Aneuvas Tech. Portable Bench

Final Report

Hunter Daniel
Katherine Riffle
Kenyon Rowley

2019-2020

Aneuvas Technologies, Incorporated

Project Sponsor: Aneuvas Technologies, Inc.
Faculty Advisor: Dr. Becker
Instructor: Dr. Oman

1 DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

2 EXECUTIVE SUMMARY

Aneuvas Tech. is a company located in Flagstaff, AZ. ATI develops microcatheter-based medical devices to treat aneurysms and other vascular defects. The company's mission is to improve health care through minimally invasive treatments to blood vessels. The team is tasked with designing, building, and testing a portable medical bench that can be used to safely transport the devices used in research. The bench must be large enough to hold all devices required in the research process, be equipped for stable transport through connecting buildings, and be compatible with fluoroscopic imaging. Among these requirements, the bench must also have a waterproof countertop designed for spill prevention. Be able to withstand the load of a 75lb hood and have storage space added below the tabletop. This project was given a budget of $1000. The project is divided into three parts: tabletop design, storage, and shock absorption.

3 ACKNOWLEDGEMENTS

In pursuit of completion of this project, the team thanks the advisors and resources provided from Northern Arizona University. This includes the team's capstone advisor, Dr. Oman, and the project's client, Dr. Becker.

4 TABLE OF CONTENTS

Contents

5 BACKGROUND

5.1 Introduction

The Aneuvas Tech. project tasks the team with the design and construction of a portable medical bench. The bench's main functional requirements include transporting the medical devices used in the treatment of aneurysms, compatible with fluoroscopic imaging, and shock absorption wheels. The project's client wishes to replace the existing bench design with one that has more functions and makes the treatment process easier and more effective. Upon completion of the bench, the project's client will be able to transport medical devices in a safer and more effective manner. With the added requirements, the new design will offer more functionality than the previous. Although there is an existing bench design that is able to transport medical devices, an improvement is much needed, as it is not x-ray compatible and is only used for storage and transport. With the addition of the concepts in this project, the new design has the same functionality as the old but improves on these functions and add to them. The new design secures the devices, is x-ray compatible, is constructed with shock absorbing tires, is designed to prevent spills, and adds storage space. These improvements will make the job of the project's client easier and allow for more effective treatment for patients

5.2 Project Description

The project's sponsor provided the following quote:

"The scope of this project is to design, build, and test a portable bench that can be used with the company's delicate blood flow model of the brain. The bench must be large enough to contain the delicate experimental setup, allowing for stable transport of the setup to adjacent buildings, and be compatible with fluoroscopic imaging of the blood flow model through the bench surface."

6 REQUIREMENTS

The following sections detail the customer requirements, gathered from the client description along with meetings with the client, and their transformation into engineering requirements for evaluation of the bench. A functional decomposition model is used to evaluate generated concepts, along with black box models of all critical components to find out what would go in and what would come out of critical subsystems. A House of Quality (HOQ) diagram shows how the customer requirements became engineering requirements and are evaluated based on weights of the customer requirements. Finally, standards, codes, and regulations are stated and how they apply to the project.

6.1 Customer Requirements (CRs)

Table 1: Customer Requirements

Customer Requirement	Weight (9/3/1)
Durable and Robust Design	9
Reliable Design	9
Safe to Operate	9
Maneuverability	9
Cost within Budget	3
Aesthetically Pleasing	1
Multipurpose Design	3
Lightweight Design	3
Shock Absorption	9

Adequate Storage Space	3

The Customer Requirements are rated on a 9/3/1 scale, as shown in the table above. A nine would mean very important, a three would mean moderately important, and a one would mean not so important to the client. For durable and robust design, the portable bench must be easily transported inside and outside of buildings and withstand the stresses of going over bumps and obstacles, while supporting the devices and clean-room hood. The design must be reliable in performance of all its basic needs. It must be safe to operate. The bench will be transporting over 100 lbs. of equipment and must be safe to transport. It must maneuver over terrains associated with NAU campus. The cost of the device must be within a budget of $1000, including everything associated with the project. Aesthetic is for display purposes only and not a big concern for the project. The design must allow for multipurpose use as a desk. It must be lightweight, to be transported by one person with ease. The design must be shock absorbing, for transportation of benches across parts of campus. There must be adequate storage space for transporting all the necessary accessories.

6.2 Engineering Requirements (ERs)

The following table illustrates the overall engineering requirements for the portable bench, which were compiled from transforming customer requirements into engineering requirements that could be measured. Changes that have been made to this section include the liquid drainage.

Table 2: Engineering Requirements

Engineering Requirement	Units	Target Value	Tolerance
Cost	$	1000	+/- 100
Weight	Lb.	100	+/- 10
Fitting Through Doorway	ft^2	7.5	+/- .1
Tabletop Yield Strength	psi	5	+/- 1
Effective shock absorption	in/s^2	5	+/- 5
Tabletop Deflection	in	0.25	+/- .05
Tabletop Thickness	in	1.00	+/- 0.10
Bench Height	in	36.00	+/- 0.10
Storage Volume	Ft^3	5	+/- 1
Temperature resistance	°F	50	+/- 50

Liquid Drained	%	80	+/- 10

6.2.1 ER #1: Cost

6.2.1.1 ER #1: Cost - Target = Cost around $1000

The target value for the cost of the project was set at $1000 by the client. This is important for delivering a quality product for the client while also utilizing the full budget allotted to us.

6.2.1.2 ER #1: Cost - Tolerance = +/- $100

Based on discussions with the client, approval could be granted to go over budget if needed. This is due to the client wanting a quality product and not wanting to be limited to the original budget.

6.2.2 ER #2: Overall Weight

6.2.2.1 ER #2: Weight - Target = 100 lbs.

This target value was created for the client to easily be able to transverse the portable bench with one person. This weight signifies the force the tabletop and metal frame will need to account for.

6.2.2.2 ER #2: Weight - Tolerance = +/- 10 lbs.

The tolerance for the weight was selected based on the added force the bench may experience while being in motion and added equipment that may be added to it.

6.2.3 ER #3: Fitting Through Doorway

6.2.3.1 ER #3: Cross-sectional Area - Target = 7.5 ft^2

This ER was set because the bench would need to both fit through a doorway horizontally and vertically. The team was given a maximum height of three feet and a maximum width of two and a half feet.

6.2.3.2 ER #3: Cross-sectional Area - Tolerance = +/- .1 ft^2

The tolerance was selected due to having almost no wiggle room. Ideally, the target would either be met or would be less.

6.2.4 ER #4: Tabletop Yield Strength

6.2.4.1 ER #4: Tabletop Yield Strength - Target = 5 psi

This was determined based on the cross-sectional area of the tabletop and the amount of weight that the tabletop would need to support. This also considers a factor of safety.

6.2.4.2 ER #4: Tabletop Yield Strength - Tolerance = +/- 1 psi

The tolerance was selected with the tabletop material in mind. With the change from oak to Formica, the team needed to rework the calculations for the tabletop’s yield strength. This tolerance will include the weight of the clean room hood and the addition of other equipment.

6.2.5 ER #5: Effective Shock Absorption

6.2.5.1 ER #5: Shock Absorption - Target = 5 in/s^2

The shock absorption engineering requirement was created in response to the wheels of the bench. Our client, Dr. Becker, emphasized that the bench needed to be able to move over small obstructions that are found in the path of the bench in transport.

6.2.5.2 ER #5: Shock Absorption - Tolerance = +/- 5 $\frac{in}{s^2}$

The tolerance for the wheels was selected in the interest of having confidence that the bench can be transported effectively without any damage being induced on the equipment the bench is carrying.

6.2.6 ER #6: Tabletop Deflection

6.2.6.1 ER #6: Tabletop Deflection - Target = 0.25 in.

The deflection of the tabletop was calculated based on the material the team selected. This deflection accounts for how the tabletop may deform when the forces are introduced to it without breaking occurring.

6.2.6.2 ER #6: Tabletop Deflection - Tolerance = +/- 0.05 in.

This tolerance was measured to ensure the maximum amount of deflection the table can withstand to stay within a reasonable amount of safety.

6.2.7 ER #7: Tabletop Thickness

6.2.7.1 ER #7: Tabletop Thickness - Target = 1.00 in.

The thickness of the tabletop was chosen to the specifications of our client, Dr. Becker. Dr. Becker believed a thickness of 1in would be best for the tabletop.

6.2.7.2 ER #7: Tabletop Thickness - Tolerance = +/- 0.10 in.

The tolerance for the tabletop thickness was calculated to ensure the bench was within the range Dr. Becker preferred but was also strong enough to support the equipment used in testing.

6.2.8 ER #8: Bench Height

6.2.8.1 ER #8: Bench Height - Target = 36.00 in.

The bench height was a set range given to the team. The bench could not exceed a height that would prevent it from traveling through doors with the clean room hood on while also providing leg room for someone working with the bench to be used as a desk.

6.2.8.2 ER #8: Bench Height - Tolerance = +/- 0.10 in.

Considering the set parameters of the bench height, the tolerance was selected at a small value to ensure the travel capacity of the bench was kept.

6.2.9 ER #9: Storage Volume

6.2.9.1 ER #9: Storage Volume - Target = 5 ft^3

The storage space was calculated due to the specifications provided by Dr. Becker. Dr. Becker articulated that having a storage space added to the bench that could hold some equipment and office supplies would be beneficial. The team decided on the volume with the size of the equipment in mind.

6.2.9.2 ER #9: Storage Volume - Tolerance = +/- 1 ft^3

The tolerance of the storage was decided in order to provide the space needed but to not reduce the space under the bench that would account for leg room if the bench was being used as a desk.

6.2.10 ER #10: Temperature Resistance

6.2.10.1 ER #10: Temperature Resistance - Target = 50°F

The temperature resistance was calculated with the ambient temperature and temperature of fluids used during the experiments conducted by Dr. Becker and his team.

6.2.10.2 ER #10: Temperature Resistance - Tolerance = +/- 50°F

The tolerance for the temperature was decided to ensure the materials selected in the design of the bench would be able to withstand a drastic change in temperature and remain in tact.

6.2.11 ER #11: Liquid Drained

6.2.11.1 ER #11: Liquid Drained - Target = 80%

This engineering requirement was recently added. Dr. Becker suggested that our team should add a drainage component to the bench. Our team responded by designing a trough component to the side. Our team decided that by reducing 80% of the maximum spills that occur, Dr. Becker would be satisfied and able to continue his work.

6.2.11.2 ER #11: Liquid Drained - Tolerance = +/- 10%

A tolerance of 10% was decided because if our team can eliminate at least 70 percent of spillage, Dr. Becker could easily wipe up the remaining spillage contained within the cleanroom hood.

6.3 Functional Decomposition

The team began its design process by meeting with the project's client, Dr. Becker. In this meeting the team discussed the project's direction. Dr. Becker explained his ideal bench and the functions he desired most. In that meeting, the team found shock absorbing wheels and a x-ray compatible tabletop were most important. After this meeting, the team generated a black box model.

6.3.1 Black Box Model

When creating the black box model, the team broke down the project into three main components of the bench, the tabletop, storage, and frame.

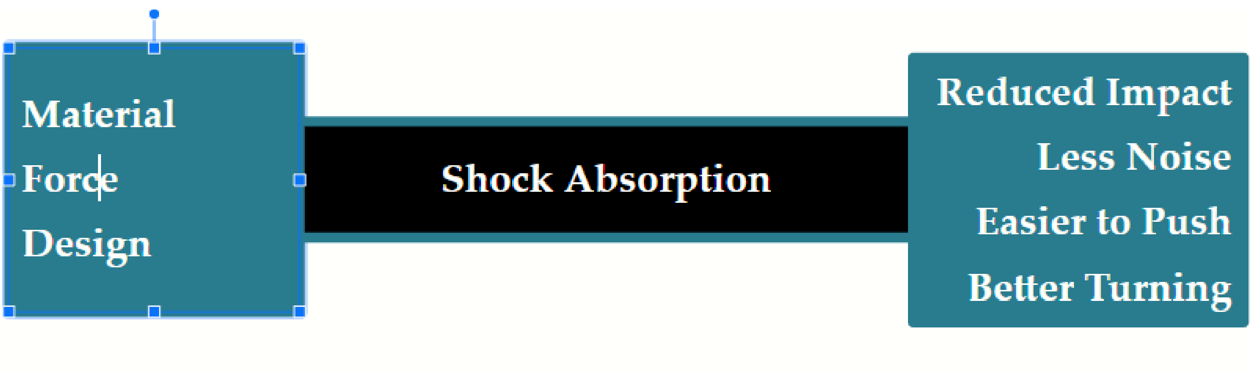

Figure 1: Shock Absorption Black Box

Figure 2: Storage Black Box

6.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The black box models used help the team determine how to begin the construction process for the bench. The team was able to prioritize the needs of the project's client.

6.4 House of Quality (HoQ)

Besides the black box model, the team also used a house of quality to assist them in determining the importance of each design component. The house of quality used by the team is shown below and ranks the design of the bench.

Table 3: HoQ

Customer Requirement	Weight	Engineering Requirement	Cost($)	Weight(lb)	Fitting through doorway(ft^3)	Yield Strength(psi)	Effective Shock Absorption(a)	Deflection(in)	Thickness(in)	Height(in)	Strain(in/in)	Temperature (°F)
1. Durable and robust design	9		3			3	3	9				1
2. Reliable design	9		3	3	3	3	3	3		3	3	1
3. Safe to operate	9		1	3	1	3		3		3	3	9
4. Maneuverability	9		1	9	9				1	3		
5. Cost within budget	3		9	3	1				1		1	
6. Aesthetically pleasing	1		1									
7. Multipurpose design	3		3									
8. Lightweight design	3		3	9	3				3	3		
9. Shock absorbing wheels	9										9	
10. Adequate storage space	3											
Absolute Technical Importance (ATI)			118	171	129	81	54	135	21	90	57	99
Relative Technical Importance (RTI)			0.12	0.18	0.14	0.08	0.06	0.14	0.02	0.09	0.06	0.10
Target ER values			1,000	50	40	10	5	0.25	1	36	0	50
Tolerances of Ers			100	10	5	5	5	0.05	0.5	1	1	50
Testing Procedure(TP#)			n/a	1	1	2	3	2	1	1	2	4

6.5 Standards, Codes, and Regulations

The following table represents standards of practice and codes that have applied to the design of the portable bench. These standards affect the project in general by guiding in the design of certain components. The tabletop had to be carefully designed in order to be sent out to a manufacturer so that the team received the product that we thought we were.

Table 4: Table of Standards

Standard Number or Code	Title of Standard	How it applied to Project
ASNI/AAMI HE 74:2001	Human Factors Design Process for Medical Devices	Helped in the design of how the device interfaces with the user in a safe manner.
ASME Y14.5-2009	Dimensioning and Tolerancing	Helps with making drawings of parts to be manufactured with GD&T specifications for manufacturing. Manufacturing of the tabletop required GD&T.

ASCE 37-02	Design Loads on Structures	Provides guidance on designing for loads on top of the tabletop, mainly the cleanroom hood and medical devices being stored on top.
ASCE 7-05	Minimum Design Loads on Structures	Shows minimum design loads for structures including floors, which will be modeled with the tabletop.

7 Testing Procedures (TPs)

This section discusses the testing procedures for each respective ER. This section reflects the original plan and schedule that happened before the shutdowns took place, so the scheduled dates for the testing procedures are retained so that a similar timeline could be followed. All the testing will be completed by the end of the week beginning March 30th in order to make necessary changes if need be. All tests will be conducted on Friday's in order to have our client, or one of his advisors around to supervise the tests. Numerous tests will be conducted for all testing procedures, to verify that the system is reliable and robust. The team has a goal of 100 percent client satisfaction and will ensure the system will perform as intended by Dr. Becker.

7.1 Testing Procedure 1: Project Cost

7.1.1 Testing Procedure 1: Objective

This test will be executed by examining the bill of materials once the final product has been completed. This will possibly change after all testing procedures have been completed. This corresponds to ER1 (Cost Target).

7.1.2 Testing Procedure 1: Resources Required

This will require the final product to be completed with an updated bill of materials. This requires a Bill of Materials approval from Dr. Becker and Dr. Oman.

7.1.3 Testing Procedure 1: Schedule

This test will be in two cycles, after the final product is completed, and after all testing procedures are completed. For the first cycle, the week of March 23rd and for the second cycle (if necessary), the week of March 30th.

7.2 Testing Procedure 2: Portable Bench Specifications

7.2.1 Testing Procedure 2: Objective

For this test, the specs of the bench will be analyzed. This includes tabletop thickness, bench height, and storage volume. This testing procedure corresponds to ER7 (Tabletop Thickness), ER8 (Bench Height), and ER9 (Storage Volume). Volume specifically will use the devices required by Dr. Becker to be stored underneath to make sure everything fits.

7.2.2 Testing Procedure 2: Resources Required

SolidWorks drawings of the bench will be the first check. This has already been completed. After the product has been finished, a tape measure will be used to ensure that the tabletop thickness and bench height are correct. For the storage volume, the necessary devices needed to be stored underneath will be used. Also, it will require Dr. Becker to supervise and make sure that the devices fit in locations that he approves of.

7.2.3 Testing Procedure 2: Schedule

SolidWorks drawings have already been completed for the bench and everything has been checked multiple times. Hands on testing will begin the week of March 23rd.

7.3 Testing Procedure 3: Transporting Portable Bench

7.3.1 Testing Procedure 3: Objective

For this test, the team will be transporting the bench around the Wettaw Building on campus to test the bench fitting through doorways, and the wheels giving the necessary shock absorption. This corresponds to ER3 (Fitting Through Doorway) and ER5 (Shock Absorption).

7.3.2 Testing Procedure 3: Resources Required

An escort from Dr. Becker or one of his lab assistants is required.

7.3.3 Testing Procedure 3: Schedule

SolidWorks testing has already been completed. Material testing will be conducted the week of March 23rd.

7.4 Testing Procedure 4: Temperature Resistance

7.4.1 Testing Procedure 4: Objective

For this test, the team will be running some of the components used with the bench and testing how the material responds to this. This corresponds to ER10 (Temperature Resistance).

7.4.2 Testing Procedure 4: Resources Required

The Hot Plate and Generator used with the medical devices will be required for this test. Additionally, an extremely cold day in Flagstaff will be required for testing its out-door temperature resistance. To test the cold-temperature resistance, other testing procedures will be applied to the portable medical bench while outside in the cold. These testing procedures will be the ones testing ER4 (Tabletop Yield Strength), ER5 (Shock Absorption), and ER6 (Tabletop Deflection).

7.4.3 Testing Procedure 4: Schedule

This test will be completed the week of March 23rd.

7.5 Testing Procedure 5: Liquid Drainage/ Deterioration

7.5.1 Testing Procedure 5: Objective

For this test, the team will make sure that liquid spilled on the tabletop will both drain and not deteriorate the tabletop itself. The team will make sure that the drainage system (the gutter tray and pipe) effectively drains 80%+ of the two liter spill. This corresponds to ER11 (Liquid Drained).

7.5.2 Testing Procedure 5: Resources Required

The blood-viscosity substitute liquid recommended and provided by Dr. Becker or one of his lab assistants is required. The cleaning fluid used in Dr. Becker's lab will also be required and provided by his lab assistants. This will also require the gutter tray and pipe to be completed.

7.5.3 Testing Procedure 5: Schedule

This will take place the week of March 23rd.

7.6 Testing Procedure 6: Weight

7.6.1 Testing Procedure 6: Objective

For this test, the team will measure the weight of the completed portable medical bench to ensure that it is an acceptable weight. This corresponds to ER2 (Overall Weight).

7.6.2 Testing Procedure 6: Resources Required

The resources required for this testing procedure are SolidWorks for a simulated weight measurement, and an industrial scale from 98c. Dr. Becker's approval is required.

7.6.3 Testing Procedure 6: Schedule

The SolidWorks Model has been evaluated. Testing for the overall weight of the device will take place the week of March 30th.

7.7 Testing Procedure 7: Tabletop

7.7.1 Testing Procedure 7: Objective

This test will check the tabletop yield strength and the tabletop deflection. These two tests correspond to ER4 (Tabletop Yield Strength) and ER6 (Tabletop Deflection).

7.7.2 Testing Procedure 7: Resources Required

SolidWorks analysis was already conducted for the design. The next step of the test will require the entire assembly of the portable bench to be completed. This will happen the week of March 23rd. The team will need to bring the completed device to the Wettaw Building on campus and load the tabletop with the cleanroom hood and the cleanroom filter. Measurement will be taken for the tabletop deflection with a tape measure.

7.7.3 Testing Procedure 7: Schedule

The test will be conducted the week of March 30th.

8 DESIGN SPACE RESEARCH

8.1 Literature Review

The literature review is used to research sources of design, and each section has the technical focus of an aspect of the bench design: shock absorption, wheels, and tabletop designs. The team used the Cline Library and textbooks used in previous classes to provide the necessary background.

8.1.1 Shock Absorption

Shock Absorption research features four separate designs: MRF dampers, a cam mechanism, a camera stabilization system, and the honeycomb tire.

Engineering Analysis of Smart Material Systems [1]

This book details the specific applications of smart materials. This is useful in determining the characteristics of a MRF damper. By using this source, the team was able to theorize what level of shock absorption was attainable.

Magnetorheological Fluid Dampers: A Review on Structure Design and Analysis [2]

This article details the emergence of MRF dampers in the field of engineering. By inspecting the characteristics of the fluid, the authors deconstruct the wide range of applications for MRF's. These characteristics include vibration control through quick actuation as well as offering large force capacity and low power consumption. This article is useful in visualizing application of this substance in the project.

Design of a Self-Leveling Cam Mechanism for a Stair Climbing Wheelchair [3]

This article explores the latest devices invented to assist people with physical disabilities in overcoming architectural obstacles. In particular, the authors discuss the design of a self-levering wheelchair. This design assists those that are unable to climb stairs by designing a wheelchair that is able to scale the obstruction. This article gained interest from the team due to the bench needing to be able to be very accessible in the field.

System For Camera Stabilization [4]

This patent assembly is a rig for supporting a camera. It is made of many rods that can slide, to provide movement capabilities for the camera. The takeaway for our design is the stabilization aspect. Each rod is equipped with a spring positioned to bias the camera toward a specific position, such that when the camera moves forward it is biased back by spring and vice versa. If the shock absorption for the portable bench is not achieved through the wheels, it should be achieved through the legs or the tabletop; this device provides a potential spring function for the legs of the tables to be biased upward or downward during transport.

Investigation on the Static And Dynamic Behaviors of Non-Pneumatic Tires with Honeycomb Spokes [5]

This article evaluates the honeycomb tire design. This design utilizes a non-pneumatic tire concept. This design has many applications in the field due to the tire not being able to be punctured and go flat, no air-pressure maintenance, and for its shock absorption properties. The tire is able to deform under impact of obstructions in its path, making it of interest in the development of a shock absorption property needing to be added to the bench design.

8.1.2 Wheels

Wheel research focused on specific aspects of five designs which could be applied to the wheel design: beads within a medical bed, hydraulic jack, deployable center wheels, shock absorbing wheels, and pneumatic tires.

Medical Table Assembly Having [...] An Associated Method of Immobilizing Object [6]

This medical table patent includes a method of immobilization of an object upon the bench. This method could be useful for restraining the medical device upon the Aneuvas Tech. portable bench. The method includes the use of actuators which cause interior side panels to automatically clamp down on the object. It is able to attain immobility of the object through a plurality of beads within the medical bed, as shown in Figure 3. It uses a vacuum source in fluid communication with the void with beads. A takeaway from this design, if not the entire assembly, might be to use beads within the tires, and to deploy a vacuum within the associated void when the table should not be in motion.

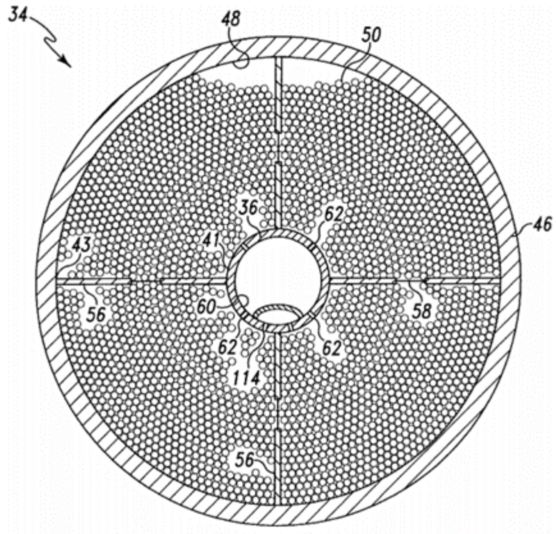

Figure 3: Beads Within the Medical Bed

Brake For Caster Wheels [7]

This brake activation structure patent was created for a mobile medical table for a patient. There are two takeaways from this assembly: the complex but attainable braking system that allows for smooth braking and includes gears; the hydraulic jack for controlling the patient height relative to the wheeled base. The braking system would allow for smooth stop, since Dr. Becker wants the portable bench to be movable by means of one person only. In the patent assembly, the braking system can be activated by the attendant from either end of the patient table. It additionally provides control of the direction of the wheels to this attendant. The hydraulic jack may prove useful for Dr. Becker because he wants to both be able to work at the bench while sitting and while standing. In the patent design, the hydraulic jack is accessed by foot pedals on the sides of the patient bed. Both aspects are controlled by foot pedals.

Carrier With Deployable Center Wheels [8]

This patent assembly features additional wheels that can be deployed during transport. This design is not specifically a medical bench or patient table, but was intended for use in the medical field for such designs. It is meant to be an addition to patient-carrying devices. It includes pedals for steering, a braking system, and a process for attaching it to existing medical beds. The main takeaway from this design is the deployable center wheels, illustrated in Figure 4. In the design, these are the wheels that control the steering. Our portable bench could use this steering mechanism, or it could use just the extra support and stabilization that comes from having two additional wheels. This could reduce shock by providing more points of contact with the ground during movement, and making the center wheels removable or deployable gives the option of having more room around the bench during use and non-transport.

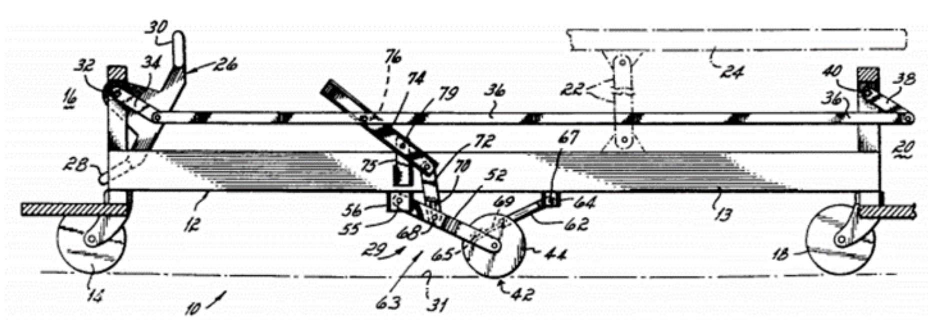

Figure 4: Deployable Center Wheels

Method Of Making Shock Absorbing Wheels [9]

This invention is a high strength, shock absorbing wheel composed of a two piece hub and axle shaft bearings. The wheel is divided symmetrically into two pieces for the purpose of a plurality of concentric grooves about the outer edge and corresponding keyways within. When the tire is molded onto the hub, the tire material flows into the grooves and keyways which provides a system for absorbing and distributing impact shock between the structure of the wheel. This method of wheel construction could be used for the wheels of the portable bench, should the shock absorption need to be achieved through the wheels.

Mechanics of the Pneumatic Tire [10]

This article sheds new light on a widely understood concept. The mechanics and properties of different tire material and style are analyzed to provide for a more in depth knowledge on this design. This design would be the cheapest and easiest concept for the shock absorption aspect of the project.

8.1.3 Tabletop

For the tabletop, research investigated designs for the tabletop itself, as well as existing cart and storage designs.

Medical Applications of Polycarbonate [11]

The first source is an online magazine that describes the medical uses of polycarbonate, which is under investigation for the tabletop material. It discusses the typical uses of polycarbonate in medical applications, which includes taking x-rays through, which is one of the big customer requirements for this project. It also details its ease of use for sterilization of the material itself which also hits another requirement. Polycarbonate also can withstand high temperatures, which is not a requirement but should be considered due to the technology used on the tabletop itself. Polycarbonate itself is very strong, which is an important consideration due to possibly over 100 lbs. of weight being on top of the table.

Lightweight Convertible Transport Cart [12]

The second source is a patent that shows a cart design that is lightweight, but also durable. Another request from the client was that the cart be able to be transported by one person, and for this, the bench needs to be light, while also maintaining strength. This cart design allows for one person to easily transport it over many terrains. The cart in the patent has tires that are pneumatic, which goes hand in hand with what we are looking into for wheel design itself. The cart is made of metal; however, its design will be considered for the portable bench.

Mobile Medical Emergency and Surgical Table [13]

The third source is a patent that shows a medical bench design used for emergencies. While the project bench will not be used for emergencies, the portable and storage aspects in this patent were noted. This bench uses a drawer design for its storage medium. Drawers are something that the team has been looking into for options for the bench. Because the bench will be used not only as a portable bench for the blood flow model of the brain, but also as a desk, this patent holds merit for its portable and storage design. The bench itself also has raised platforms, which were of desire of the client.

Best Storage Layout Optimization for Your Business [14]

The fourth source is a website which describes the advantages and disadvantages of U-shaped storage, which is another storage design consideration. It describes how it is the best way to maximize available space, which is important considering special constraints. It also describes a disadvantage in that it is harder to gain access to storage done this way versus pull-out storage. Considering that whatever is stored underneath will likely not need to be accessed rapidly, this is a great option. However, for doubling as a desk, this option is not as versatile.

POWERTEC Table Top Fasteners [15]

The fifth source is a catalog which shows different ways of attaching parts to a surface. This is important for implementing the pre-constructed clean-room hood into the design. It must be attached to the top of the tabletop while also being able to remove it with ease. This catalog shows many different fasteners that we could utilize with our design. There are a wide range of options including: screw in, clamping, and clipping.

8.2 Benchmarking

After doing literature review research, the design and challenges are better understood, the portable bench is re-divided into three sections for subsystems in benchmarking: shock absorption, tabletop, and storage.

8.2.1 System Level Benchmarking

This section analyzes existing full designs. The adjustable height work table is one that might be purchased if not for the project; the portable school desk and the existing cart are systems currently being used as a temporary substitute for the project design.

8.2.1.1 Existing Design #1: Adjustable Height Work Table [16]

The system level benchmarking chosen is a tool bench sold at Home Depot. This existing design is chosen because it resembles the overall shape and function of the medical bench that is needed to be created in this project. Although the work table is similar, there are many factors about the table that would need to be improved to meet the requirements given in the project description. The material of this table is mostly wood. This would be suitable for most of the bench but would need to be altered in some parts in order to be x-ray compatible. The wheels of the table have no shock absorption properties. This would need to be addressed on the bench. There is no storage provided in the table design, which would also need to be addressed to meet the bench requirements.

8.2.1.2 Existing Design #2: Portable School Desk [17]

This existing design is chosen based on its function as a school desk, while also having portability. While not being exactly a comparable design, aspects of it make sense for the bench design. Being a specialty project, not many existing designs exist for this. The desk itself has storage underneath, which is needed for our design. It also has wheels that can all lock, which expresses its versatility. It has a pull-out drawer on one side, which will be utilized in our design as well. This design is well suited for our project but would need some aspects changed. The storage itself is too small, but the idea is there. The desk is made of wood, and while most of the portable bench will be wood, the actual tabletop needs to be made of a material with minimal x-ray interference. The wheels will also need to be modified to support more weight during transit to other locations.

8.2.1.3 Existing Design #3: Dr. Becker's Cart Substitution

This system level benchmark is the cart currently being used for a medical bench, shown in Figure 5. This cart is currently viable for transporting the medical equipment but not for transporting the devices while they are in use. The cart is an appropriate size for storing and transporting the medical devices because it is on wheels, can fit through doors, and has open storage space on the bottom. The medical devices require an upgrade from this cart for the following reasons: the cart does not have shock absorption; the cart does not fit with the clean-room hood; the cart will not be big enough to store the newly ordered medical devices; the cart does not have additional storage space for the clean-room hood filter; the cart cannot be used for X-Rays. Dr. Becker requires upgrades to the cart for the following reasons: the cart cannot be used as a desk; the cart is not tall enough to stand while working at; the cart is only viable for transportation, not use, of the medical devices. The following aspects of this current cart are considered viable for its purposes: the cart has a durable/robust design; the medical devices' cords have access to the storage space where the generator would be located; the cart was not expensive; the cart is lightweight and maneuverable, and can be moved by one person only; the cart is not damaged by the temperatures used on the tabletop.

Figure 5: Dr. Becker's Current Cart

8.2.2 Subsystem Level Benchmarking

The subsystems (shock absorption, tabletop, and storage) each have different aspects that are researched and analyzed in this section.

8.2.2.1 Subsystem #1: Shock Absorption

Shock absorption is listed as a required characteristic of the wheels of the medical bench design. This subsystem is important to design correctly because the bench will be transported within the Wettaw Biology building on campus. The bench will need to be able to be transported through the halls of the building as well as enter an elevator and go through floors. In transit, there are many obstructions and bumps in the floor of the building. Due to the bench storing medical devices, the bench's wheels need to be able to soften the impact, allowing for safe transport of the devices.

8.2.2.1.1 Existing Design #1: MRF Damper

The MRF damper is an existing design that utilizes the characteristics of the fluid to absorb impact. The damper is actuated through a magnetic field that causes the viscosity of the fluid to increase and assist in lowering the impact force. This design could be utilized in the bench by implementing the wheels with the MRF dampers and actuating the fluid while the bench is moving.

8.2.2.1.2 Existing Design #2: Honeycomb Tire Design

This concept uses a non-pneumatic tire design. The airless tire has a honeycomb like center. The tire is able to deform upon impact and is unable to go flat if punctured. This design could be utilized on the wheels of the bench due to its low maintenance and impact absorption characteristics.

8.2.2.1.3 Existing Design #3: Descriptive Title

This design uses the basis air tire concept. Out of all the other concepts considered for shock absorption, this is the most simple and cheap. The need for shock absorbing tires is necessary but may not need a complex solution.

8.2.2.2 Subsystem #2: Tabletop

All details of the tabletop subsystem should be accounted for. This section of the design has the most functions and incorporates the most client preference. The most important requirements are: the tabletop is X-Ray machine compatible, both the material should not interfere with X-Rays, and the geometrical design of the tabletop should be mechanically compatible with the X-Ray machine; the tabletop should fit together with the clean-room hood; the tabletop should not fail under regular use from the medical devices, considering high temperatures and spills; the tabletop should have enough space to store the required medical devices and allow for cords from the medical devices to travel to the storage area; and the tabletop should fit through doors. Client preferences for the tabletop include: a durable, robust, and reliable design; safe use; an inexpensive design; a multipurpose design; and a tabletop that is easy to clean spills from. To achieve these many functions and requirements, options for specific aspects of the tabletop were explored. Options for countertop material were researched and drainage systems were explored.

8.2.2.2.1 Existing Design #1: Combination Medical Bed and Hospital Table [18]

This design is a medical bed and surgical table that is X-Ray compatible. To permit the use of the bed as an X-Ray table, channel means are included for holding X-Ray cassettes underneath the surface of the tabletop. These means may be useful to Dr. Becker's X-Ray procedures and further research on this may be necessary. The center section of this medical table is made of radio-translucent material, polycarbonate resin, to function as an X-Ray table. The workspace of the portable bench needs to be similarly X-Ray compatible as this medical table is, and can be made similarly out of polycarbonate.

8.2.2.2.2 Existing Design #2: Perforated Scrub Sink [19]

This design is an anti-splash and non-contaminating scrub sink. Similar technology can be used in the portable bench tabletop, if necessary. The bottom of the sink is perforated, which in the portable bench tabletop would remove spills from the vicinity of the medical devices. In the scrub sink patent, there is reduced pressure below the perforated area to draw fluid below. This design can be comparable to a slotted sink rack [20] for the portable bench purposes. The benefits to this design is that the spills would be immediately removed from the medical devices, but it may be more difficult to sanitize.

8.2.2.2.3 Existing Design #3: Basin Scrub Sink [21]

The scrub sink has an elongated basin, and the bottom of the basin is contoured to avoid splashing. The portable medical bench would not require such a steep contour because splashing is not a concern, but a basin contour might be useful to provide a uniform slope instead of a radial slope for the tabletop drainage system. The benefits to this design is that it is easy to sanitize, but if it is too sloped then using the devices and workspace may prove difficult, and if it is not sloped enough then the spills would remain in the vicinity of the medical devices.

8.2.2.3 Subsystem #3: Storage

Storage underneath the bench is one of the customer-required aspects of the project. This subsystem is important to the design because it is needed for storage of components that do not need to be on top of the table, i.e. the battery. The storage itself needs to be big enough to hold everything, while also being small enough not to hinder people working at the bench both standing and sitting. It also needs to be strong enough and tall enough that nothing will fall out of the storage during transportation to places around campus.

8.2.2.3.1 Existing Design #1: U-Shaped Storage

U-shaped storage is an existing design which utilizes its volume to maximize its storage space. However, this storage medium is unable to move, and therefore reduces its ability to be multipurpose. This is desirable because items stored underneath the desk will not need to be accessed right away.

8.2.2.3.2 Existing Design #2: Pull-Out Drawer

Pull-out drawer design is an existing design which emphasizes its versatility. This design is desired because of its desk-like features, which hits one of the customer requirements for the design. It is undesirable however because it means there will be less space for storage because of the fact that it pulls out and is not stationary.

8.2.2.3.3 Existing Design #3: U-Shaped/Pull-Out Hybrid

This design is a hybrid of the first two designs. One half is U-shaped, to basically be L-shaped, and the other half has a pull-out drawer. This design is desirable because it can have stationary storage while also having pull-out storage for easy access. The drawer will be a key component in being more desk-like, as pencils, pens, paper, etc. can be stored in it, and accessed with ease.

9 CONCEPT GENERATION

There are three full system concepts and ten subsystem concepts.

9.1 Full System Concepts

9.1.1 Full System Design #1: Tabletop (and) Access to U-Shaped Storage

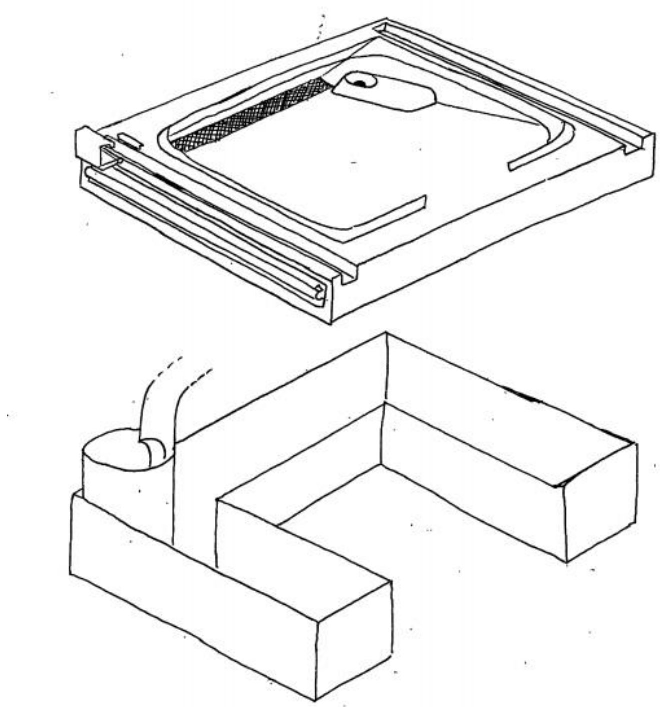

Figure 6: Tabletop (and) Access to U-Shaped Storage

Figure 6 illustrates the necessary indentation on the workspace that the clean-room hood attaches by; this feature can utilize sliding the clean-room hood into the indentations, as shown, or can be designed for just placing the clean-room hood into the tabletop indentations; this feature should include a securing clamp, as shown. The handles in this design are also included through an indentation in the side of the tabletop. Aside from the indentations, the rest of the tabletop is a workspace, utilizing the subsystems basin drainage with a spill container, an elevated device platform with a cord guidance hole, and spill guards around the edge of the workspace. This Figure illustrates how the drainage subsystems would divert liquids to a spill container in storage. The storage is U-Shaped. The benefits of this design correspond to the subsystems' respective benefits

Table 5: Pros and Cons of Full System Design #1

Pros	Cons
Maximum Storage Space	Tilted Workspace
No X-Ray Interference	Shallow Tilt = Restricted Drainage
Clears/Protects Workspace Of Spills	Spills Move In Device Vicinity
Sanitization	Tight Fit For Some Devices
Contains Spills	Storage Not Accessed With Ease
Multi-Use For Desk	Restricts Modularity Of Workspace Devices
Maneuverable	

9.1.2 Full System Design #2: Drawer Storage and Tabletop Features

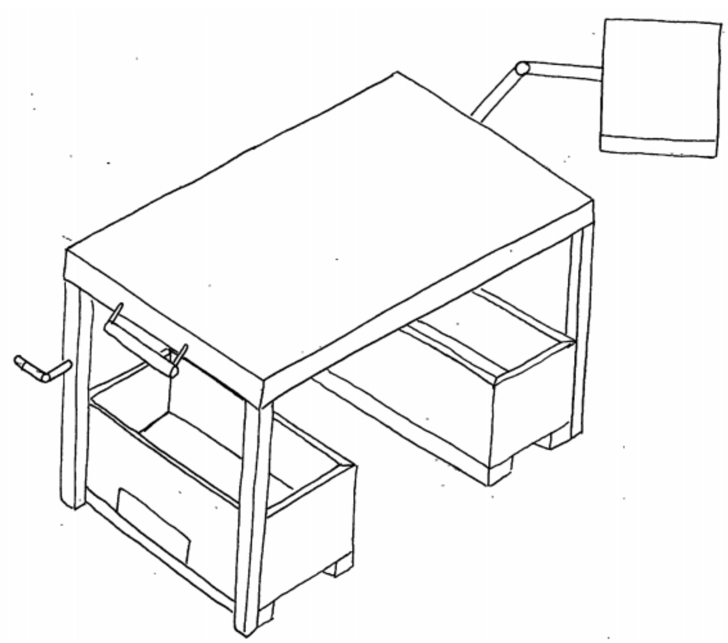

Figure 7: Drawer Storage and Tabletop Features

This design, shown in Figure 7, features two drawers on both short sides of the storage area. These drawers allow for easy access to the devices in storage, but restricts the amount of storage space due to its divided nature. The lack of central storage provides X-Ray machine access to the workspace from below, and allows the portable bench to be used as a desk. Other features of the portable bench encourage desk use, including the jack to adjust the tabletop height and the swiveling laptop support. These features may be unnecessary for the purpose of the portable bench and may add to complications and cost. The design importantly features a handle for maneuvering the bench. The storage drawers are within the boundaries of the bench legs so that a clean-room cover or tarp could be attached around the storage during transportation, to protect from contaminants outside of buildings. This design simply demonstrates how the storage space and tabletop should be positioned in relation to each other.

Table 6: Pros and Cons of Full System Design #2

Pros	Cons
Easy Access To Storage	Less Storage
Laptop Support	Unnecessary Additions
X-Ray Machine Compatible	
Desk Features	

9.1.3 Full System Design #3: Complete Storage Assembly

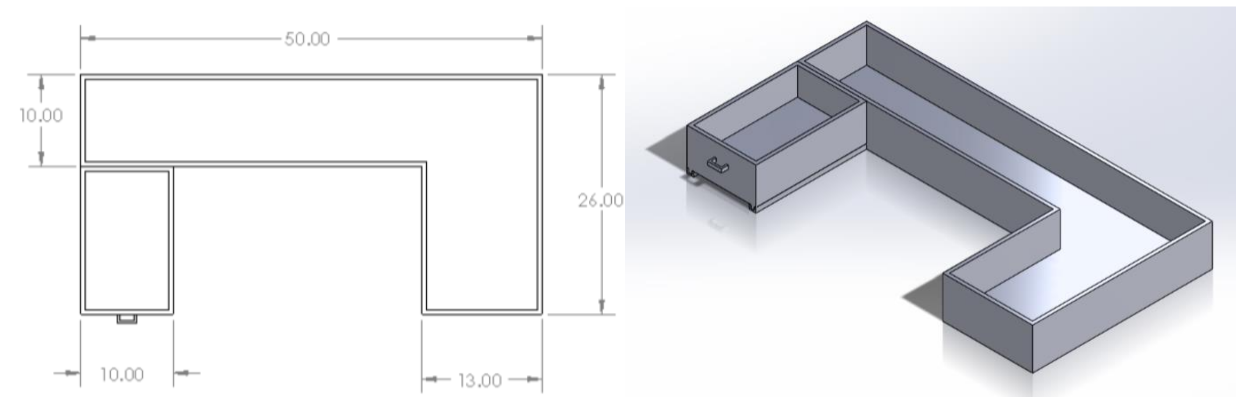

Figure 8: Complete Storage Assembly

The design, shown in Figure 8 is compatible with the tabletop base subsystem elevated devices, Figure 13, to form a full system design. The benefits of the tabletop base are therefore respective to that subsystem. This storage assembly utilizes the most important benefits from the considered storage subsystems. The overall design is U-shaped to provide X-Ray machine access and leg-room for desk space, as well as allow for maximum potential storage space. The design is slightly asymmetrical to best utilize storage for the stationary devices and allow them to have more positioning options. The asymmetry is not over-emphasized so as not to restrict the workspace or the X-Ray machine's access, and still allow comfortable desk-use. The L-shaped storage shelf is not modular, so as not to restrict the storage space. The easily accessed drawer is for office supplies, and the shelf is for stationary devices and generators that do not need to be moved frequently.

Table 7: Pros and Cons of Full System Design #3

Pros	Cons
Multi-Use As Desk	Division Affects Storage Space
Maximum Storage Space	Not Parallel To Clean-Room Hood
X-Ray Machine Design Compatible	Not All Storage Has Ease Of Access

Larger Storage Space For Devices	
Smaller Storage For Office Supplies	
Features Some Ease Of Access	

9.2 Subsystem Concepts

9.2.1 Subsystem #1: Shock Absorption

Shock absorption is a main function required in the initial project description and stated as a strong need from the project's client. Currently, the bench being used has rubber wheels. These wheels offer little to no absorption of impact while the bench is moving, making it very difficult to transport. This causes concern when the medical devices are moving with the bench.

9.2.1.1 Design #1: MRF Damper

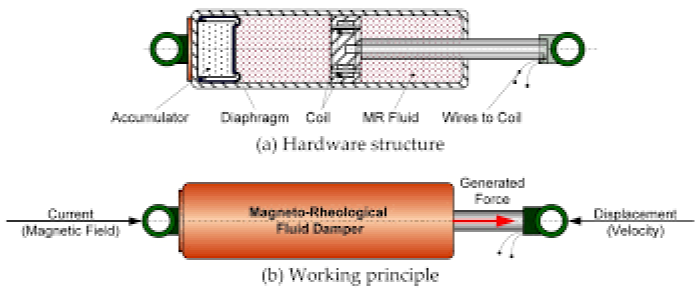

Figure 9: MRF Damper

Figure 9 shows one of the concept designs being considered for the shock absorption requirement. This fluid is composed of micron size ferromagnetic particles that, when introduced to a magnetic field, align and increase in viscosity. The damper requires actuation to be used properly and is the most expensive option but is also the most effective in impact absorption.

9.2.1.2 Design #2: Honeycomb Tire

Figure 10: Honeycomb Tire Design

Figure 10 depicts the honeycomb design. This design utilizes a non-pneumatic tire that deforms upon impact. This design would be difficult to build but offers little to no maintenance and has impact absorption without the need of actuation.

9.2.1.3 Design #3: Pneumatic Tire

The pneumatic tire design is widely used in forms of wheels. It is often made of rubber and filled with air. This design may not offer as much shock absorption on the field as other concepts but is by far the most simple and cheap.

9.2.2 Subsystem #2: Tabletop

The tabletop design had many aspects to consider options for, as shown in the tabletop blackbox model Figure 6. The tabletop should contain spills and restrict liquid from damaging the medical devices. Designs for this are considered in this section. For the tabletop to be X-Ray machine compliant, it needs to be made of the appropriate material. The material will be best determined after a geometric design is finalized. The geometric design needs to be compatible with the X-Ray machine mechanics, which only provides constraints on widths and depths, so it does not provide a problem that requires multiple designs. The tabletop should be able to support the clean-room hood: this requirement will affect both material choice and design, so the design best suited for this is included in all tabletop designs. The tabletop should fit through doors, a design constraint on width that is applied to each tabletop design. The tabletop should provide cord access to the storage area, a design capability explored in this section.

9.2.2.1 Design #1: Grate Drainage

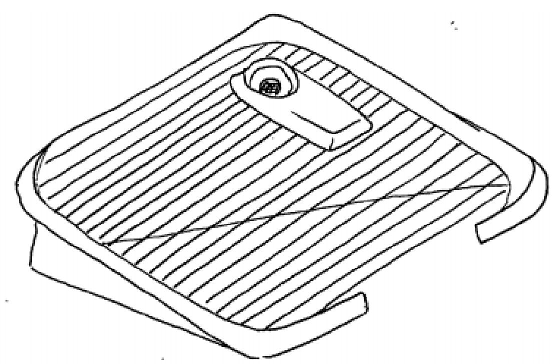

Figure 11: Grate Drainage Workspace Design

The Grate Drainage option shown in Figure 11 allows spills to fall beneath the workspace. This design includes the other parameters required, such as width and depth restrictions and clean-room hood compatibility. Beneath the workspace is a steeply contoured basin to ensure the spills fall to the spill container in the storage space, as shown in Full System Design #1 and Figure 6. This prevents spills from harming the medical devices without having to use the devices on a tilted platform. This design protects against spills while also providing a flat workspace. Unfortunately, Dr. Becker informed the team that a grate or perforated design would affect the video imaging from the X-Ray machine. Sanitization may be difficult, depending on method, and the portable bench would be more unlikely to be used as a desk if the workspace is a grate.

Table 8: Pros and Cons of Subsystem Design #2.1

Pros	Cons
Flat Workspace	X-Ray Interference
Protect Devices From Spills	Sanitization

Spills To Spill Container	Not Desk-Like

9.2.2.2 Design #2: Basin Drainage

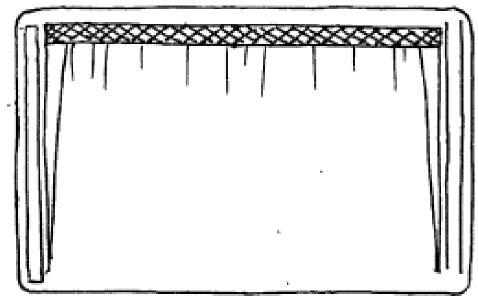

Figure 12: Basin Drainage Tabletop Design

The Basin Drainage design shown in Figure 12 drains spills from the immediate workspace toward the back of the tabletop and clean-room hood assembly. The spills are directed back by the slanted contour of the workspace and drained by a long basin to the spill container, similar to the one in Full System Design #1 and Figure 6. This provides drainage for spills and keeps loose liquids out of the workspace. The long basin design instead of single-drain design allows for a uniformly tilted workspace instead of a radially tilted one, to provide slightly better balance for the medical devices. The devices would still be functioning on a tilt, however, so the tilt should be kept to a maximum of ½ inch to 1 inch deep from one end of the tabletop to the other. This may restrict the drainage effectiveness, depending on material finish and type of liquid spilled. The liquid spills would still be moving around the devices, instead of instantly dropping out of the workspace. This design remedies the X-Ray interference caused by a Grate Drainage system, and provides a surface easier to sanitize. It would also more likely be used as a desk since the surface is uniform, only slightly tilted.

Table 9: Pros and Cons of Subsystem Design #2.2

Pros	Cons
No X-Ray Interference	Tilted Workspace
Clears Workspace Of Spills	Shallow Tilt = Restricted Drainage
Sanitization	Spills Move In Device Vicinity
Contains Spills	
Multi-Use For Desk	

9.2.2.3 Design #3: Elevated Platforms (No Drainage)

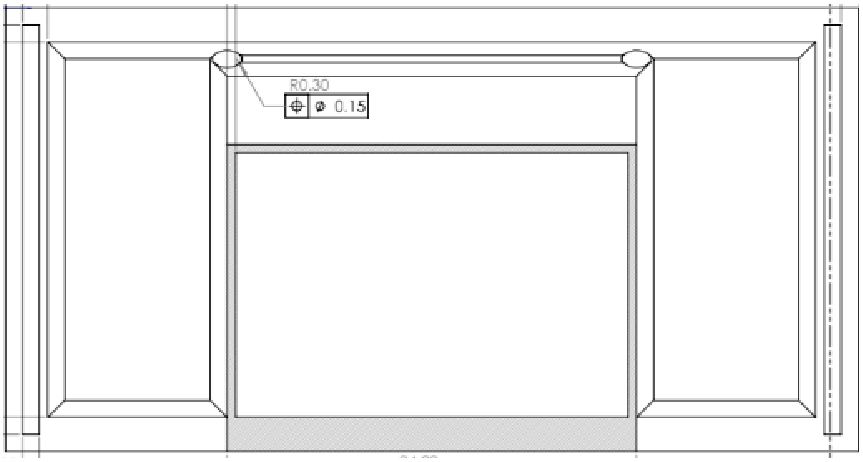

Figure 13: Elevated Platforms (No Drainage) Tabletop Design

This Elevated Platforms design shown in Figure 13 clears the devices away from potential spills by resting them on elevated platforms beside the workspace. These platforms would be permanent fixtures, as modularity introduces complications in sanitization practices. There would be an introduced issue of lack of modularity of the devices themselves; because the devices could only be placed on the platforms located to the sides of the workspace, this limits the position the user could place these devices around the workspace to only the sides. The workspace itself would consequently be smaller than an open-plan workspace. The back of the tabletop includes a spill guard, but the spills would not otherwise be contained. Sanitization would be an easy process with a smaller, contained workspace, the workspace would easily be used as a desk, and there is no X-Ray interference.

Table 10: Pros and Cons of Subsystem Design #2.3

Pros	Cons
Protect Devices From Spills	Spills Not Contained
Flat Workspace	Restricts Modularity Of Devices
No X-Ray Interference	Smaller Workspace
Sanitization	
Multi-Use For Desk	

9.2.2.4 Design #4: Partitions with Cord Holes (No Drainage)

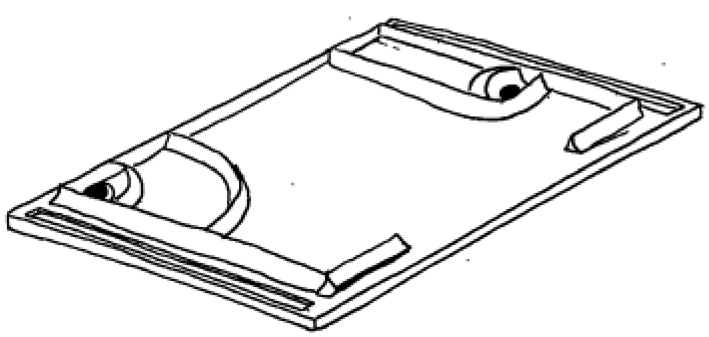

Figure 14: Partitions with Cord Holes Tabletop Design

This Partitions with Cord Holes design, shown in Figure 14, provides the medical devices protection from spills using spill guards. This approach has nearly identical benefits as Design #3 Elevated Platforms, but this design also explores Cord Guidance Holes, which further restrict modularity of the devices. Unlike the other designs, which require the devices' cords to be attached by zip-tie to the shorter sides of the tabletop to travel to the generator in the storage area, this design provides spill-protected guidance for the cords directly through the table to the storage area. This keeps cords out of the workspace and protects them from the outside area of the table. The Cord Guidance Holes, however, introduce the threat of liquid spills to travel along the cords directly to the generator.

Table 11: Pros and Cons of Subsystem Design #2.4

Pros	Cons
Protect Devices From Spills	Spills Not Contained
Flat Workspace	Restricts Modularity Of Devices
No X-Ray Interference	Smaller Workspace
Sanitization	Generator Vulnerability
Multi-Use For Desk	
Protect Cords From Outside World	
Keep Cords Out Of Workspace	

9.2.3 Subsystem #3: Storage

The storage system has few purposes it should be designed for. They are described in the storage blackbox model, Figure 2. The most important design requirements are that there is enough storage space and the storage unit is cost-effective. The design must allow cord access from the devices on the tabletop to the generators in the storage area. The design should allow easy access to the stored devices and generators.

9.2.3.1 Design #1: U-Shaped Storage

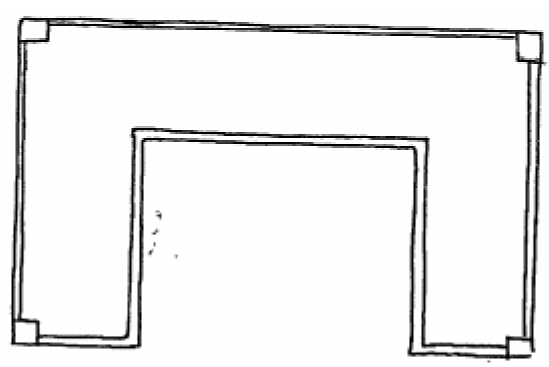

Figure 15: U-Shaped Storage Design

This U-Shaped Storage design, illustrated by an aerial view in Figure 15, allows for storage of the specific medical devices and generators while also allowing the X-Ray machine to access the workspace from beneath. The U-shape also enables the portable bench to be used as a desk. This U-shaped storage is a sturdy, u-shaped shelf mounted at the bottom of the bench legs. The storage shelf is within the boundaries of the bench legs so that a clean-room cover or tarp could be attached around the storage during transportation, to protect from contaminants outside of buildings. The devices in storage may not be easily accessed or moved around frequently with this design.

Table 12: Pros and Cons of Subsystem Design #3.1

Pros	Cons
Multi-Use As Desk	Tight Fit For Some Devices
Maximum Storage Space	Storage Not Accessed With Ease
X-Ray Machine Design Compatible	

9.2.3.2 Design #2: Drawer Storage

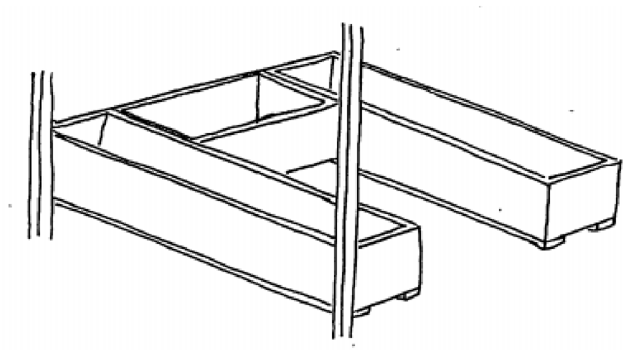

Figure 16: Drawer Storage Design

This design, shown in Figure 16, is also U-Shaped, but each of the shorter sides of the storage are drawers. The storage could alternatively be designed with the one long side being all shelf, with the two drawers being proportionally shorter, but the drawers would then most likely not hold medical devices. The U-Shape design retains the same benefits, except that the divided aspects of the drawer design restricts storage space and placement of medical devices and generators. If the devices are regularly stationary, the additional access to them may be unnecessary while also reducing the overall storage space opportunity.

Table 12: Pros and Cons of Subsystem Design #3.2

Pros	Cons
Ease Of Access	Divided Design Restricts Placement
Multi-Use As Desk	Unnecessary Access to Stationary Devices
X-Ray Machine Design Compatible	

1.1.1.1 Design #3: Asymmetrical Storage Design

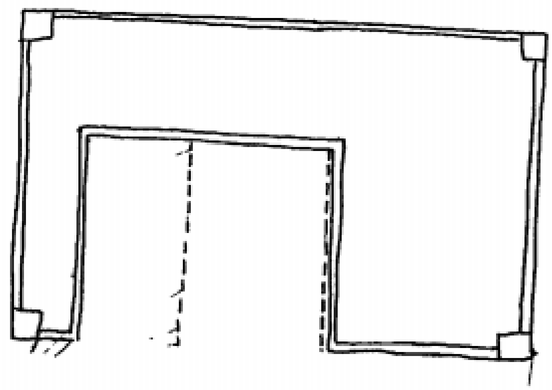

Figure 17: Asymmetrical Storage Design

The asymmetrical storage design, illustrated by an aerial view in Figure 17, is similar to the U-shape design. One of the shorter sides of the storage area is significantly narrower, and the other is wider. This provides a larger storage space for the medical devices and generator, and more options for how the devices are stored, rotationally. The smaller storage area would be used for office supplies. The dotted lines in Figure 17 indicate the location the X-Ray machine could be placed during use, with the left boundary being the edge of the workspace as defined by the pre-constructed clean-room hood. This design might cause complications with the design of the tabletop, since the tabletop should be designed according to the pre-constructed clean room hood whose workspace access is centered on the tabletop. If the workspace remains centered, and not extended left or right, the desk space could be potentially limited. If the workspace is extended, then there would be less spill-protected room for medical devices on the tabletop.

Table 13: Pros and Cons of Subsystem Design #3.3

Pros	Cons
Larger Storage Space For Devices	Not Parallel Design to Clean-Room Hood
Smaller Storage For Office Supplies	Limited X-Ray Machine Compatibility
Client Preferred	Limited Desk Space
Lacks Ease Of Access	Causes Tabletop Complications

10 DESIGN SELECTED – First Semester

The following sections show technical selection criteria, along with rationale for design selection using a decision matrix to evaluate the generated design concepts. It is noted, however, that our selected design is not final because the client has not responded with input.

10.1 Design Description – First Semester

10.1.1 Final Design: Tabletop

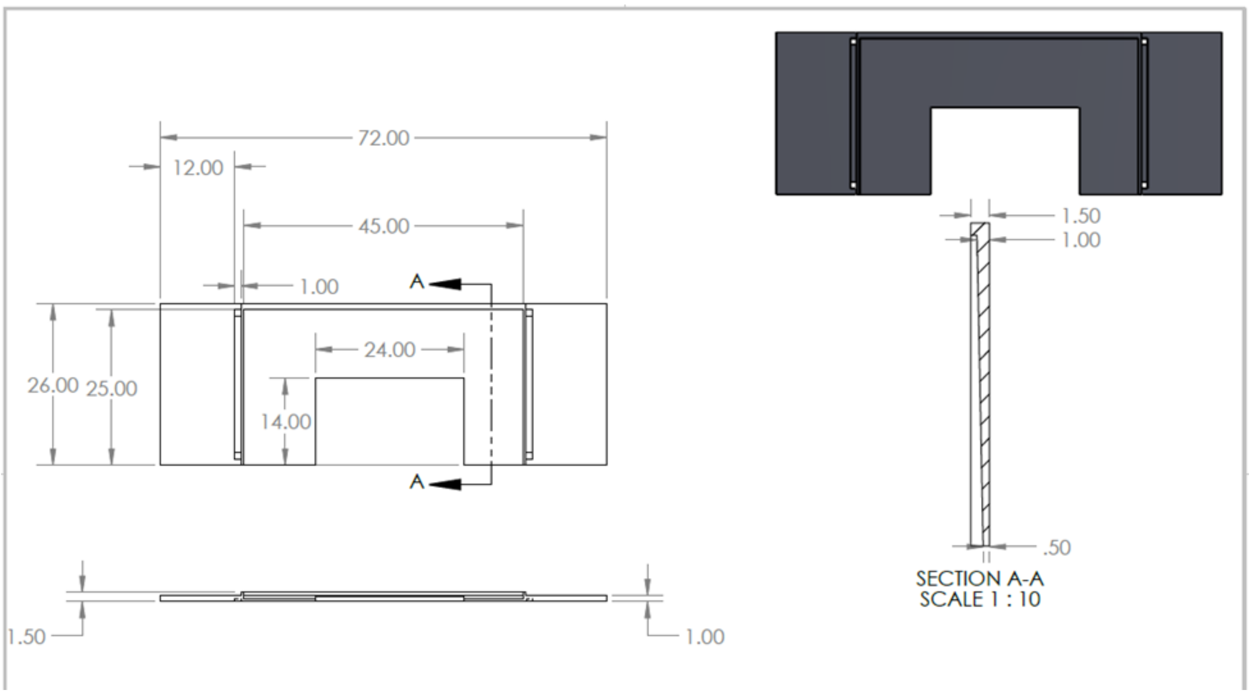

Figure 18: Final Tabletop SolidWorks Design

Figure 18 depicts the final design for the tabletop, with measurements in inches. The polycarbonate workspace is attached to the 14”x24” area in the center of the tabletop. This area corresponds to the clean-room hood workspace access. Polycarbonate does not span the entire tabletop because it is not sturdy enough to support devices or normal desktop live loads without movement. The deflection relies inversely on Young’s Modulus, measuring elasticity, and the value of Polycarbonate is too low, around 〖10〗^6psi, to allow for a low deflection at such a thin workspace. The workspace area may have to be reduced if, during testing, the polycarbonate is determined to be too flexible for its thickness. A different material is used for the rest of the tabletop because it should be a material that does not require reinforcements across the workspace area, to minimize x-ray videography/imaging interference. The tabletop is made 1.0” thick so that it does not interfere, geometrically, with the x-ray machine, which should reach as close to the top of the workspace through the thickness of the workspace as possible. This thickness has not changed during past revisions. The 25”x45” workspace area in the middle of the tabletop is contained within the clean-room hood area. It features a tilt for liquid spill drainage as shown in Section Cut A-A of Figure 9. This differs from the prior revision, shown in Figure 9, which does not feature the tilt, and instead uses elevated platforms to protect the devices from spills. The tilt is 0.5” downward from the back of the workspace to the front of the workspace and was added as such per client request. The workspace also features a containing spill guard, protecting the clean-room hood grooves from spills, and containing spills from falling behind the cart. This was also featured in the previous revision. The clean-room hood grooves provide an area for the clean-room hood to be placed into. The clean-room hood will be removed or attached by two people, placing it down onto the table, per client instructions, and will not slide off of the table. This was made clear early in the process and has not changed during revisions. The last change to the tabletop from the prior revision is an increase in table length to 72”, per client request. This length is added to either side of the workspace, keeping the clean-room hood centered on the tabletop.

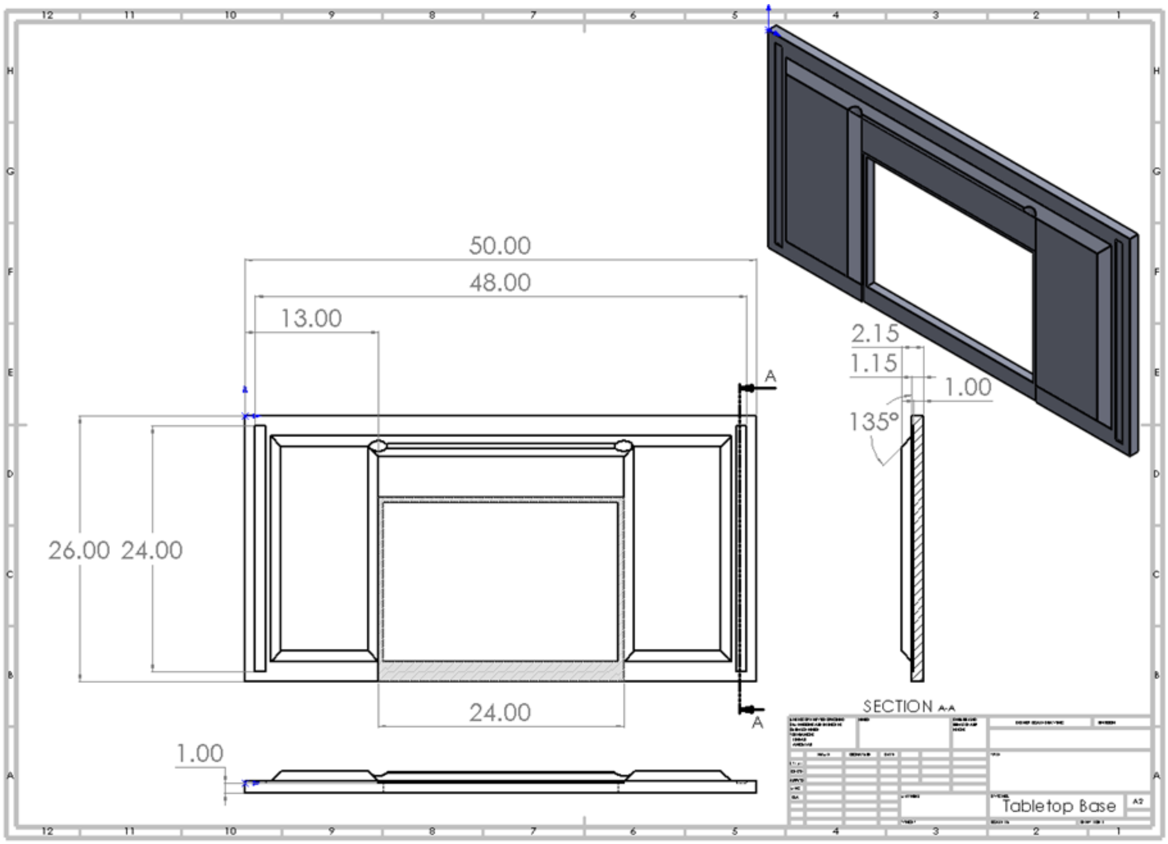

Figure 19: Preliminary Report Tabletop SolidWorks Design

The tabletop prototype, shown in Figure 19, is a 3D printed 1:14 scale model of the final SolidWorks design. The prototype provided a visualization for the thickness of the table relative to its length and width. It showed that the thickness will be sufficient relative to the placement of the supports (legs), but that the tabletop thickness will be insufficient to support any of the weight of the clean-room hood. The clean-room hood weight should be placed completely onto the table legs, so a hole was employed through the table, at the ends of the clean room hood and to direct its weight directly to the legs, with no stress supported by the table. These holes are shown in Figure 19.

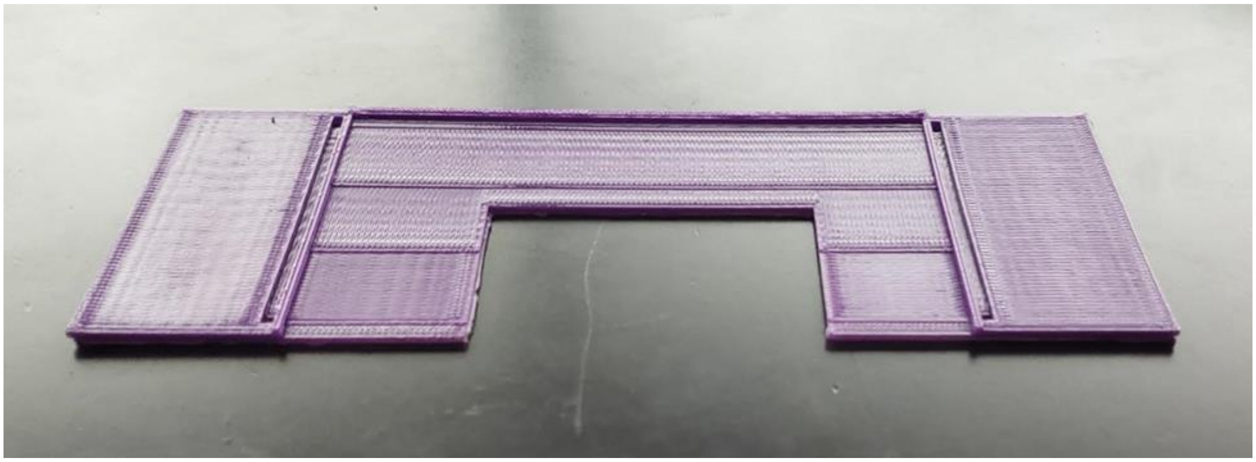

Figure 20: Final Table top Design Prototype

10.1.2 Final Design: Storage

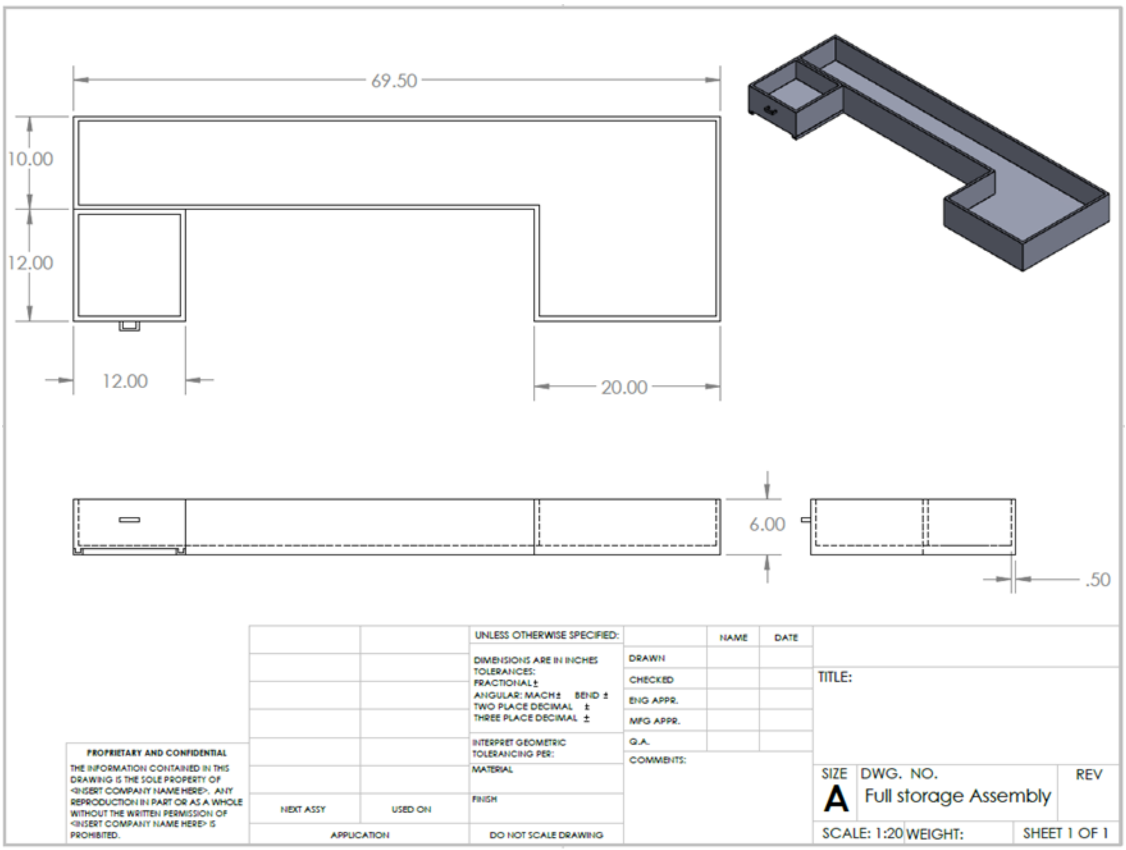

Figure 21: Final Storage SolidWorks Design

Figure 21 depicts the final design for the storage, in inches. The U-shape design was chosen for the storage area, so that the cart could be used as a desk with space for sitting. Moreover, this space is necessary to allow for the x-ray machine to fit directly beneath the workspace for videography and imaging. The storage area is almost six feet, the length of the table, but the reasons for its specific dimensions were provided by the client for this revision, an update from the Preliminary Report design, shown in Figure 22. A drawer for office supplies, requested by the client, pulls out for accessibility, and is shown in Figure 21 to be 12”x12”, enough area for office supplies. Its width is the distance from the location of the legs to the edge of the tabletop. It would not be appropriate to extend any of the storage area past the dimensions of the tabletop, due to accessibility and safety issues, aesthetics, and to provide a way to attach a laminate film for clean-room effect within the storage area during transport. The height of the back-most area in the L-shape storage shelf, 10" in the figure, is determined by keeping the storage within the confines of the table legs, and the back of the workspace. It is not susceptible to being leaked on if the workspace leaks where it is sealed; this precaution was emphasized by Dr. Becker. Similar precaution is taken for the storage area on the right, the larger portion of the L-shaped area, shown as 20" wide in the figure. It is dimensioned to be placed right of the above tabletop workspace, but is also centered between the right table legs, so that the storage is balanced. The changes from prior revisions include a wider length, to match the tabletop, and a wider storage area on the right side of the L-shape. The storage area has also been dimensioned to regard the tabletop and legs, since the dimensions for the tabletop have been further verified by the client.

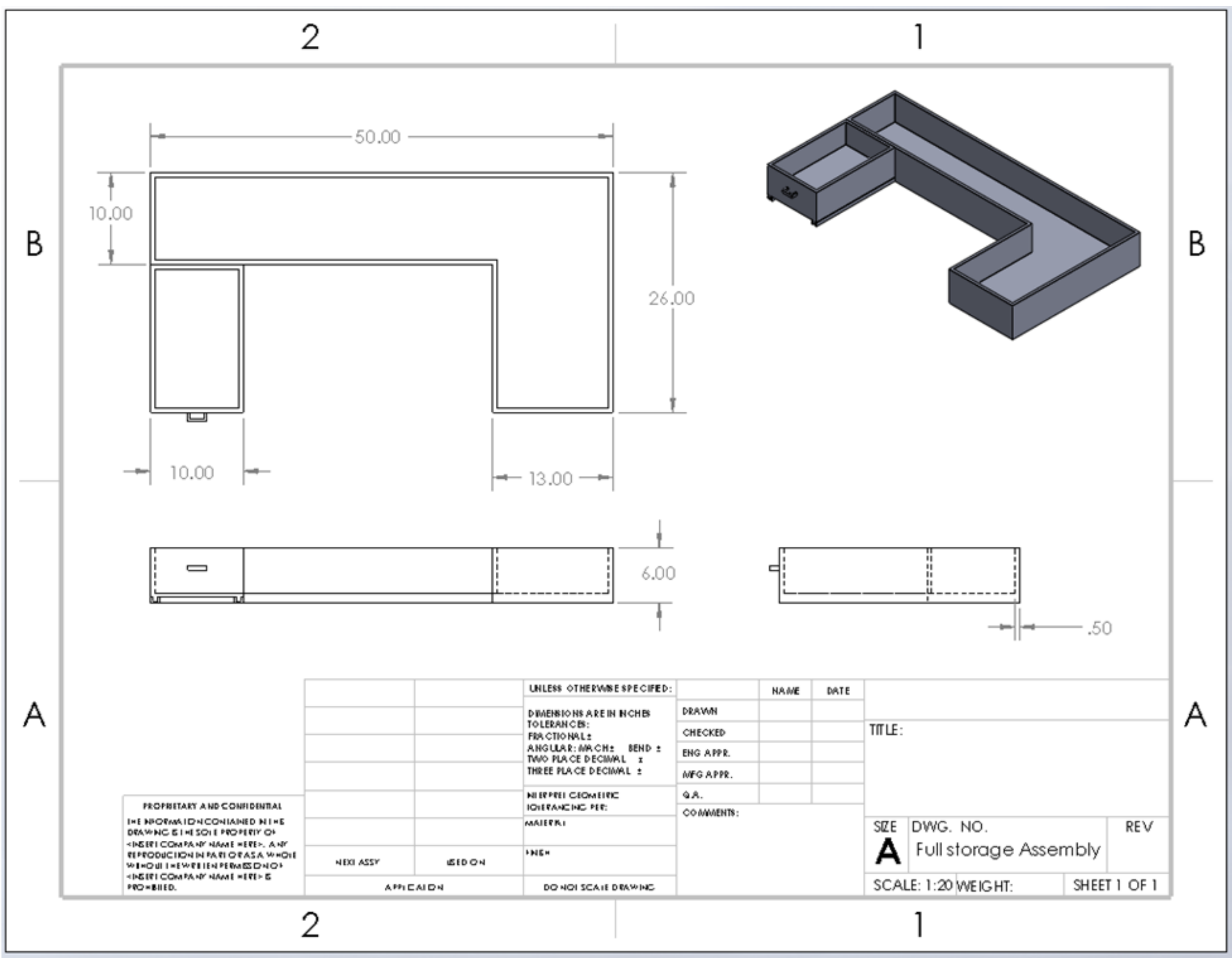

Figure 22: Preliminary Report Storage SolidWorks Design

The storage prototype, shown in Figure 23 below, is a 1:3 scale foam board construction of the final SolidWorks design. Seeing the proportions of the different areas in the storage assembly allowed visualization of what medical devices would be placed in each region. The largest region, the right-most area, will most likely hold the heaviest equipment. Because it will hold the heaviest and largest devices and equipment, that storage area should be balanced between the rightmost legs to allow for balance and equal support.

Figure 23: Final Storage Design Prototype

10.1.3 Final Design: Shock Absorption and Full Assembly

Polyurethane foam tires are attached to the bases of the legs for shock absorption. This selection was instructed from the client, and has changed from the suggested pneumatic tires analyzed in the Preliminary Report. The polyurethane foam wheelbarrow tires will not deflate or flatten.

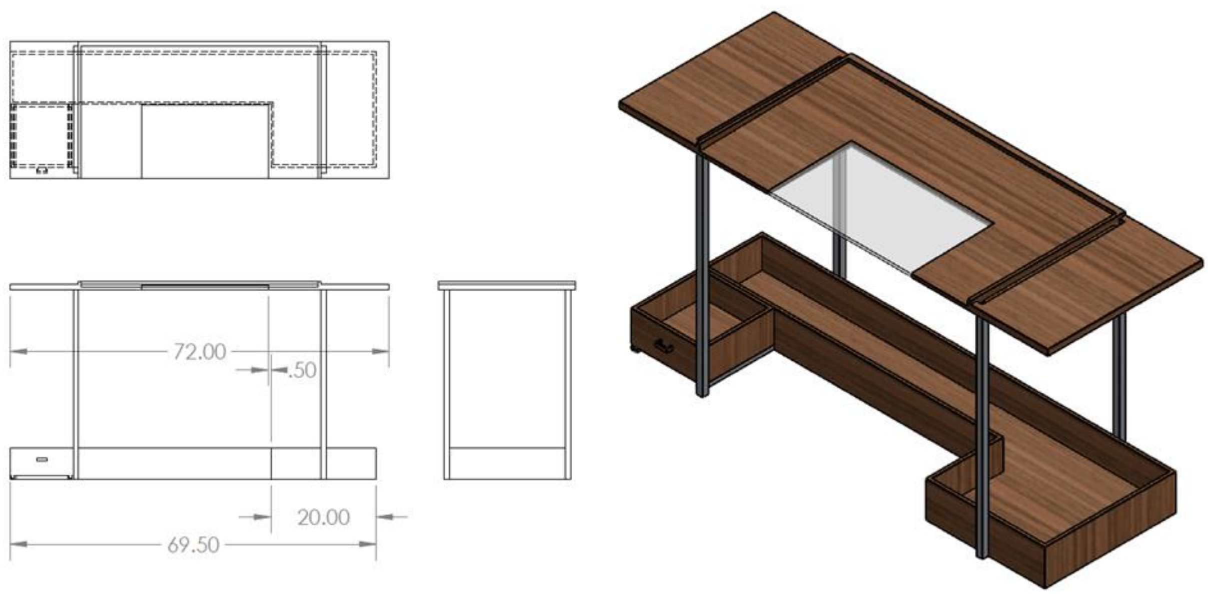

Figure 24: Final Assembly SolidWorks Design

The SolidWorks assembly, shown in Figure 24, depicts the tabletop, with the polycarbonate workspace, fitting together with the storage area and the placement of the table legs. The placement of the table legs is pre-determined by the clean-room hood. The clean-room hood weight will be diverted to the legs, and it reduces the amount of stress on other areas of the tabletop or beams to place the legs directly under the corners of the clean-room hood frame. The aerial view depicts the storage area being separated from the workspace, in case of leakage in the seal. The aerial and front views show that the storage has a shorter length than the tabletop on the right side, but is flush with the tabletop on the left side. The side view shows that the tabletop extends farther than the legs, but that the storage area is contained within the dimensions of the table legs.

10.2 Implementation Plan – First Semester

The implementation plan regarding the portable bench is as follows. The team will be using the machine shop, also at home methods for implementing and bringing the design to life. The team will be getting most of the material required for the design from Home Depot, with a couple things coming from amazon. The breakdown of the full bill of materials for this project can be found in Appendix A. One of the members of our team is planning on getting a machine shop certified in order to do some of the building of the portable bench in the machine shop. We will start ordering some materials from Home Depot and Amazon over winter break/early January to ensure that everything gets delivered in time. The tabletop component of this project will be manufactured in house, using mostly a table saw with fasteners with a drill to assemble it. The wood surface will be coated in order to protect it from deforming from spills. The polycarbonate will be attached to the surface using an adhesive. The tabletop part of the design will be the most time-consuming part of manufacturing so this will be done first. We have determined to start building this by February of next year, with expected completion by mid-February. The storage part of the design will also be manufactured in house, using a table saw and drill. This along with the legs and tire assembly will be step two in the implementation plan. We expect to start after the tabletop is finished in mid-February and finish by the beginning of March. This will allow us to assemble everything together by Mid-March, in order to be about a week early for the deadline of having the final product completed by the end of March. After this, testing proof will begin in early April and U-grads will happen at the end of April.

11 IMPLEMENTATION – Second Semester

The implementation section describes the full process of manufacturing of the portable medical bench. It includes updates in the design to the manufacturing process, every iteration of the portable medical bench design, and the reasons for these changes.

11.1 Manufacturing

The following details how the portable medical bench is manufactured. It combines outsourcing and in-house manufacturing. The tabletop and frame are outsourced, the storage is built in-house, and the wheels will be ordered. The components will be combined in-house.

11.1.1 Tabletop

The tabletop will be manufactured by Only Table Tops. The process of getting the tabletop manufactured began with its design. The team analyzed the material that will be used to make the tabletop and calculated the thickness that would be necessary to support the loads of the equipment used in the experiments. The team then created the design in Solidworks and created a drawing. That drawing was then sent to be approved by the company to receive a quote. The company quoted the design for $545.

11.1.2 Frame

The frame is ordered from Mayorga's Welding. The design of the frame was done similar to the tabletop, ensuring it can safely support the loads of the equipment. They quoted around $450 for the design.

11.1.3 Storage

The storage was built in-house. The materials required for storage construction are a sheet of plywood, nails, wood glue, wood putty, sandpaper, paint primer, paint, and a knob. The team uses specific equipment in order to build the storage: a table saw, hand saw, nail gun, impact drill, tape measure, measuring square, paint brush, paint roller, and a sander. The first step is cutting the necessary pieces from the 4'x8' sheet of plywood. The storage is then assembled one side at a time. The drawer consists of a box inside of a box; due to the drawer being so small, drawer slides have been omitted. After all the pieces are assembled, the storage is sanded. The storage is then coated with primer, covering all the crevices of the wood, because this shows after a coat of paint is on. After this is complete, a coat of black paint is applied to match the tabletop. The storage is then examined to determine if more coats of paint are necessary. Finally, the drawer knob is attached. Currently, the storage is at the point of applying paint and the knob, then it will be complete.

11.1.4 Wheels

The wheels are purchased from McMaster-Carr and are attached to the frame with 4 bolts for each wheel. Each wheel is designed to carry a load of 250 lbs., a load support that was decided based on client preference and achieving a factor of safety of about 3 when considering the total weight of the device and the items the device would be carrying. Currently, these wheels have been ordered and have come in.

11.2 Design Changes

This section chronologically discusses the design changes that have occurred for the wheels, tabletop, frame, and storage. Changes in design are primarily articulated through SolidWorks. Prototypes are included. The section then discusses the current state of the system manufacturing process.

11.2.1 Revision 0: SEM1

The first iteration of the design focused on the tabletop and on the storage area. After consulting with the client, the chosen wheels are pneumatic tires.

11.2.2 Tabletop

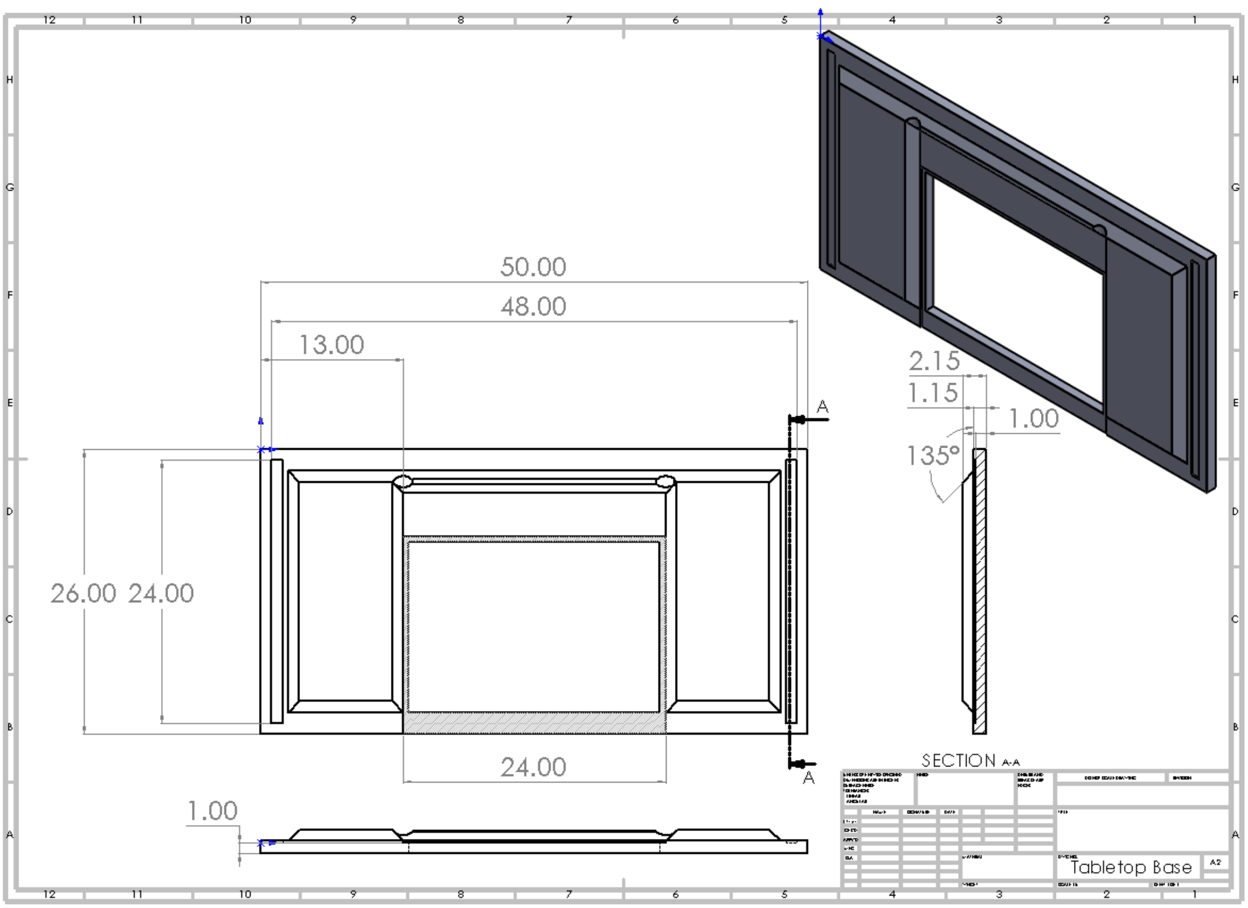

Figure 25: Tabletop REV0

The tabletop for the original design has the horizontal dimensions of the clean room hood that it supports.

The design features platforms for the devices to rest on so that they are protected from spills, a polycarbonate workspace for x-ray compliance, and grooves for the clean room hood to rest in. The dimensions are tight with the clean room hood to ensure easy maneuverability and fitting through doorways. The platforms protect devices from workspace spills. The workspace is polycarbonate so that the tabletop is x-ray compliant. The grooves support the clean room hood so that the clean room hood does not fall, improving operational and portability safety.

11.2.3 Storage

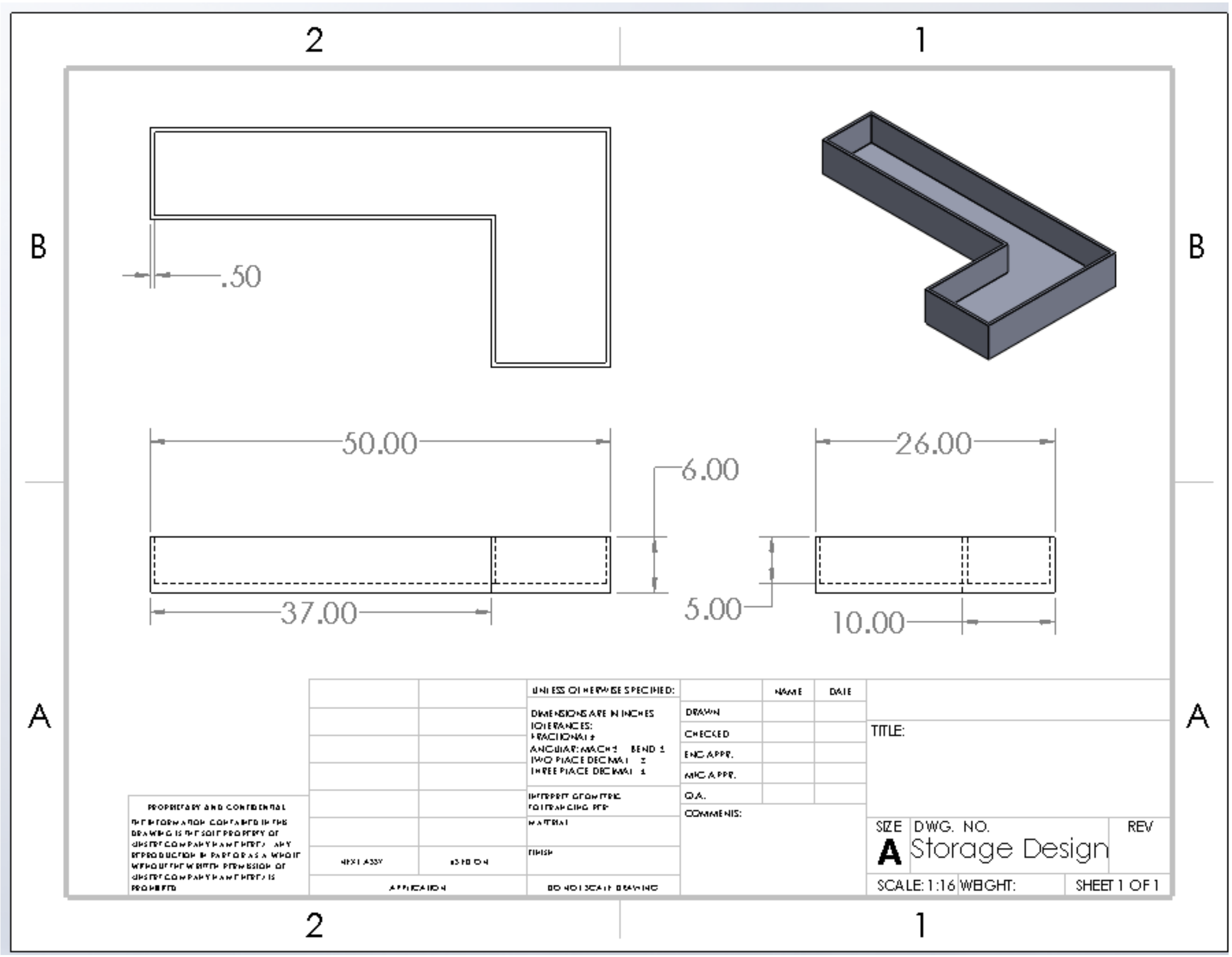

Figure 26: Storage REV0

The original storage design is L-shaped to provide leg-room for the bench to additionally be used for a desk. There is adequate storage for the medical devices required from Dr. Becker. The storage area is also dimensioned so that if there is a leak around the polycarbonate workspace, the spill does not enter the storage area.

11.2.4 Revision 1: SEM1

This section describes the final design for the first semester, comparing it to the original design. Client requests for this revision include increasing the tabletop length to six feet, employing a different type of shock absorbing tires, and providing storage specifications. The design is illustrated through SolidWorks 3D modelling, and through prototypes of some of the design's particular aspects. The final design is communicated by first describing the tabletop, storage, and shock absorption components, then presenting the design as a full assembly, to show how the components fit together with the table legs, and to explain aspect placement.

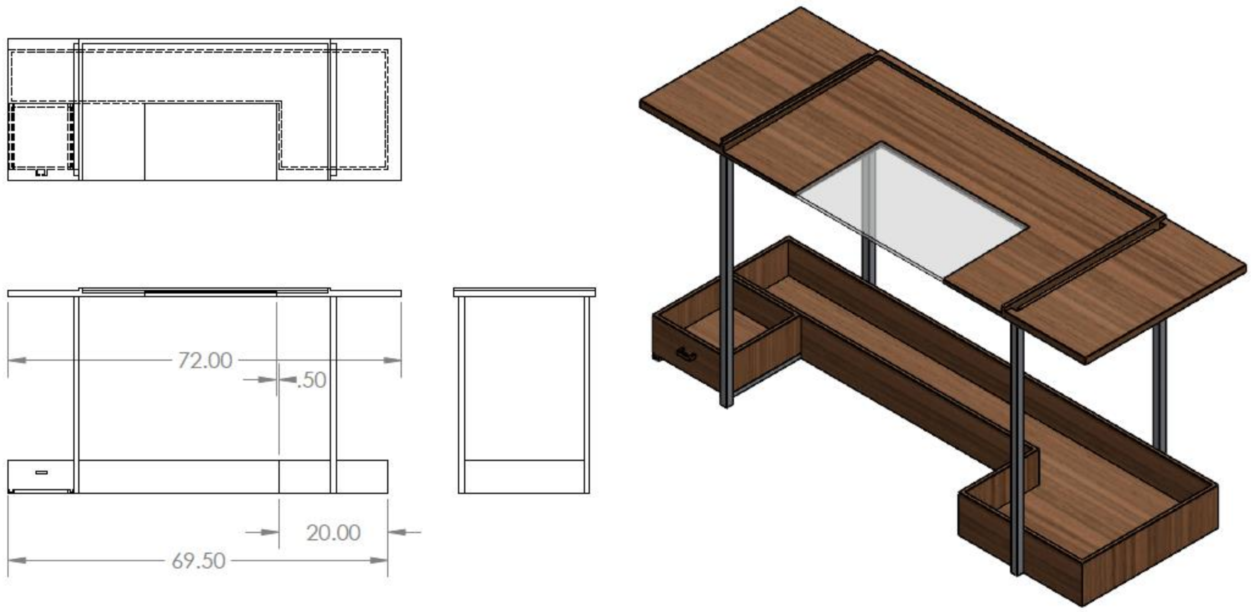

Figure 27: Final Design First Semester

The SolidWorks assembly, shown in Figure 27, depicts the tabletop, with the polycarbonate workspace, fitting together with the storage area and the placement of the table legs. The placement of the table legs is pre-determined by the clean-room hood. The clean-room hood weight will be diverted to the legs, and it reduces the amount of stress on other areas of the tabletop or beams to place the legs directly under the corners of the clean-room hood frame. The aerial view depicts the storage area being separated from the workspace, in case of leakage in the seal. The aerial and front views show that the storage has a shorter length than the tabletop on the right side, but is flush with the tabletop on the left side. The side view shows that the tabletop extends farther than the legs, but that the storage area is contained within the dimensions of the table legs. Polyurethane foam tires are attached to the bases of the legs for shock absorption. This selection was instructed from the client, and has changed from the suggested pneumatic tires from REV0. The polyurethane foam wheelbarrow tires will not deflate or flatten.

11.2.5 Tabletop

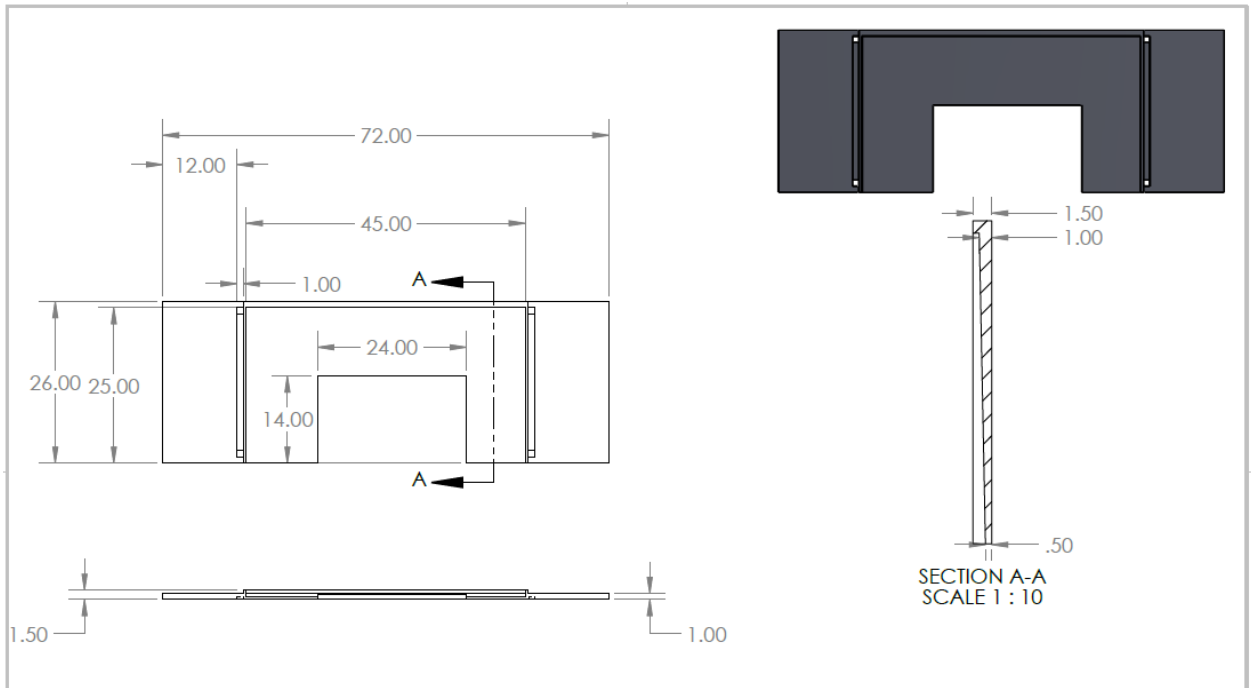

Figure 28: Tabletop REV1

Figure 28 depicts the first semester final design for the tabletop, with measurements in inches. The polycarbonate workspace is attached to the 14”x24” area in the center of the tabletop. This area corresponds to the clean-room hood workspace access. Polycarbonate does not span the entire tabletop because it is not sturdy enough to support devices or normal desktop live loads without movement. The deflection relies inversely on Young’s Modulus, measuring elasticity, and the value of Polycarbonate is too low, around 10^6psi, to allow for a low deflection at such a thin workspace. The workspace area may have to be reduced if, during testing, the polycarbonate is determined to be too flexible for its thickness. A different material is used for the rest of the tabletop because it should be a material that does not require reinforcements across the workspace area, to minimize x-ray videography/imaging interference. The tabletop is made 1.0” thick so that it does not interfere, geometrically, with the x-ray machine, which should reach as close to the top of the workspace through the thickness of the workspace as possible. This thickness has not changed during past revisions. The 25”x45” workspace area in the middle of the tabletop is contained within the clean-room hood area. It features a tilt for liquid spill drainage as shown in Section Cut A-A of Figure 4. This differs from the prior revision, shown in Figure 1, which does not feature the tilt, and instead uses elevated platforms to protect the devices from spills. The tilt is 0.5” downward from the back of the workspace to the front of the workspace and was added as such per client request. The workspace also features a containing spill guard, protecting the clean-room hood grooves from spills, and containing spills from falling behind the cart. This was also featured in the previous revision. The clean-room hood grooves provide an area for the clean-room hood to be placed into. The clean-room hood will be removed or attached by two people, placing it down onto the table, per client instructions, and will not slide off of the table. This was made clear early in the process and has not changed during revisions. The last change to the tabletop from the prior revision is an increase in table length to 72”, per client request. This length is added to either side of the workspace, keeping the clean-room hood centered on the tabletop.

The tabletop prototype, shown in Figure 29, is a 3D printed 1:14 scale model of the final SolidWorks design. The prototype provided a visualization for the thickness of the table relative to its length and width. It showed that the thickness will be sufficient relative to the placement of the supports (legs), but that the tabletop thickness will be insufficient to support any of the weight of the clean-room hood. The clean-room hood weight should be placed completely onto the table legs, so a hole was employed through the table, at the ends of the clean room hood and to direct its weight directly to the legs, with no stress supported by the table. These holes are shown in Figure 29.

Figure 29: Prototype Tabletop REV1

11.2.6 Storage

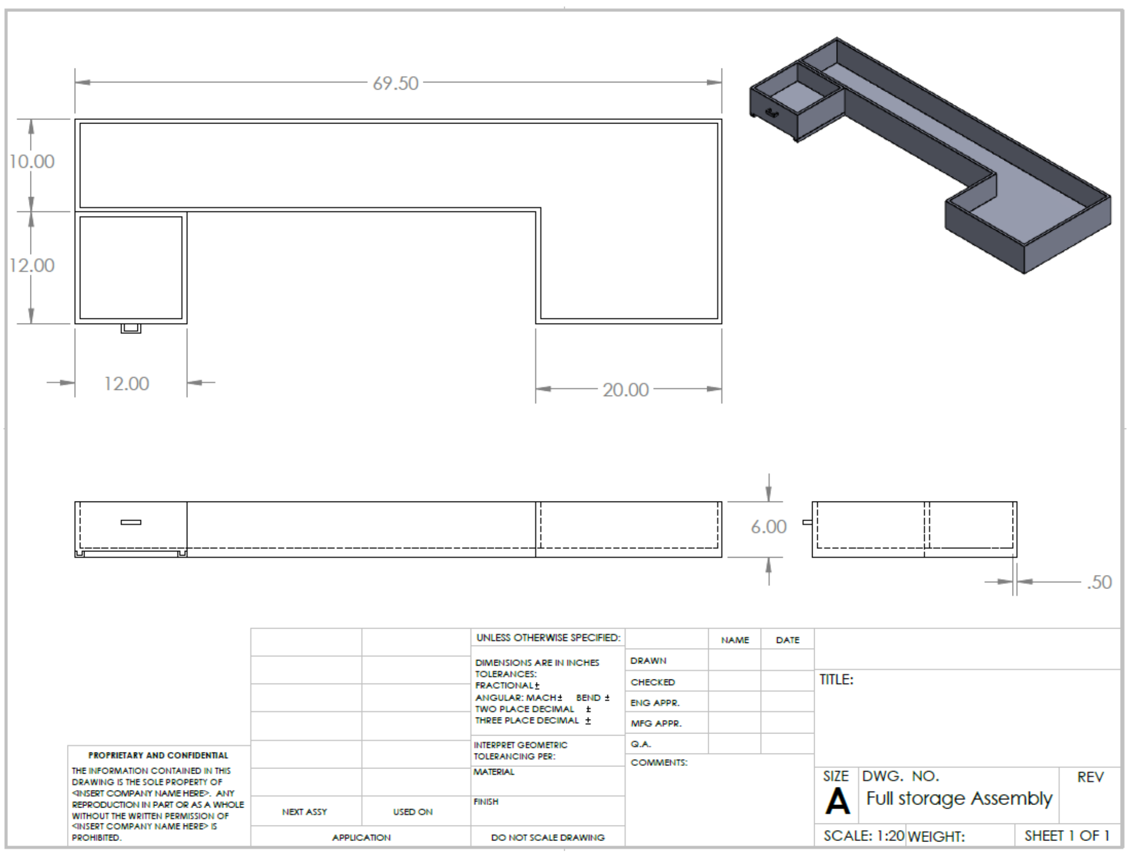

Figure 30: Storage REV1

Figure 30 depicts the first semester final design for the storage, in inches. The U-shape design was chosen for the storage area, so that the cart could be used as a desk with space for sitting. Moreover, this space is necessary to allow for the x-ray machine to fit directly beneath the workspace for videography and imaging. The storage area is almost six feet, the length of the table, but the reasons for its specific dimensions were provided by the client for this revision, an update from the Preliminary Report design, shown in Figure 13. A drawer for office supplies, requested by the client, pulls out for accessibility, and is shown in Figure 12 to be 12”x12”, enough area for office supplies. Its width is the distance from the location of the legs to the edge of the tabletop. It would not be appropriate to extend any of the storage area past the dimensions of the tabletop, due to accessibility and safety issues, aesthetics, and to provide a way to attach a laminate film for clean-room effect within the storage area during transport. The height of the back-most area in the L-shape storage shelf, 10” in the figure, is determined by keeping the storage within the confines of the table legs, and the back of the workspace. It is not susceptible to being leaked on if the workspace leaks where it is sealed; this precaution was emphasized by Dr. Becker. Similar precaution is taken for the storage area on the right, the larger portion of the L-shaped area, shown as 20” wide in the figure. It is dimensioned to be placed right of the above tabletop workspace, but is also centered between the right table legs, so that the storage is balanced. The changes from prior revisions include a wider length, to match the tabletop, and a wider storage area on the right side of the L-shape. The storage area has also been dimensioned to regard the tabletop and legs, since the dimensions for the tabletop have been further verified by the client.

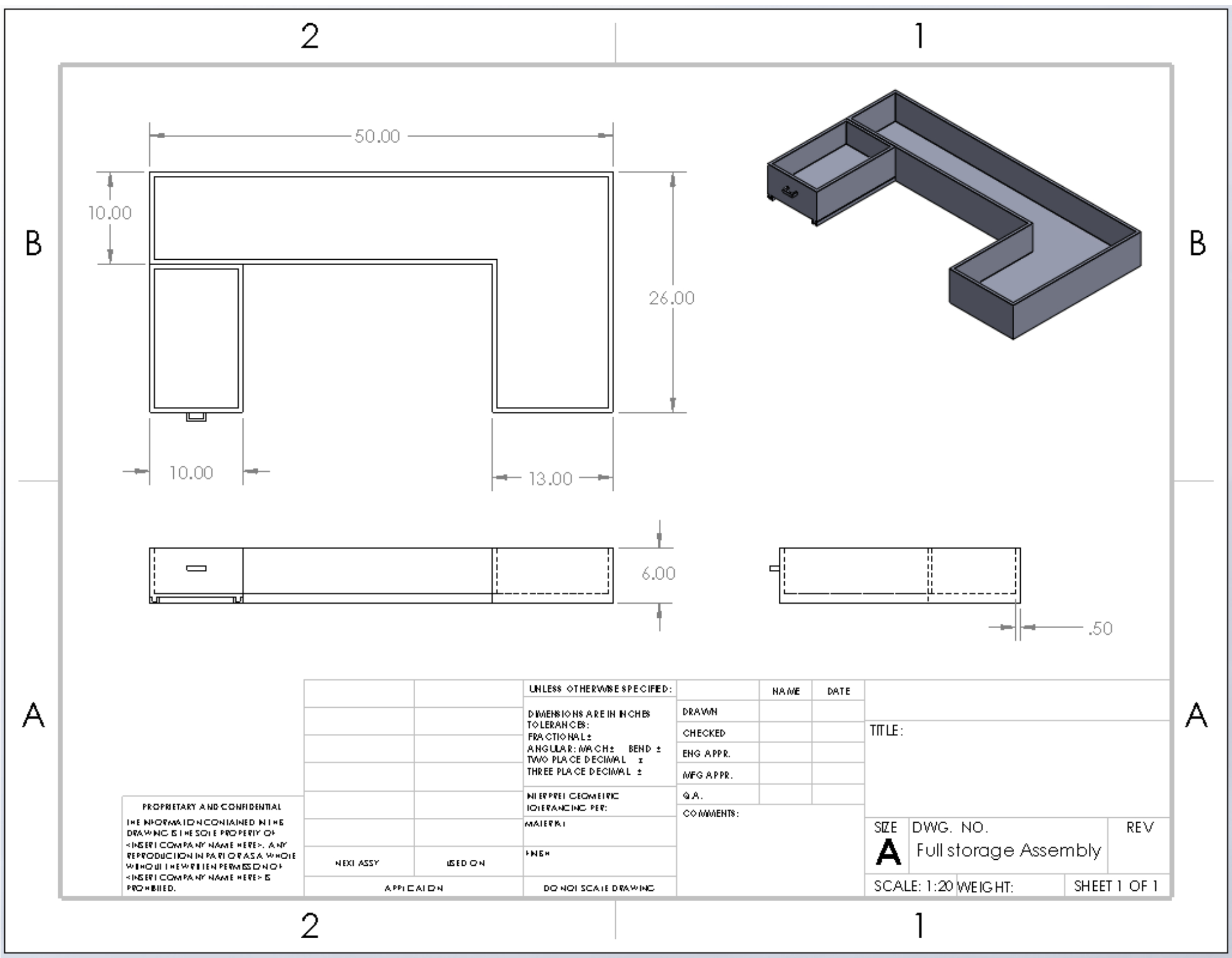

Figure 31: Storage REV0

The storage prototype, shown in Figure 32 below, is a 1:3 scale foam board construction of the final SolidWorks design. Seeing the proportions of the different areas in the storage assembly allowed visualization of what medical devices would be placed in each region. The largest region, the right-most area, will most likely hold the heaviest equipment. Because it will hold the heaviest and largest devices and equipment, that storage area should be balanced between the rightmost legs to allow for balance and equal support.

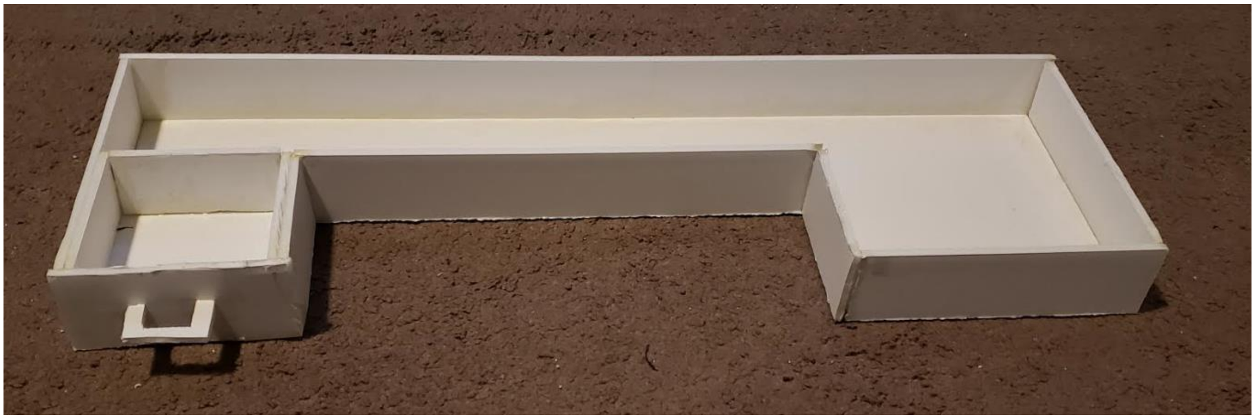

Figure 32: Prototype Storage REV2

The prototype shown in Figure 33 is constructed of wood to 1:3 scale of the design. It displays how the storage aligns with the tabletop, and how both are aligned with the legs. The prototype shows the position of the polycarbonate workspace relative to the tabletop and the storage area. The storage area is not enclosed, so that cords may go from the storage area to the tabletop. The storage is not centered with the tabletop, but instead is appropriately aligned with the polycarbonate workspace and necessarily balanced to be centered between the front and back legs. The clean-room hood frame is to be positioned directly above the legs of the table.

Figure 33: Prototype 2

11.2.7 Revision 2: SEM2

Revision 2, starting in Semester 2, began by providing the clients Dr. Oman and Dr. Becker with the following options, Figures 34 to 37, to determine the best attributes for the bench. The main options shown are to decide on the width of the frame, whether the width should be the same as the clean room hood for maximum support, or whether the width should accommodate the air filter width for storage during transport. The issue is that the horizontal dimensions of the air filter match those of the clean room hood.

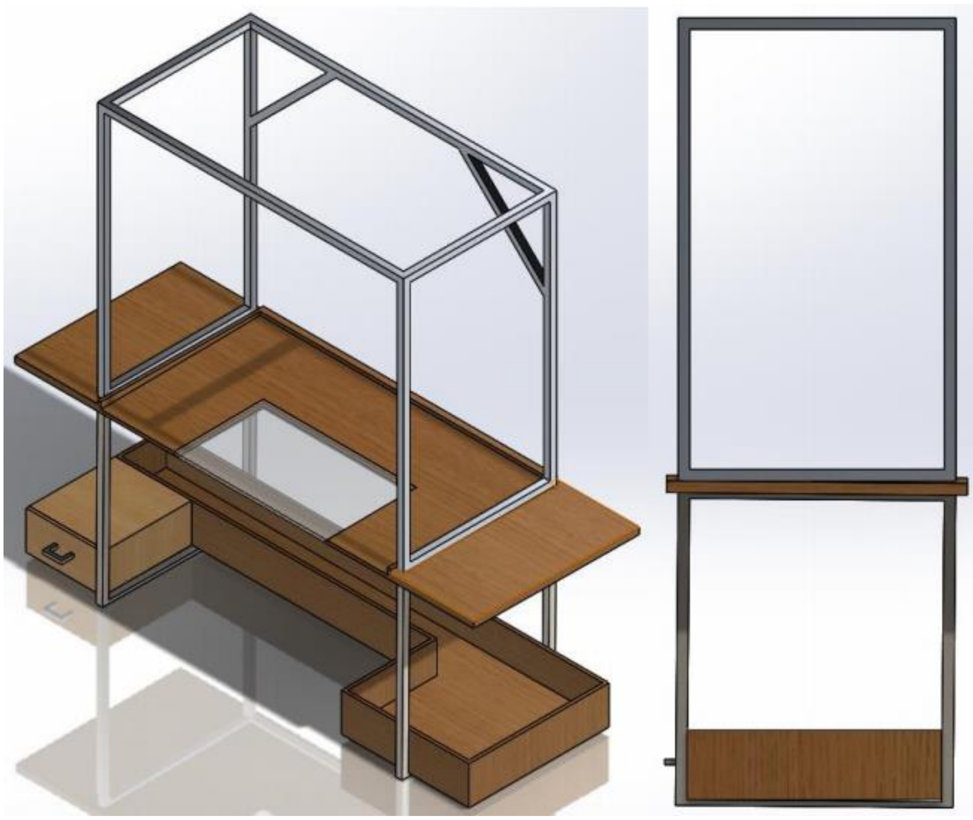

Figure 34: SEM2 Options: In-Line with Clean Room Hood, No Air Filter Support

Figure 35: SEM2 Options: In-Line with Clean Room Hood, shown with Air Filter Dimensions

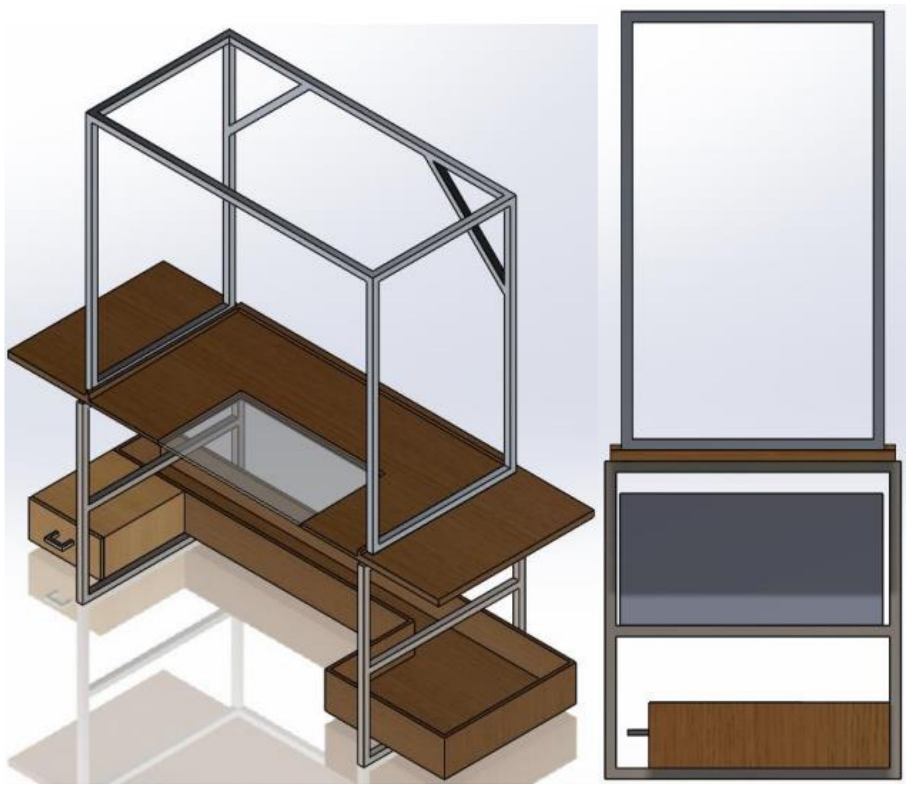

Figure 36: SEM2 Options: Wider than Clean Room Hood, shown with Air Filter Dimensions/Support

Figure 37: SEM2 Options: Frame Width Options with and without support

The options presented to the clients determined the following characteristics for the portable medical bench. The frame should definitely feature air filter storage for transport, as shown in Figure 36, so the frame is widened and support shelves are added. Dr. Oman suggests adding in triangular supports. The final frame design includes the Bolt Plates, detailed in Figure 38. Because this is the frame design used for manufacturing, all dimensions are specified and the Bolt Plates for wheel attachments are included. The frame includes the tilt, as during the meeting the client preferred the frame to have a tilt instead of the tabletop itself. Dr. Becker indicated a preference for 1” tilt downward from back to front. The tabletop will be attached to the frame with brackets.

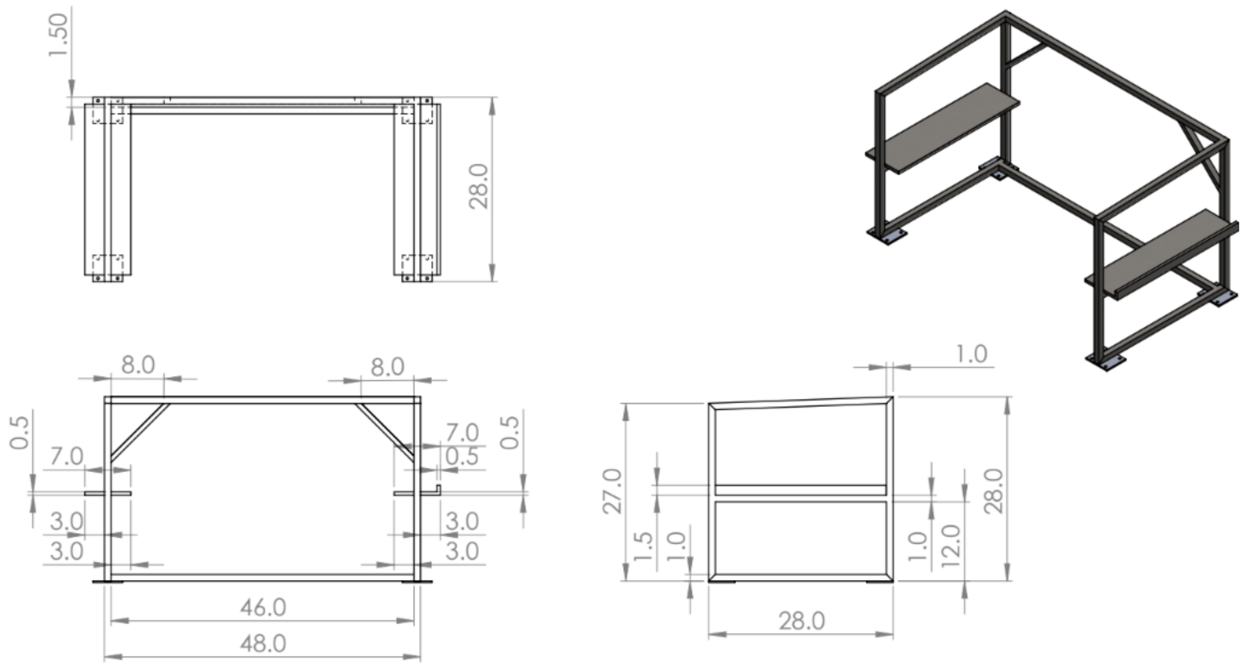

Figure 38: Frame: REV2

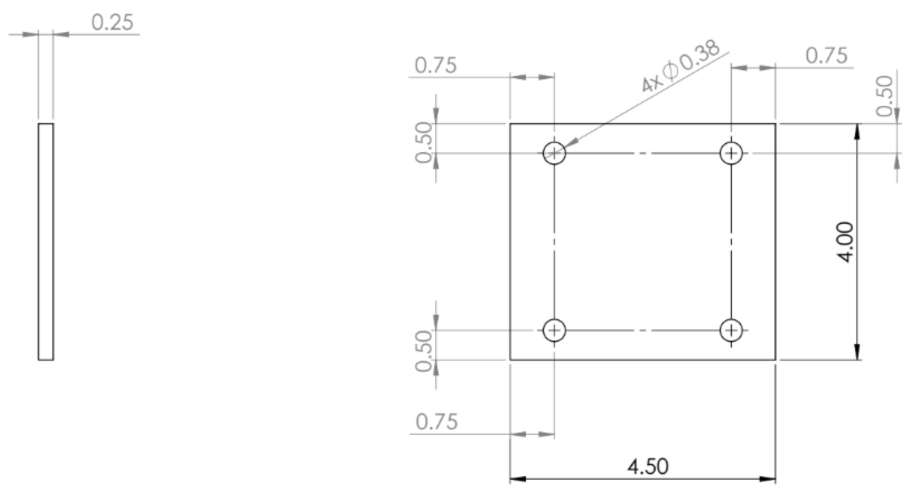

Figure 39: Bolt Plate: REV2

The tabletop design was changed almost entirely, no longer featuring a polycarbonate workspace. Instead, for x-ray compatibility and spill-safety, the workspace is constructed of Formica. All features are removed from the tabletop, and the result is shown in Figure 39. Additional features added to the tabletop are shown in the following Figure 40.

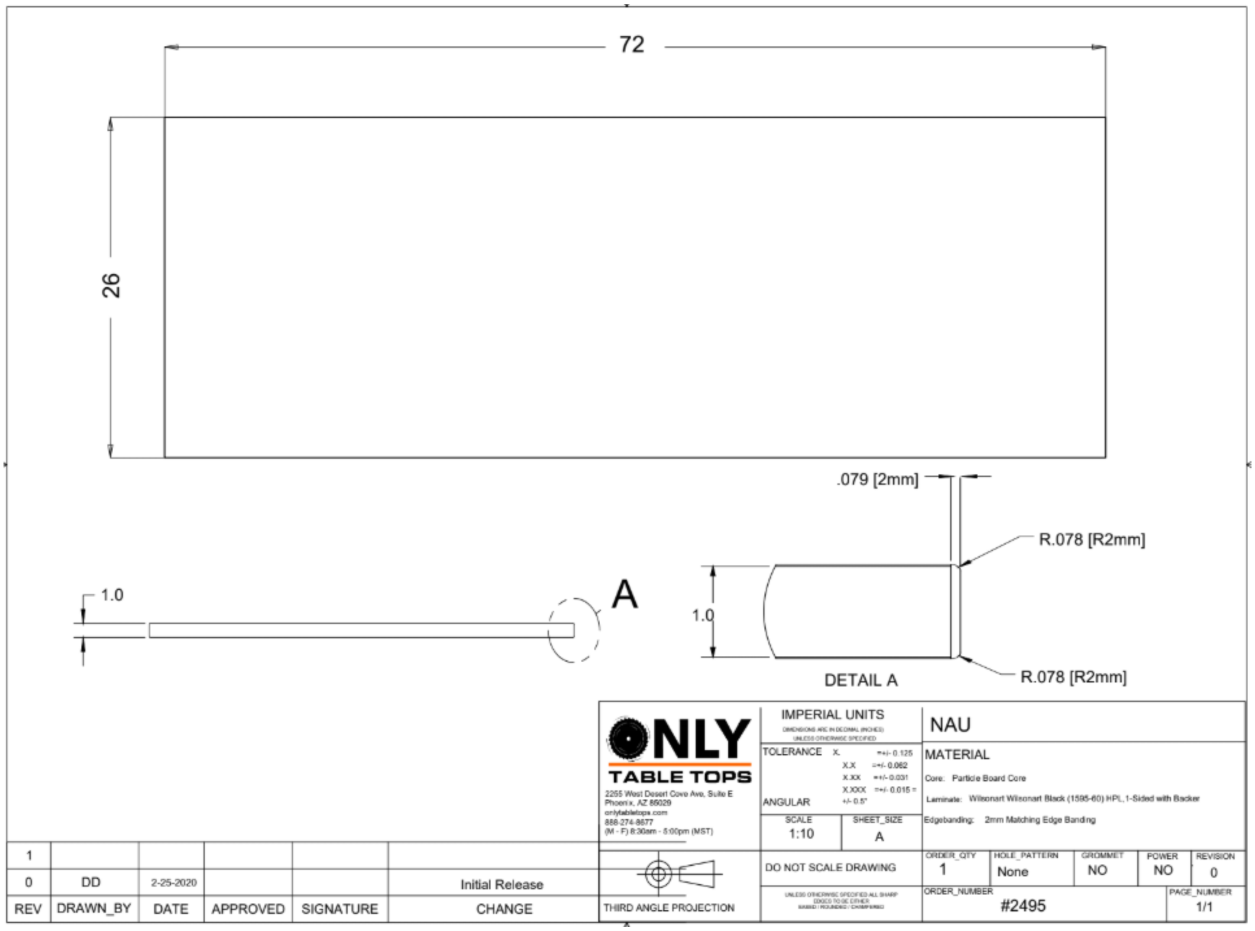

Figure 40: Tabletop: REV2

During the meeting, Dr. Becker indicated preference for a gutter tray, shown attached to the tabletop. The tabletop will have a wedge or support attached at the front of the tabletop beneath the clean room hood so that the workspace will feature a tilt for spills, but the clean room hood may still sit flat. Additional spill guards are attached to the tabletop, outside of the clean room hood so that they do not interfere with the clean room hood polycarbonate. The following Figure 41 also illustrates the dimensions of the medical devices that are stored on the portable medical bench. The tires approved by the client are shown in the figure as well.

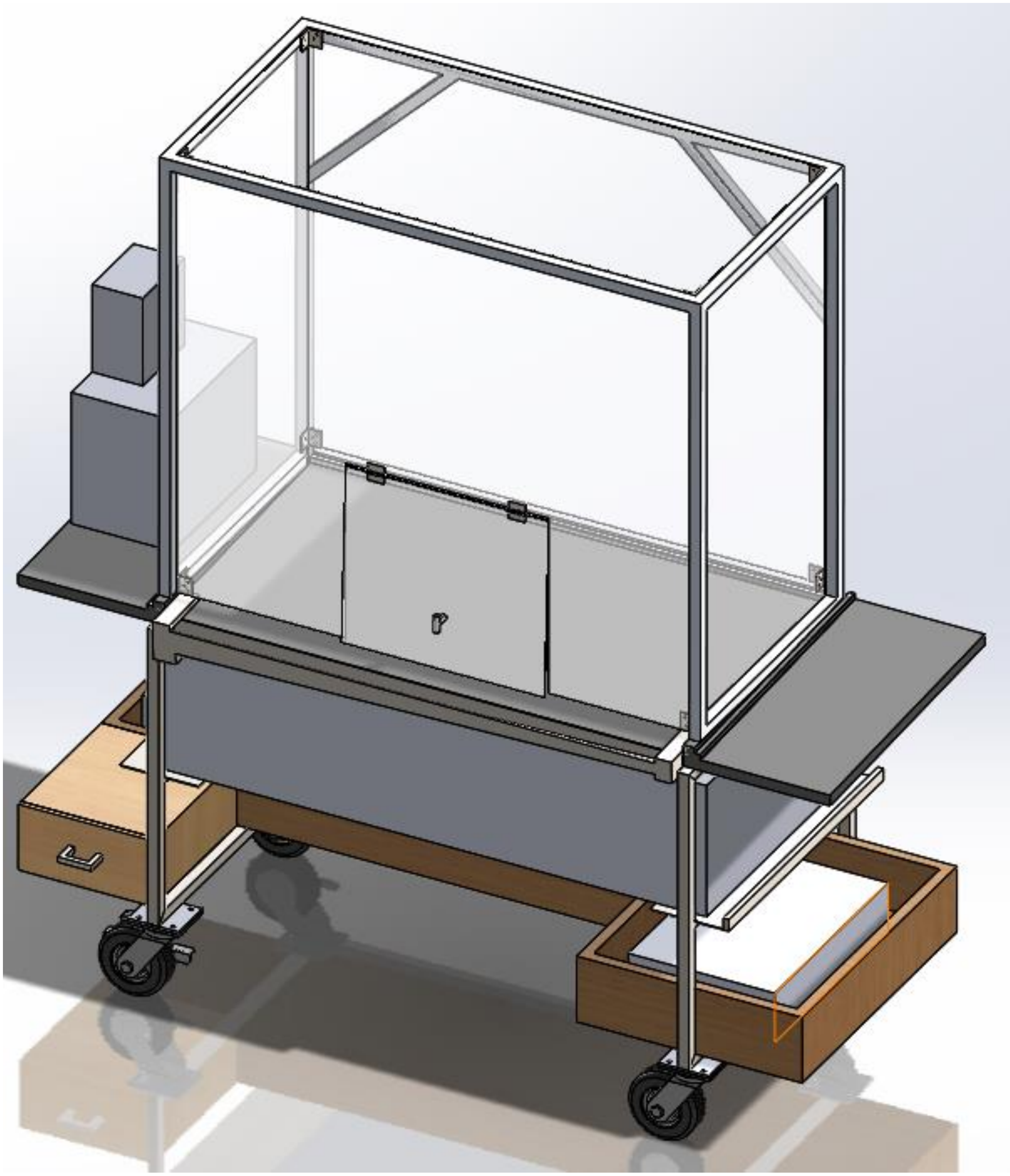

Figure 41: Assembly: REV2

The following Figure 42 shows the current state of the storage assembly. Its construction, and relative change, is detailed in the prior section. It is shown as part of the assembly in the previous Figure 41.

Figure 42: Storage: REV2

11.3 Implementation – Weeks 7-11

In the recent weeks, the team has made an abundance of progress towards the completion of the bench. The components of the bench have been completed. Getting the wedges manufactured and then assembling the bench is all that is to be completed. For the wheels, the team ordered to the specifications that Dr. Becker desired. The steel for the frame was ordered and welded by the team. The manufacturing for the tabletop has been completed and picked up by the team. The only major design changes made by the team came in the frame. The frame material had to be changed due to high costs of stainless steel. Also, the team intended to send out the frame to be welded but ran into budget constraints, so the welding was done in house. Also, the supports for the filter were made smaller to decrease total bench weight.

11.3.1 Manufacturing

11.3.1.1 Tabletop

Dr. Becker required the tabletop to be x-ray compatible and spill-preventing. The team decided to use a manufacturer for its completion. The team got in contact with the company *Only Table Tops*. The team gave the dimensions of the table and selected the material. The team decided to have the tabletop be made of Wilsonart in order to be x-ray compatible. The team also had the sides of the table rounded as per client preference. The tabletop was recently completed and received by the team. Analysis was carried out in excel in order to verify that the tabletop could support the loads it would be carried.

11.3.1.2 Frame

The frame's design has been slightly altered from last semester. The supports made to hold the filter have been made smaller to decrease the weight. The team wanted to use stainless steel but due to high cost could not do so. The steel needed to make the frame was ordered and received by the team. The team welded the pieces together to make the frame. The wheels were attached to the frame. Analysis was performed in excel and solidworks to make sure that the frame could hold the loads it would be carrying, and for estimating the total weight of the frame, as the team wanted to keep the frame as light as possible without compromising strength.

11.3.1.3 Storage

The design of the storage has not been changed much since last semester. The storage was intended for equipment needed by Dr. Becker and his team during experiments. The team altered the dimensions slightly in order to fit the devices. The team purchased the wood needed at a hardware store and built the storage on their own using a table saw and nails. The storage has been assembled. Dr. Becker requested that the storage not be attached to the frame and that the storage be black to match the tabletop. Analysis was carried out in excel to make sure that the storage would be strong enough to hold the medical devices stored within it.

11.3.1.4 Wheels

The wheels were chosen by Dr. Beker. He wanted wheels that would reduce the shock of transport and have two of the wheels be locking. The wheels were ordered and have now been received by the team. The wheels have since been attached to the frame. Analysis was performed in excel to make sure that the correct grade of bolts were selected for the wheels to be attached to the frame.

11.3.1.5 Tabletop Wedges

The wedges have been designed and material was ordered in order to manufacture these wedges with a CNC plasma cutter. These have since been put on hold and at the moment, the team is unsure if they will be made. The team decided to go with steel material in order to make them durable.

11.4 Design Changes -Weeks 7-11

The following will show some of the design changes made by the team for the tabletop, frame, and storage.

11.4.1 Design Iteration 1: Change in Tabletop discussion

For the tabletop, the design changed from square edges to rounded edges at the request of the client. This is to eliminate sharp edges. The client also specified a color of black and that change was made.

Figure 43: Tabletop preliminary design.

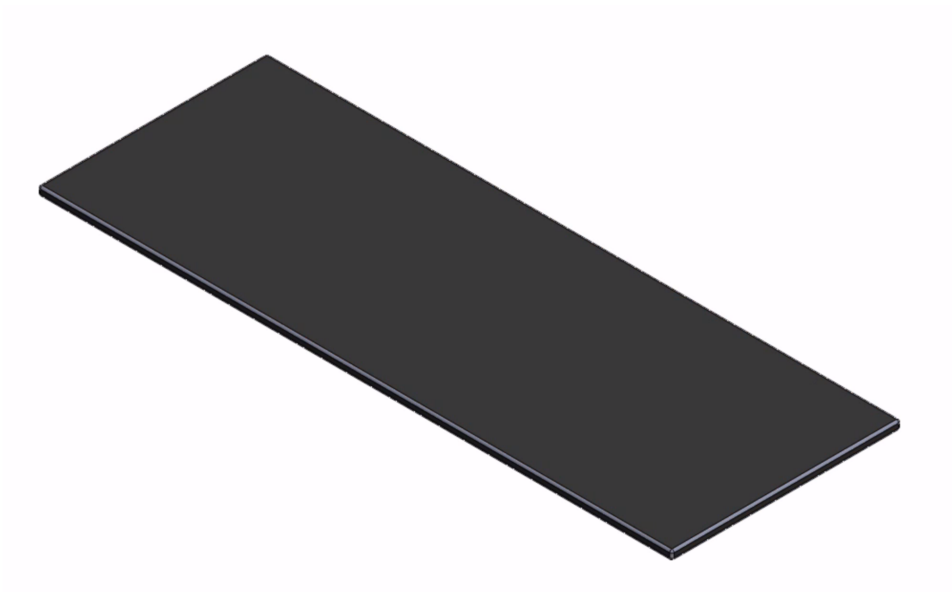

Figure 44: Tabletop final design.

11.4.2 Design Iteration 2: Change in Frame discussion

For the frame, the design changed from stainless steel to low carbon steel in order to save money. The team also added structural components to the frame after analysis in SolidWorks. Also, the shelves were reduced in size due to overdesign and weight concerns. Lastly, a frame component on the bottom was moved slightly in order to be able to weld a plate for bolting the wheels to the frame and fit the bolts. Those changes will be reflected below.

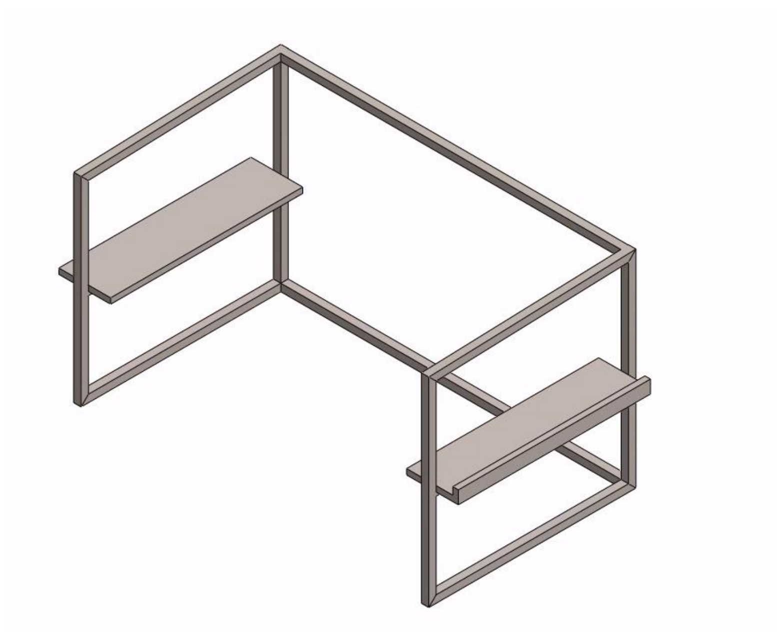

Figure 45: Frame Preliminary Design

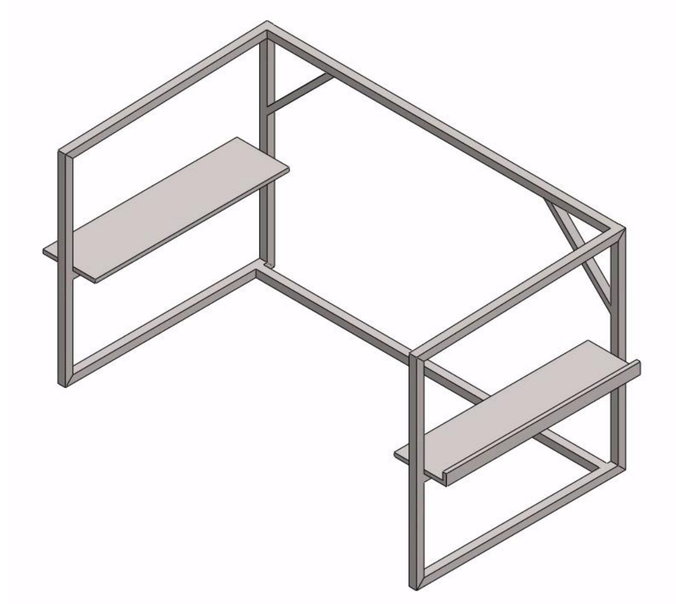

Figure 46: Frame Final Design

11.4.3 Design Iteration 1: Change in Storage discussion

The storage design originally had 1” thick wood but was changed to 0.5” wood for practical and cost reasons. This was analyzed with excel to ensure that 0.5” would be strong enough. The drawer slides were omitted because of the drawer being so small. Also, the hardware was changed from a handle to a simple knob. These changes were reflected below.

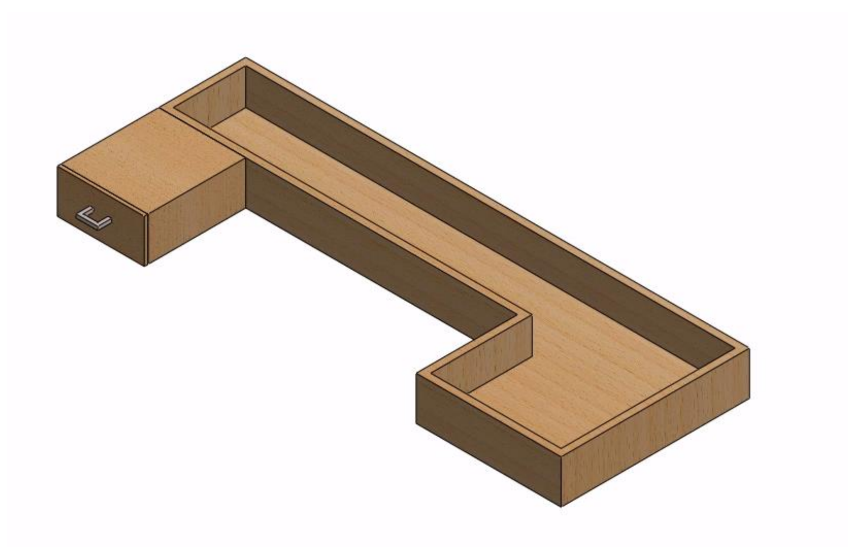

Figure 47: Storage Preliminary Design

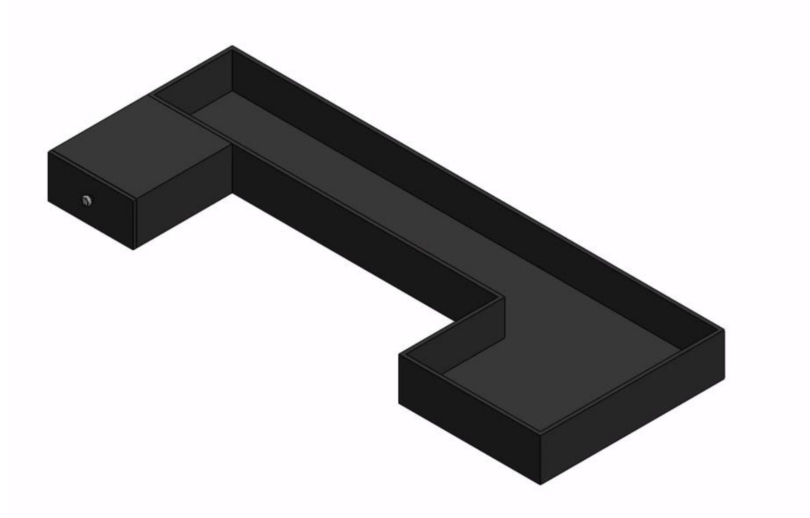

Figure 48: Storage Final Design

12 RISK ANALYSIS AND MITIGATION

12.1 Potential Failures Identified Fall Semester

In Table 2, *S* is Severity, *O* is Occurrence, *D* is Detection, and *RPM* is Risk Priority Number. In Semester 1, three subsystems were analyzed for potential failure in the design. These subsystems are the tabletop, storage, and wheels design. Within the tabletop design, the raised platform, drainage, and zip tie concepts were considered. The storage design included the U-shape and drawer concepts. The wheels design considered the polyurethane concept. The ranking system was based on a 1-9 numerical scale. The scaling was evaluated by 1-2 being considered very low occurrence, 3-4 slightly likely, 4-5 likely, 6-7 above average, and 8-9 very concerning. The following sections discuss each potential critical failure.

Table 14: FMEA Analysis

Part	**Failure**	**Effects**	**S**	**Cause**	**O**	**Test**	**D**	**RPN**	**Recommendation**
Wheels	Corrosive Wear	No Transport	9	Over Stressing	5	Wear	5	225	Material
Spill Guard	Chemical Spill	Spills	7	Maintenance	7	Chemical	5	245	Material
Zip Ties	Deformation	Devices loose	8	Over Stressing	7	Stress	6	336	Thickness
Drainage	Chemical Spill	No waste disposal	7	Chemical Wear	6	Chemical	5	210	Material
U-shape	Impact wear	Broken Storage	6	Impact Loading	6	Impact	6	216	Cushion
Drawers	Impact wear	No Storage	6	Impact Loading	6	Impact	6	216	Cushion
Bolts	Breaking	No Transport	9	Strength	5	Strength	5	225	Choice
Wedges	Unbalance	Derailment	8	Unbalance	7	Stress	5	280	Clamps
Gutter Tray	Detachment	Spill/weakness	7	Loose Clamps	8	Strength	5	280	Clamps

Handle	Detachment	Table Falling	9	Shear	5	Strength	5	225	Strength

12.2 Risk Mitigation

Potential Critical Failure 1 : Polyurethane Wheel→Flat-Free Rubber Tire

The polyurethane wheel was introduced through client suggestions. It was introduced due to it having a non-flat design. The potential failure of the tire was determined to be corrosive wear. The potential effects of this failure include not being able to transport the bench. The severity of this potential failure was ranked a 9. This failure was mitigated by reconsidering the tire to instead be a flat-free rubber-treaded tire chosen by Dr. Becker. The new chosen tires are replaceable if they do fail. Additionally, they are rated to support 250lbs each. A new risk has been introduced, discussed as Potential Critical Failure 11.

Potential Critical Failure 2: Raised Platform→Spill Guards

The raised platform concept was designed to prevent spills. The potential failure occurs from direct chemical attack. The potential effect of failure would have spills occurring. The severity of this occurring was ranked as a 7. This failure was mitigated through proper material selection, steel, of the wedges that provide spill protection. It is compatible with the chemicals used in sanitation. Proper material of the tabletop was also chosen to be compatible with the chemicals. A new risk has been introduced, discussed as Potential Critical Failure 12.

Potential Critical Failure 3: Zip Ties

The zip tie concept was designed to secure the medical devices on the tabletop. The potential failure occurs from deformation wear of the zip ties rubbing against the tabletop material. The effects of this failure include the devices not held in place. The severity of this failure was ranked as an 8. These failure effects were mitigated by providing storage for most of the devices during transportation, including the air filter. The failure effects not mitigated are that the devices' wires may not be secure, but zip ties can be replaced. The current state of Zip Ties is that the tabletop will not have access to any of the devices before the semester's end, so the team cannot secure the devices' wires. The Zip Ties as provided by the team are cancelled, but can easily be added to the bench by a lab assistant. No new risk was introduced.

Potential Critical Failure 4: Drainage

The potential failure occurs from direct chemical attack. The effect of this failure is an improper disposal of waste. The severity of this failure was ranked as a 7. This failure was mitigated through proper material selection and through a gutter tray system. This system will not be completed by the team, but can be manufactured in the future by the client or a lab assistant. It could be easily attached through clamps to the tabletop. A new risk has been introduced, discussed as Potential Critical Failure 13.

Potential Critical Failure 5: U-Shape

The potential failure occurs from impact wear. The effect of failure is lack of use of storage. The severity was ranked a 6. This failure was mitigated by increasing the support of the storage by the frame to strengthen the storage base. The storage is also removable, in case it needs to be replaced due to damage. No new risk was introduced.

Potential Critical Failure 6: Drawers

The drawer concept was introduced to maximize space for storage without taking away space for the medical devices being stored under the tabletop. The potential failure occurs from impact wear. The effects of this failure are lack of use of storage. The severity of this failure was ranked a 6. The failure was mitigated by embedding the drawer into the storage area to reinforce its strength. The number of drawers was reduced to one and its size was greatly reduced. It is mainly to be used for office supplies, further reducing the risk. No new risk was introduced.

Potential Critical Failure 7: Single Handle

The single handle was introduced by the project's client as a preference. The potential failure occurs from corrosive wear. The potential effects of this failure are difficulty transporting the bench. The severity of this failure was ranked a 5. This failure was mitigated by planning to have the handle be constructed of chemically-resistant material such as steel. The handle will not be completed this semester. Not including a handle introduces a new risk, discussed as Potential Critical Failure 14.

Potential Critical Failure 8: Inclined Tabletop

The inclined tabletop concept was designed to assist in directing spills. The potential failure occurs from direct chemical attack. The potential effects of this failure could cause spills to seep into the devices on the tabletop. The severity of this failure was ranked a 9. This failure was mitigated through proper material selection that is compatible with the chemicals used in sanitation. An additional risk was identified - an uneven tabletop workspace if it were to be utilized. This risk was mitigated by tilting the frame instead of angling the tabletop surface. This risk was mitigated so no new risks were introduced.

Potential Critical Failure 9: Polycarbonate Workspace

Polycarbonate was used for the material because it is x-ray compatible. The potential failure occurs from deformation wear. The potential effects of this failure could distort the x-ray imaging needed during treatment. The severity of this failure was ranked an 8. This failure was mitigated by removing the polycarbonate workspace from the design.

Potential Critical Failure 10: Polycarbonate Workspace

The grooves were designed to hold the hood in place. The potential failure occurs from deformation wear. The potential effects of this failure could result in the hood not being secure. The severity of this failure was ranked as a 7. This failure was mitigated by removing the polycarbonate workspace from the design.

New Potential Critical Failure 11: Wheel Bolts

The wheel bolts are required for attaching the wheels to the frane. The potential failure occurs from the wheel bolts breaking by not being strong enough. The potential effects of this failure could result in not being able to transport the bench or even collapsing the entire bench and breaking the devices. The severity of this failure was ranked a 9. This failure was mitigated by choosing the correct wheel bolts that have the necessary strength to not break.

New Potential Critical Failure 12: Wedges

The wedges are used to level the support of the clean room hood, since the tabletop is resting on a tilted bench frame. The potential failure occurs from the clean room hood not being properly attached to the wedges, from the wedges not being properly adhered to the tabletop, and from the adhesion not being strong enough. The potential effects of this failure could result in the clean room hood derailing from the wedges. The severity of this failure was ranked as a 8. This failure can be mitigated by attaching the clean room hood to the wedges with clamps, or a track. This failure is also mitigated by properly, permanently adhering the wedges to the tabletop.

New Potential Critical Failure 13: Gutter Tray

The gutter tray is to catch, contain, and direct any spills from the tabletop. The tabletop is tilted to direct the spills to the gutter tray, especially large spills that would otherwise puddle onto the floor. The potential failure occurs from the gutter tray not being strongly attached to the tabletop, and the spill consequently not being caught by the gutter tray. The severity of this failure was ranked as a 7, similar to other potential critical failures having to do with chemical spills. This failure can be mitigated by attaching the gutter tray to the tabletop with strong, locking clamps. The gutter tray will not be constructed by the team this semester.

New Potential Critical Failure 14: Handle

The handle was designed to move the bench. Until there is a handle, the bench will be maneuvered by pushing and pulling on the tabletop. This can lead to the attachments of the tabletop to the frame failing by shear. The severity of the tabletop falling is ranked 9. This failure can be mitigated by making sure the tabletop attachments are strong enough until the handle is installed. The handle will not be constructed by the team this semester.

13 TESTING

The following table shows the engineering requirements that were necessary for the design to meet. The budget only exceeded the original target by an approved amount. The shock absorption method was using wheels specifically chosen and approved of by the client, so the shock absorption was approved. The tabletop thickness was controlled by the company that the commission of the tabletop was done through, so the thickness tolerance was met. The bench height was met by calculation, but the tabletop was not constructed so this is only hypothetical. The required storage volume was achieved by calculation and by measuring the storage capacity to what the client had instructed the medical devices would require, but the devices were never placed into the storage and so the storage volume required was met only by calculation. The other testing procedures were not carried out due to shutdowns and restrictions, as well as not being able to construct the bench together. These requirements are the weight tolerance, bringing the bench to Wettaw to fit it through the doorways along its path, testing the tabletop yield strength and deflection with weights, measuring the actual tabletop thickness and bench height, placing the devices into the storage area while it is attached to the frame, and ensuring it has temperature resistance to the generator and hot plate. Lastly, the team was not able to construct the gutter tray and handle, which are needed to test the drainage capabilities of the bench. Because the testing procedures were not carried out, there were no design changes due to test results in this semester.

Table 15: Engineering Requirements

Engineering Requirement	Units	Target Value	Tolerance	Met?
Cost	$	1000	+/- 100	Approved
Weight	lb	150	+/- 10	Test
Fitting Through Doorway	ft^2	7.5	+/- .1	Test
Tabletop Yield Strength	psi	5	+/- 1	Test
Effective shock absorption	in/s^2	5	+/- 5	Approved
Tabletop Deflection	in	0.25	+/- .05	Test
Tabletop Thickness	in	1.00	+/- 0.10	Met
Bench Height	in	36.00	+/- 0.10	Met
Storage Volume	ft^3	5	+/- 1	Met
Temperature resistance	°F	50	+/- 50	Test
Liquid Drained	%	80	+/- 10	Test

14 FUTURE WORK

Future work for this project must begin with finishing the testing procedures. Unfortunately, the team was unable to complete the desired tests. The testing procedures are imperative in determining if the design meets the engineering and client’s requirements. After testing procedures are complete, changes to the design can be made to improve it.

15 CONCLUSIONS

The report describes Aneuvas Technologies, Inc. and their purpose for contracting a portable medical bench. The client requires a medical research device table that is compatible with x-ray imaging and the respective machine, that can store the devices and support their necessary clean-room hood, and that can successfully transport the apparatus from one building to another with shock absorption. The main requirements are that the portable medical bench is durable, sturdy, reliable, safe, maneuverable during transport, and absorbs shock. The applicable standards and codes are outlined. The testing procedures to ensure the requirements are described for the next semester; testing will take place before, during, and after construction of each part and the full assembly; the most important tests are the frame stress and strain for durability, the tabletop and workspace deflection and rigidity for reliability, the apparatus temperature resistance for safety, and shock absorption. Risk analysis pinpoints focus areas for testing and design; the highest ranked risk analyses involve liquid spills affecting the medical research devices and shock absorption. The final solution and outcome of the semester is an assembly separated into three subsystems: tabletop, storage, and shock absorbing tires. The tabletop and storage are around six feet long, with the workspace and supported clean-room hood centered on the table; there is drainage control to protect the devices, and additional design dimensions for further drainage protection in case of leak or failure; the materials and thicknesses are compatible with x-ray imaging. The storage area is designed so that the bench can be used as a desk and to minimize interference with the x-ray imaging machine; there is maximum storage space with a large, more centrally supported area for heavier devices. The chosen shock absorption, as preferred by the client, are two pairs of wheelbarrow tires. The entire assembly will be maneuverable and strong enough to support the clean room hood, filter, and all devices.

15.1 Contributors to Project Success

The purpose of the project is designing and constructing a bench compatible with ATI's devices, procedures, and delicate brain blood flow model. The bench will be used to transport the experimental setup to adjacent buildings, in addition to the usual requirements - compatible with and non-intrusive of ATI's medical tests supportive of the setup's size and weight, and providing security of additional accessories and storage. A working portable bench will be tested, prototyped, and constructed. Through prototyping, individual analysis, and research, the team was able to complete a design, order the project's material, and construct nearly all of the bench components. The team has successfully followed the purpose of the project. The parameters that the bench design needs to follow for it to be successful and viable for its uses are defined by the client and decided upon by the team. In the process of developing the device, the team has gained experience in working with project expectations and designing and constructing a functioning product that meets requirements and is of high quality. During the project, the team gained lots of experience working with changing expectations and developing a functioning product alongside the preferences of the client. The team wants to honor Aneuvas Technologies, Inc.'s mission to improve human healthcare by designing minimally invasive devices for treatment of vascular defects. The team worked carefully with the preferences and requirements of the research laboratory to ensure the research would be carried out easily and effectively through the use of the medical bench. The team honored each of the requirements that the research laboratory indicated would be helpful to have as part of their bench. The goals also included creating a cost effective device and staying within budget, which the team has achieved through constructing the bench's frame from ordered material; going over budget was approved because the client chose specifically the more expensive components to be ordered.

Some ground rules that the team established included meeting in person weekly in the engineering building, consistent communication with the project client and instructor, and respect given to all team members. The team did very well in keeping up with the scheduled meetings, and this became essential to the project's success. Consistent communication with the project's client was at times difficult, but through a meeting during the second semester the team and the client decided on a final design for the bench. The team members all respected and supported each other throughout the semester.

Meeting often within the team encouraged quality submissions, because each assignment was edited by every team member according to the rubric. There were only a few times that an aspect of an assignment was missed because each member reviewed the assignments to account for quality. Though it made it more difficult to organize which responsibilities belonged to specifically which team member overall, having every team member help each other with tasks allowed for higher quality of each submission. The team accounted for organizing responsibilities on an assignment-by-assignment basis, where each team member was given tasks for each assignment. Often, team members would help each other complete their tasks. During the second semester, project manager Kenyon Rowley took over specific responsibilities, which better divided the assignments and responsibilities per team member; this helped establish more structure to the project assignments.

Successful performance from the team was seen most when our artificial deadlines were followed and when a team member asked for help on a task early on in the assignment. The tools used during the semester included SolidWorks, which was also explored by each of the team members through their self assignments, and individual analyses. The individual analyses regarded drainage, frame strength, and tabletop strength. Reconsidering these aspects during the second semester allowed the team to verify and expand on specific aspects of the project. During construction, minimal changes were inputted into the design for improvement. Technical lessons learned were through frame and storage construction. Changes made to the design during construction were only minimal. Techniques were learned to construct the frame itself and attach the bolt plates and wheels. The storage area was constructed through woodworking techniques. During the first semester, SolidWorks skills were improved to communicate specific designs effectively for manufacturing.

15.2 Opportunities/areas for improvement

The team overall has been successful regarding the purpose, and has stuck to the general purpose of helping ATI's research laboratory by frequently working alongside them to develop their bench. The goals had become more difficult to achieve as they continued to be detailed by the client throughout the first semester. The final proposal design did not address an issue brought up by the client too late into the first semester. The goals included parameters for the bench to be viable, and the proposed bench meets all of the goals presented in the team charter. Additional goals, however, were introduced to the project throughout the semester, and not all of those obstacles have been resolved at this time. The team was not able to establish a final design with the client until the second semester, later than necessary for beginning manufacturing.

One major thing that could be improved upon would be client meetings. Meeting up with the client at times was difficult due to the client not being able to make meetings, or not showing up to scheduled meetings. Because of this, the team could not get certain questions asked and answered at times and either had to wait until a later date or incorporate those specific ideas anyway and ask for feedback later. This was mitigated by having one long meeting with the client that included Dr. Oman and that was meant to establish the very final design that would be manufactured; this meeting was meant to be a final meeting, so the client's decisions during this meeting were used.

Not much was negative about the team as a whole but one thing that could be improved upon would be time management. At times, it seemed like the team was scrapped for time. One example of this would be the final CAD during the first semester. The team had some things that needed to be addressed with the client but was unable to until a date closer to the due date because of what was addressed above, client issues. This major design obstacle was discovered toward the end of the first semester, when the client indicated that he wanted to be able to store the air filter in the bottom of the portable bench, a problem not previously explored. The issue is that the air filter's dimensions exactly match the top of the table's hood/ Both are heavy so the four corners of the hood should be directly supported by the table legs, achieved through locating the table legs directly beneath these four corners. Because the air filter's dimensions match the hood, there is insufficient room to store the hood horizontally beneath the tabletop. Storing the hood vertically may be an issue for the client, because it is heavy so maneuvering it to place sideways beneath the tabletop may be difficult, but the client was unable to meet to discuss solutions to this. This problem was the starting point of the next semester and a final decision was reached with the client for design. Working within the team and having been given final decisions from the client during the second semester greatly improved the team's time management capabilities. The main obstacle of time management during the second semester was that some of the components for the bench, including the tabletop, were commissioned as instructed by the client, and the commission was barely finished before shutdowns took effect. The commission time cut into the team's construction time and the team was not able to finish construction before shutdowns started.

During the first semester, the most important skill that needed improvement was SolidWorks so that specificities in design could be communicated during manufacturing. SolidWorks skills were improved upon by the teammates, learning GD&T and weldments so that the client could better choose a final design and so that the construction could be accurate to the design. Learning this solidworks helped communicate the project needs during the tabletop commissioning and during the frame designs regarding weldments. During the second semester, the most important skill that needed to be learned was welding. Project Manager Kenyon Rowley constructed the bench frame with supports for the air filter and attached the bolt plates using this skill.

Some organizational actions that can be taken to improve performance from the first semester were defining the responsibilities and roles. Being a small team, at times one member of the team had much more work to do than others because of roles constantly changing. Defining the team responsibilities and roles was done by the project manager, who defined his own responsibilities and roles to better divide the assignments and aid in time management.

16 REFERENCES

[1] D. Leo, Engineering analysis of smart material systems. Hoboken, NJ,:Wiley, 2007.

[2] X. Zhu, X. Jing and L.Cheng, "Magnetorheological fluid dampers: A review on structure design and analysis", Journal of Intelligent Material Systems and Structures, vol.23, no.8, pp 839-873, 2012.

[3] G. Quaglia and M. Nisi, "Design of a self-leveling cam mechanism for a stair climbing wheelchair," Mechanism and Machine Theory, vol. 112, pp. 84-104, 2017.

[4] X.Jin, C. Hou, X. Fan, Y.Sun, J.Luv and C. Lu, "Investigation on the static and dynamic behaviors of non-pneumatic tires with honeycomb spokes", Composite Structures,vol. 187, pp. 27-35, 2018.

[5] E. Robecchi and L. Amici, "Mechanics of the Pneumatic Tire. Part 1. The Tire Under Inflation Alone", Tire Science and Technology,vol 1, no.3 pp. 290-345, 1973.

[6] S.P. Moenning, C. Manker, "Medical Table Assembly Having A Restrainment Apparatus Mounted Thereto And An Associated Method Of Immobilizing Object," U.S. Patent 5 855 207, January 5, 1999.

[7] J.R. Hansen, et al., "Brake For Castered Wheels," U.S. Patent 6 264 06 B1, July 24, 2001.

[8] E.H. Fullenkamp, et al., "Carrier With Deployable Center Wheels," U.S. Patent 5 348 326, September 20, 1994.

[9] M.F. Di Leo, "System For Camera Stabilization," U.S. Patent 8 985 878 B2, March 24, 2015.

[10] T. Djerf, "Method Of Making Shock Absorbing Wheels," U.S. Patent 4 879 794, November 14, 1989.

[11] Anonymous, "Medical Applications of Polycarbonate," MDDI Online, 07-Aug-2017. Available: https://www.mddionline.com/medical-applications-polycarbonate. [Accessed: 18-Oct-2019].

[12] "US20020105169A1 - Lightweight convertible transport cart," Google Patents. [Online].

Available: https://patents.google.com/patent/US20020105169A1/en. [Accessed: 29-Sep-2019].

[13] "US6546577B1 - Mobile medical emergency and surgical table," Google Patents. [Online]. Available: https://patents.google.com/patent/US6546577B1/en. [Accessed: 29-Sep-2019].

[14] "Best Storage Layout Optimization for Your Business: U Flow or Through Flow?," Specialized Storage Solutions, 26-Jul-2019. [Online]. Available: https://www.specializedstorage.com/2018/07/17/u-or-through-for-best-warehouse-layout-optimization/. [Accessed: 02-Oct-2019]

[15] Mac, Lamar, Michael, Eric, Patrick, and Timothy, "POWERTEC Table Top Fasteners, 10-Set-71094," The Home Depot, 13-Oct-2019. [Online]. Available: https://www.homedepot.com/p/POWERTEC-Table-Top-Fasteners-10-Set-71094/307984214. [Accessed: 02-Oct-2019].

[16] "Workbenches & Workbench Accessories - Garage Storage." The Home Depot , www.homedeopt.com/b/Storage-Organiztion-Garage-Workbenches

[17] "Portable Modern Writing Desk Study Table Student Learning Desk - Buy Adjustable Student Desk and Chair, Student Desk and Chair, Kid Study Set Product on Alibaba.com," www.alibaba.com. [Online]. Available: https://www.alibaba.com/product-detail/Portable-Modern-Writing-Desk-Study-Table_60770655860.html?spm=a2700.7724857.normalList.201.4ae077657Bddlu. [Accessed: 14-Oct-2019].

[18] J.B. Waters, et al., "Combination Medical Bed and Hospital Table," U.S. Patent 4 669 136, June 2, 1987.

[19] E.D. Davis, "Scrub Sink," U.S. Patent 3 992 730, November 23, 1976.

[20] A.F. Kukulski, "Sanitary Sink Rack," U.S. Patent 1 774 278, September 14, 1928.

[21] T. Brendgord, "Scrub Sink," U.S. Patent 3 728 745, April 24, 1973.