutdown. Finally, a rigorous testing phase would be carried out in accordance to the Testing Review. It would be determined which tests were verified and which did not. For the tests that were not verified, the non-conformance procedure could be carried out until the test is satisfied. Once all the testing has been completed, and been verified, then we can begin assembling the total prototype and begin evaluating the functionality. This prototype can be further evaluated for further development to better improve the design, functionality, and cost. Due to our cost restraint, we were unable to use Medical grade metal, and thus this prototype may not be ideal in the medical industry. Further improvements to the design, would be to use a more sturdy and secure interface. Currently a component similar to that of a tripod attachment system is being used due to the affordability. However, a more rigid, and secure part can be interchanged and thus have a better functional result.

The findings from this project will be very beneficial for the medical environment. This prototype offers possibilities that can provide the patient with a more comfortable product. To go over the project needs, this prototype can help provide ideas for new innovative products such as customizable and more comfortable equipment such as hospital beds. This prototype may fill a void in the business market such as affordability, and thus businesses may be interested in pursuing such a product. Lastly, this project can be very useful for future engineering capstone students that are pursuing a degree in Bioengineering as this project will teach them more about the medical industry and the role of engineers within it.

4.5 Self-Evaluation

Criterion	Ranking	Justification
Explain the importance of compliance with the Professional Engineers Act and other relevant laws, regulations, intellectual property guidelines and contractual obligations and follow best practices.	Meeting	The team, having had a conflict with a former client, does not use any IP associated with his company (VIBRAINT). The team demonstrates integrity and adheres to the PEA. The team also follows the engineering process by successfully designing a solution to their problem statement (Section 1.2).
Employ strategies for reflection, assessment and self-assessment of team goals and activities in multidisciplinary settings.	Exceeding	The team successfully employs several self-evaluations strategies. This includes: Deviations from Plan (Section 4.1), where the team describes how the original was not followed and its impact, Failure Report (Section 4.2), where the team describes the main project failures, and Lessons Learned (Section 4.3), where the team describes how we would run each phase differently.
Adhere to written instructions in a professional context.	Exceeding	The team is able to explain mechanical and electrical design in a professional manner. See Sections 2.2 and 2.3.
Evaluate critical information in reports and design documents.	Exceeding	The team performs simulations and a thorough Design Compliance Analysis (Section 2.4) by using their schematics and circuit designs. Also, see all subsections of Section 2.0.
Appraise possible improvements in the problem-solving process.	Exceeding	Using feedback from previous reports, the team is able to enhance their solutions to their problem; this is done throughout the document.
Justify the strength and limitations of the solution and make recommendation for possible improvements.	Exceeding	The team describes strengths and limitations of the design in Section 2.4.8.

Section 5.0: Appendix

5.1 Requirements Review Table

Requirement ID	Description	Requirement Type and Rationale	Validation Method and Criterion Timing
FNC 1.1	The product shall be composed of two parts: a lower module (i.e. the base) and an upper module (i.e. the attachment).	Functional: This system acts as a universal base. As a result, the upper module is detachable and interchangeable. The lower part is the base, whereas the upper part acts as the attachment.	Once the base and attachment have been manufactured, they will be checked if they are attachable. This will be done by using the “interface” to help compile these two modules together. Criterion will be completed during the design process.
FNC 1.2	The base shall have an interface by which any upper module can be attached.	Functional: In order to have the upper and lower module connect, a universally adaptable interface is needed to combine these parts. As such, it is vital for the base to have an interface module.	For this product to be competitive in the market, the interface must be universal to allow multiple upper modules. The requirement will be validated near the end of the prototyping phase; if the base has an interface the requirement has been fulfilled. Criterion will be completed during the design process.
FNC 1.3	All upper modules shall have an interface by which the base can be attached.	Functional: In order to have the upper and lower module connect, a universally adaptable interface is needed to combine these parts. As such, it is vital for the attachment to have an interface module.	For this product to be competitive in the market, the interface must be universal to allow multiple upper modules. The requirement will be validated near the end of the prototyping phase; if the upper module has an interface the requirement has been fulfilled. Criterion will be completed during the design process.

FNC 1.4	The base shall allow the upper module to have a free rotational movement (i.e. 360-degree movement about a pivot).	Functional: This universally functional base must be user friendly. As such, the attachment should be able to rotate 360 degrees. This rotational movement will allow the user to rotate the attachment and help improve comfortability to the patient.	This criterion is set to make the system competitive with other products in the market. The requirement will be validated if the upper attachment is able to rotate fully during the testing prototyping and prototyping phase. Criterion will be completed during the design process.
FNC 1.5	The base shall allow the upper module to have a “seesaw” motion (i.e. tilting motion on the axis parallel to ground).	Functional: This universally functional base must be user friendly. As such, the attachment should be able to rock up and down (perpendicular to the floor). This seesaw movement is essential to the project as it provides more customizability for the patient and overall, makes the base more user friendly.	When the upper module is attached, the requirement will be validated when the arm is able to move in a “see-saw” motion during testing. Criterion will be completed during the design process.
FNC 1.6	The base shall contain a central actuator that controls the linear movement of the upper module (i.e. the height is adjustable).	Functional: An actuator is a component that is responsible for movement in a mechanical device. This component is required to allow for motor movement rather than manual.	To test the actuator, a weight will be placed on the head of the actuator to mimic the weight of the upper module. This would help test the strength of the linear actuator. Criterion will be completed during the design process.
FNC 1.7	The base shall contain a power source to supply power to the actuator and upper module.	Functional: A power source is a component that is responsible for supplying power to other systems. The component is required in the base to allot power to the actuator and the upper module.	A customer need was to make the device more portable, as a result, a wireless system accomplishes this need. Criterion will be completed during the design process.

FNC 1.8	The lower module shall contain an emergency stop button.	Functional: It is necessary to have a “full-stop” mechanism since it provides the system with additional safety measures if there is a malfunction(s).	An electrical system will be put in place that can override entire system. The mechanism will be validated through trial runs of the system. Criterion will be met by the prototyping phase.
FNC 1.9	The lower module shall have an ON/OFF switch for the power unit.	Functional: It is a necessity for the system to have a switch that can control the power into the system. Having this switch is important because it would prevent the electrical components in the system to be “ON” at all times, yielding a safer system.	By assembling the electrical circuitry, if the switch transmits power from the power source to the load source, then the requirement has been accomplished. Criterion will be completed during the design process.
FNC 1.10	The lower module shall have a switch by which the actuator can be moved.	Functional: This switch will allow the user to control where the height of the attachment is. The user would flip the ON switch on the system causing the height to increase and would switch it OFF when the desired height is met.	It will become validated by completing the circuitry of the linear actuator and testing if the actuator functions as designed. Criterion will be completed during the design process.
FNC 1.11	The extending legs will have a locking mechanism	It is important to have a locking mechanism to ensure stability, safety, and structural integrity of the base when in use.	The locking mechanisms will be thoroughly tested for its strength, and safety during the prototyping phase. The requirement will become validated if the locking mechanism can withstand applied force by the user, without any unwarranted results. Criterion will be completed during the design process.

FNC 1.12	The lower module should be easily portable.	Functional: This device is designed to portable as it will be used in **various** medical centers (hospitals, emergency care clinics etc.). The device may be transported from room	The product needs to be portable to be a competitive product in the market. The requirement will become validated during the testing phases when an individual will maneuver the system through the halls. If there is a significant amount of hassle or issues with transporting, then the design must change. Criterion will be completed during the design process.
PRC 2.1	The time-to-setup for the system shall be a maximum of 1 minute.	Process: This is a small device, so it should not have a large time-to-setup.	A timer will be used to measure how long it takes to set up the system. Processes will be tweaked until time-to-setup is within 1 minute. Criterion will be met during the prototyping phase.
PRC 2.2	The time for the linear actuator to reach its maximum height from minimum will take no more than 30 seconds (and vice-versa).	Process: It is important to have an efficient device so that the time of operators/users will not be wasted.	A timer will be used to measure how long it takes for the actuator to reach its maximum from minimum. Its speed will be tweaked until the time is within 10 seconds. Criterion will be met during the prototyping phase.
PRC 2.3	The product shall be finalized by December 2019.	Process: Each step of the design must be planned ahead of time (e.g. CAD drawings, sketches) since the design must be developed by this date. December 2019 is also one of the deliverable deadlines.	A schedule will be made to ensure the team has a developed design by December 2019. The schedule will list the due dates of each deliverable and other important dates. Criterion will be met by the end of the design phase.

PRC 2.4	A product prototype shall be developed by March 2020.	Process: Each step of the manufacturing of the prototype must be planned ahead of time (e.g. ordering materials, booking equipment) since the prototype must be developed by this date. March 2020 is also one of the deliverable deadlines.	A schedule will be made to ensure the team has a developed prototype by March 2020. The schedule will list the due dates of each deliverable and other important dates. Criterion will be met by the end of the prototyping phase.
PRC 2.5	All product components adjustments shall be logged on a document.	Process: Documentation is essential for any stakeholders and the team. It keeps all the stakeholders on the same page and keeps a record of all work done by the team. It also helps to provide proof in any case of conflict.	Notes, photos and videos will be taken when appropriate. This will be included in a document that records the team’s formal meetings. Any adjustments or changes will be reflected in reports. Criterion will be met by final product presentation.
PRC 2.6	All product components shall cost no more than $1000 CAD combined.	Process: The project must have a financial constraint in order for production to be reasonably priced. For this project, the constraint is $1000 CAD.	Budgets will be assigned to components. Bills of materials will be used to track expenses. Criterion will be met by the material selection phase.
INT 3.1	The product shall be compatible with existing chairs, wheelchairs, and beds.	Interface (Usability): The system should be able to be used by as many clients as possible. Our targeted audience is a user in the seated position; therefore, the device must be compatible with a wide array of seating arrangements.	To test, check if various seating equipment/appliances can be used with the product. Criterion should be met by the final design phase.

INT 3.2	The interface shall have a secure connection and can only be attached/detached manually.	Interface (Usability): It is very important for the connection between the upper and lower interface to be safe and secure. As the structural integrity of this system relies on this connection, making sure the joint is secure will yield a successful system.	The requirement will become validated during the testing phase. If the male and female interfaces can attach seamlessly, easily, and safely, then this requirement will be achieved. Criterion will be met by the end of the design phase.
INT 3.3	The product shall have a modular power source.	Interface (Usability): For the product to be compatible with several upper modular devices, the power source should be able accommodate any power requirements needed. (i.e. American standard receptacle, USB/ micro USB)	By selecting a power source that is universal with many possible upper attachment pieces we can know whether the power source will be enough for the need. During the testing phase, we can complete the circuitry of the system, and test out whether the power source is a viable option for our “mock upper attachment”. Criterion will be met by the end of the design phase.
INT 3.4	The product shall have a wireless power source.	Interface (Usability): The system will consist of a wireless power source. The reason for this is because as this system needs to be portable, it is important to not limit the system by a power outlet.	Once we obtain a wireless power source, then there are no wires that would be limiting the movement of the system. Criterion will be met by the end of the design phase.
INT 3.5	The product shall have a rechargeable power source.	Interface (Usability): It is essential that the power source be rechargeable as the power source is wireless and must be able to provide power to the system for multiple uses.	This is a design need. The requirement will become validated right after purchasing the material. We will drain the battery and put it to recharge immediately after. By taking a voltmeter, we can validate whether the battery recharged or not. Criterion will be met at the end of the material selection phase.

INT 3.6	The product shall be aesthetically pleasing; it shall be appropriate for a medical environment.	Interface (Usability): A clean, polished product is more likely to attract clients/consumers.	To test, we will survey the public for their opinions on the final design to determine if the prototype is “aesthetically pleasing”. We will be making changes based on their criticism. Criterion will be met by end of the design phase.
PRF 4.1	The product shall be energy efficient, using power up to a maximum of 100 W.	Performance: The product should not consume a large amount of power since it will be active for a large portion of the day. Minimal power use will allow for lower electricity bills.	All parts come with a specification sheet; therefore, the total energy consumption can be calculated by summing all motor, microcircuit, and sensor consumption values. Criterion will be met prior to the prototyping phase.
PRF 4.2	All movement shall occur in a smooth manner; there shall be no sudden stops during movement.	Performance: As this device may be used in a medical environment, it is essential to keep the movements of the system smooth. If there are unwarranted jerks in the motion, it can cause injuries to the users.	This requirement has come due to safety needs. We will run operational tests on the system and if we notice and jerking motions, then we can tune the inputs of the system and nullify this outcome. Criterion will be met during the prototyping phase.
PRF 4.3	The run-to-break time shall be no lower than 1000 hours.	Performance: The product will be in use for the majority of the day; as such, the average time-to-failure should be a large value.	Finite Element Analysis will be conducted to determine major stress concentrations of the system; specific materials will also be chosen so the run-to-break-time will be no lower than 1000. Criterion will be met during the material selection phase.
PRF 4.4	The product shall be quiet, to a maximum of 50 dB.	Performance: The system should be quiet for use in sensitive medical areas and homes.	Dampers will be used to prevent noise, and vibration. To test, measure sound using a decibel meter. Criterion will be met by the end of prototyping phase.

PRF 4.5	The lower module shall weigh no more than 50 kg.	Performance: The system should be lightweight for easy portability/movement. It should also be heavy enough to support a large upper module.	The weight of each component will be measured; so, the final design weighting can be manually calculated. Criterion will be met by prototyping phase.
PRF 4.6	The product shall be stable such that a small impact force will not knock over the system.	Performance: The device will have movement and vibrations; so, any unexpected movement could cause harm/danger to the user. As such, the product should stand firmly on the ground.	The base will be tested to ensure its stability; it should withstand any unexpected impact. Criterion will be met at the end of the prototyping phase.
PRF 4.7	The product shall have a small, compact power unit, to a maximum size of 0.25m x 0.25m x 0.15m.	Performance: The smaller the object, the easier it is for it to be moved between different locations (i.e. less weight and space). It is also less likely to be struck.	To test, measure and check if the power unit does not exceed the maximum dimensions of 0.25m x 0.25m x 0.15m. Criterion will be met by the end of the design phase.
PRF 4.8	The product shall be compact and portable, to a maximum size of 1.5m x 1.5m x 1.5m.	Performance: The dimensions of the device should not interfere with transporting the device through elevators, halls, and multi-floored facilities.	To test, measure and check if the device does not exceed the maximum dimensions of 1.5m x 1.5m x 1.5m. Criterion will be met by the end of the design phase.
PRF 4.9	The power source shall take no longer than 5 hours to recharge.	Performance: It is important for the device recharging period to be quick as a long recharging time will limit the use of the system to a shorter period.	This requirement will be set by the user's needs. It is essential to have a short recharge time, to provide the user with maximum operational use. This requirement will be validated by measuring the times it takes the power source to recharge during operational testing. Criterion will be met at the end of the material selection phase.

PRF 4.10	The power source should not exceed a maximum operating temperature of 35 degrees.	Performance: It is important for the source to not overheat as it can cause fires, or short circuits. These unwarranted outcomes may cause injury to the users.	Requirement is set by the power source selected (for example; if the selected power had a maximum temperature of 35 degrees Celsius.) This requirement is set by the material selected. This requirement will be validated by measuring and monitoring the temperature throughout operation tests. Criterion will be met at the end of the material selection phase.
PRF 4.11	The power source should last for a minimum time of roughly 5 hours per full charge cycle.	**Performance: Having** a long operating time for the battery is important for the system as it will mean the device will be able to be used for a long period of time before having to recharge.	The requirement will be validated through operational testing, as well as through calculations using the spec-sheet (e.g. a material will be selected to provide power for a longer time period than 5 hours; 8-10 hours). Criterion will be met at the end of the material selection phase.
REG 5.1	The product shall be composed of environmentally friendly materials according to the International Environmental Product Declarations (EPD).	Regulatory (Environmental): By taking the environment into account during product development, we will not add to existing pollution/landfill issues.	When selecting a component, we will do research to check if it is an environmentally friendly material which follows EPD regulations. Criterion will be met during material selection phase.
REG 5.2	The product shall have labels that identify risks/hazards in the device following Canadian Medical Device Regulations (SOR/98-282).	Regulatory (Safety): Giving the user information about the risks/hazards in the device allows them to confidently operate and handle it.	Throughout the design phase, all risks/hazards that cannot be eliminated will have clearly labelled safety warnings of the potential risks/hazards to inform the user. Criterion will be met by the prototyping phase.

REG 5.3	The product shall not deteriorate under daily use such that the health or safety of the user is affected according to EPD regulations.	Regulatory (Safety): As a product deteriorates, it becomes less safe. This could eventually lead to broken parts (e.g. exposed wires/circuitry) which is dangerous to the user.	All material properties will be reviewed at material selection stage to ensure that the system will be durable and operational for the required time-to-break. Stress tests, simulations, and other physical tests will be performed on the selected materials. Criterion will be met during prototype testing.
REG 5.4	The product shall be sealed without exposing any unsafe/uncovered parts in accordance to the Canadian Standards Association (CSA) - Canadian Electrical Code (CE).	Regulatory (Safety): Exposed/uncovered parts may lead to unsafe usage of the device; either the device or the user can be harmed. By sealing any circuitry and/or rough edges, we can prevent hazard to the user, and damage to the system.	To test, cables should be thin enough to fit in the channels so there is no exposed circuitry. Other structural hazards shall be identified during the prototyping phase to ensure that the system has no uncovered parts.
REG 5.5	The product shall have an emergency stop button in accordance to (CSA).	Regulatory (Safety): In the case of any emergency or failure, the system will have an emergency stop button that will cut all power to the system.	An electrical system will be put in place that can override entire system. The mechanism will be validated through trial runs of the system. Criterion will be met by the prototyping phase.
REG 5.6	The product shall abide by the Canadian Medical Device Regulations (1998).	Regulatory (Legal): The Canadian Law has strict regulations on what qualifies as a medical device, its uses, and user safety.	Scheduled checks will be done to ensure the product stays within regulations. Criterion will be met by the prototyping phase.

Note: Since we are developing only the lower module, the terms “product”, “lower module”, and “base” are used interchangeably.

5.2 Receipts for Expenses

Order Placed: December 29, 2019
Amazon.ca order number: 702-6115756-8434665
Order Total: CDN$ 181.89

Shipped on January 2, 2020

Items Ordered	Price
1 of: *Cllena 24V to 12V 30A 360W Step Down Converter Voltage Reducer DC/DC Buck Transformer Regulator Waterproof* Sold by: Cllena (seller profile) Condition: New	CDN$ 58.27
1 of: *Nema 17 Stepper Motor,Quimat Stepper Motor Bipolar 0.4A 36.8oz.in(26Ncm) 34mm Body 4-lead w/ 0.3m Cable and Connector for 3D Printer CNC QD06* Sold by: QuimatCa (seller profile) | Condition: New	CDN$ 17.99
1 of: *Ulincos Auto Relay U1914 with 14AWG Wire Harness, 12V DC 30/40A SPDT 5-Pin (Pack of 2)* Sold by: Ulincos Direct (seller profile) | Condition: New	CDN$ 12.48
1 of: *Baomain Car Toggle Switch SPDT Latching (Maintained) ON-Off-ON 3 Pin 3 Position 12V 25A with Waterproof Cover for Auto Car* Sold by: Baomain (seller profile) Condition: New	CDN$ 7.39
2 of: *TCH Hardware 2 x 12" Inch 250 lb Heavy Duty Steel Drawer Slides - Full Extension Ball Bearing - Kitchen Cabinet Desk Draw* Sold by: TCH Hardware (seller profile) | Condition: New	CDN$ 37.95

Shipping Address:
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Shipping Speed:
FREE Shipping

Payment information

Payment Method:
Visa | Last digits: 3707

Billing Address:
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Item(s) Subtotal:	CDN$ 172.03
Shipping & Handling:	CDN$ 13.70
FREE Shipping:	-CDN$ 13.70

Total before tax:	CDN$ 172.03
Estimated GST/HST:	CDN$ 9.86
Estimated PST/RST/QST:	CDN$ 0.00

Grand Total:	**CDN$ 181.89**

Credit Card transactions
Visa ending in 3707: January 2, 2020: CDN$ 181.89

Amazon receipt for 1x Step Down Converter

Order Placed: December 29, 2019
Amazon.ca order number: 702-4162060-8045026
Order Total: CDN$ 9.19

Shipped on December 30, 2019

Items Ordered	Price
1 of: *CNC Router 1 Axis Controller Stepper Motor Drivers TB6560 3A Driver Board* Sold by: Shelpter (seller profile) Condition: New	CDN$ 8.19

Shipping Address:
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Shipping Speed:
Standard Shipping

Payment information

Payment Method:
Visa | Last digits: 3707

Billing Address:
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Item(s) Subtotal:	CDN$ 8.19
Shipping & Handling:	CDN$ 1.00

Total before tax:	CDN$ 9.19
Estimated GST/HST:	CDN$ 0.00
Estimated PST/RST/QST:	CDN$ 0.00

Grand Total:	**CDN$ 9.19**

Credit Card transactions
Visa ending in 3707: December 30, 2019: CDN$ 9.19

Amazon receipt for 1x Stepper Motor

Order Placed: March 2, 2020
Amazon.ca order number: 702-8370647-2751427
Order Total: CDN$ 66.89

Shipped on March 4, 2020

Items Ordered	**Price**
1 of: *1pc DC 12V Force 750N Stroke 150-700mm Multiple Sizes Metal Linear Actuator Lift Electric Motor Bracket(400mm)* Sold by: hotzzz (seller profile) Condition: New	CDN$ 66.89

Shipping Address:
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Shipping Speed:
Standard Shipping

Payment information

Payment Method:
Visa | Last digits: 1758

Billing Address:
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Item(s) Subtotal:	CDN$ 66.89
Shipping & Handling:	CDN$ 0.00

Total before tax:	CDN$ 66.89
Estimated GST/HST:	CDN$ 0.00
Estimated PST/RST/QST:	CDN$ 0.00

Grand Total:	**CDN$ 66.89**

Credit Card transactions Visa ending in 1758: March 4, 2020: CDN$ 66.89

Amazon receipt for 1x Linear Actuator

Order Placed: March 3, 2020
Amazon.com order number: 111-4740306-9913049
Order Total: USD 104.33

Shipped on March 5, 2020

Items Ordered	**Price**
1 of: *SUNWAYFOTO FB-44MAC14 44mm Tripod Ball Head Arca / Manfrotto RC2 Compatible Sunway* Sold by: OEC Camera Accessories (seller profile) | Product question? Ask Seller Condition: New	$79.00

Shipping Address:
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Shipping Speed:
AmazonGlobal Standard Shipping

Payment information

Payment Method:
Visa | Last digits: 1758

Billing address
Marutikumar B Patel
9374 Weston Road
Woodbridge, Ontario L4H 2B5
Canada

Item(s) Subtotal:	USD 79.00
Shipping & Handling:	USD 7.67

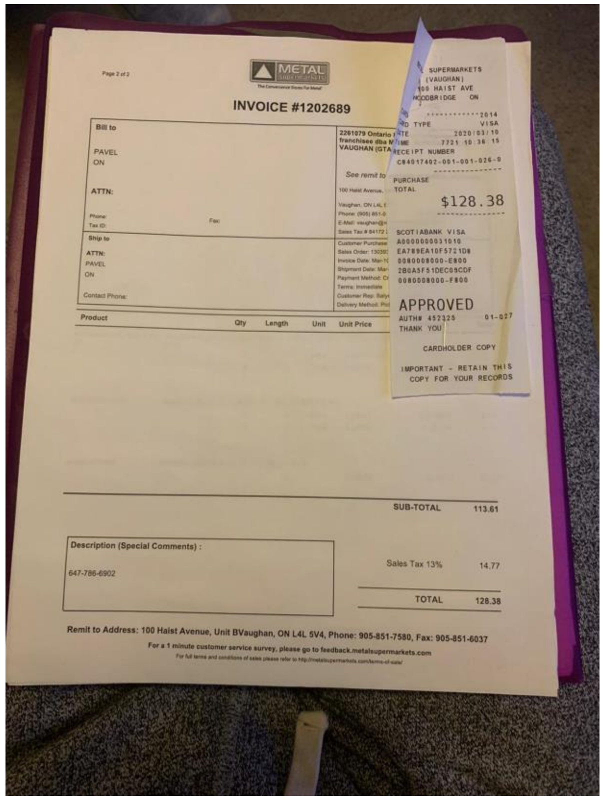
Total before tax:	USD 86.67
Estimated tax to be collected:	USD 0.00
Import Fees Deposit	USD 17.66

Grand Total:	**USD 104.33**
Payment Grand Total:	**CAD 142.91**

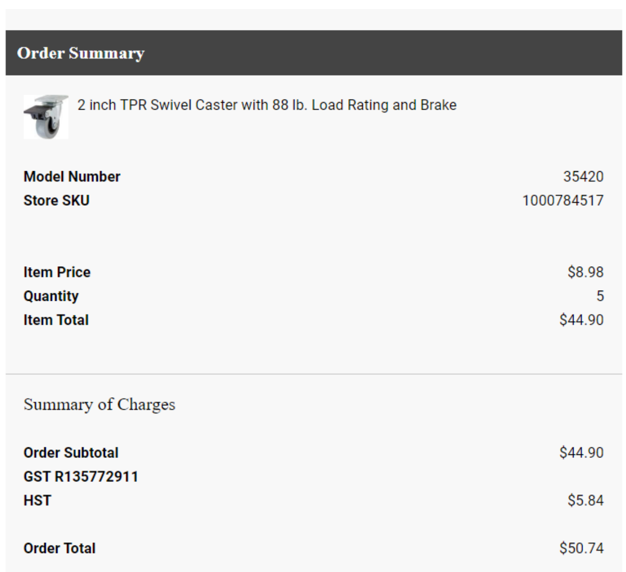
Credit Card transactions Visa ending in 1758: March 5, 2020: $104.33

ALL ITEMS IN THIS ORDER ARE SOLD BY AMAZON EXPORT SALES LLC (AES), UNLESS OTHERWISE NOTED. BY PLACING YOUR ORDER, YOU AUTHORIZE AES TO DESIGNATE A CARRIER TO CLEAR THE PACKAGE AND PAY THE IMPORT FEES ON YOUR (OR THE RECIPIENT'S) BEHALF. CUSTOMS DECLARATIONS WILL BE MADE IN THE NAME AND ON THE BEHALF OF YOUR (OR THE RECIPIENT'S) BEHALF BY THE DESIGNATED CARRIER. YOU CAN FIND THE COMPLETE TERMS AND CONDITIONS OF YOUR ORDER HERE

Amazon receipt for 1x Tripod Head



Receipt for purchase of metal



Order Summary

2 inch TPR Swivel Caster with 88 lb. Load Rating and Brake

Model Number	35420
Store SKU	1000784517
Item Price	$8.98
Quantity	5
Item Total	$44.90

Summary of Charges

Order Subtotal	$44.90
GST R135772911	
HST	$5.84
Order Total	$50.74

Receipt for purchase of wheels

5.3 Previous Project Management Documents

Old WBS: https://bit.ly/2KzRIN7

Old WPD: https://bit.ly/2VzRQCm

Old RAM: https://bit.ly/2Y3nIAZ