Aneuvas Tech. Portable Bench

Preliminary Proposal

Hunter Daniel

Katherine Riffle

Kenyon Rowley

2019-2020

Aneuvas Technologies, Incorporated

Project Sponsor: Dr. Becker

Instructor: Dr. Oman

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.

TABLE OF CONTENTS

Contents

TABLE OF FIGURES AND TABLE OF TABLES

1 BACKGROUND

1.1 Introduction

Aneuvas Technologies Inc. is a small start-up medical company located in Flagstaff, AZ that focuses on improving human healthcare through novel microcatheter-based medical devices for delivery to the blood vessels in the brain, specifically for treatment of aneurysms and other vascular defects. This project is a portable bench to support and transport the delicate blood flow model of the brain. The bench combines with a cleanroom hood for a sanitary and safe working environment. The objectives of the project include designing a bench capable of having minimal x-ray interference through the countertop surface, strong enough to hold the experimental setup along with the hood, and featuring spill prevention, shock absorption for safe transport, and adequate storage space underneath for storing accessories.

This project is of interest to the sponsor because they currently use a school desk that cannot transport the experimental setup, and use a standard cart to transfer only the experimental setup, but not the clean-room hood. This portable bench will provide versatility of getting the blood flow model of the brain to locations necessary for experiments. It will transport the experimental setup and clean-room hood to x-ray machine on the other side of the building. Maintaining the experimental setup sanitation is essential, and with the portable bench, the hood is attached to the top of the bench during transport, decreasing the model exposure to outside contaminants. It is essential that the portable bench provides a surface through which x-ray procedures can take place with minimal interference, making the bench an integral component of the experimental setup. The bench will also double as a portable desk when not in use, which is versatile to the client.

1.2 Project Description

The following is the original project description provided by the sponsor:

> 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, allow for stable transport of the setup to adjacent buildings, and be compatible with fluoroscopic imaging of the blood flow model through the bench surface.

2 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 House of Quality (HOQ) diagram shows how these customer requirements became engineering requirements and are evaluated based on weights of the customer requirements.

2.1 Customer Requirements (CRs)

Customer Requirements (weighted on 9/3/1 scale):

1. Durable And Robust Design: 9
2. Reliable Design: 9
3. Safe To Operate: 9
4. Maneuverability: 9
5. Cost Within Budget: 3
6. Aesthetically Pleasing: 1
7. Multipurpose Design: 3
8. Lightweight Design: 3
9. Shock Absorption: 9
10. Adequate Storage Space: 3

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. 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 bench across parts of campus. There must be adequate storage space for transporting all the necessary accessories.

2.2 Engineering Requirements (ERs)

Engineering Requirements:

1. Cost ($)
2. Weight (lb)
3. Fitting through doorway (ft^3)
4. Yield Strength (psi)
5. Effective spring constant ($^{lb}/_{in}$)
6. Deflection (in)
7. Thickness (in)
8. Height (in)
9. Strain ($^{in}/_{in}$)
10. Temperature (°F)

To achieve cost effectiveness, money must be meticulously spent to get the best performing design. The target value is $1000 with a tolerance of $100 that was discussed with the client. Weight of the device must be as low as possible, to easily transport the bench with ease. This has a value of 50 lbs with a tolerance of 10 lbs because the bench should be as light as possible. It must fit through doorways with a minimum volume. We assigned a target value of 40 ft^3 with a tolerance of 5 ft^3. With dimensions calculated, it should be about 40 ft^3 to comfortably fit through doors and other places. The yield strength must be high enough to withstand loads on the device. The target value is 100 psi with a tolerance of 50 psi. This value is derived from the 100 lbs of weight the table holds. The spring constant must be strong enough for the shock absorption. 20 $^{lb}/_{in}$ with a tolerance of 10 $^{lb}/_{in}$ ensures the springs are strong enough for safe transport. Deflection of the tabletop must be at a minimum. 0.25 ± 0.05 in should be used for minimum deflection considering the sensitive experimental setup. The thickness must be minimal, while maintaining strength, for minimal interference with the x-ray procedure. 1 ± 0.5 in is adequate for being x-ray compatible The height of the device must be small enough to fit the hood on top, while also fitting through doorways and into the secondary hood. The target height is 36 in with a tolerance of 0 in. This is because 36 in is height of the hood and doorways. The strain on the legs and springs must be minimal, so the target is 0 ± 5 $^{in}/_{in}$. The temperature resistance of the tabletop must resist deformation, so the target resistance of 100 ± 40 °F is established. This is due to estimates in operating temperature of the devices on top of the table, specifically the pump and battery.

2.3 *House of Quality (HoQ)*

The following Figure 1 is the HoQ diagram for the portable bench. This figure calculated what design criteria were the most important to consider when designing the bench. The three most important engineering requirements from the HoQ calculations are weight, deflection, and fitting through doorways (volume). These agree with the customer requirements and client meetings.

Customer Requirement	**Weight**	**Engineering Requirement**	Cost($)	Weight(lb)	Fitting through doorway(ft^3)	Yield Strength(psi)	Effective Spring constant(lb/in)	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	100	20	0.25	1	36	0	100
Tolerances of Ers			100	10	5	50	10	0.05	0.5	0	5	40

Figure 1: House of Quality Diagram for Portable Bench

3 DESIGN SPACE RESEARCH

This chapter discusses the varying directions that sections of the portable bench design could have gone. The design of the bench is divided into three separate entities: wheel, tabletop, and storage design. Each team member researched a particular section.

3.1 Literature Review

The literature review is used to research sources of design, and each student has the technical focus of an aspect of the bench design: shock absorption, wheels, and tabletop designs.

3.1.1 Student 1: Hunter Daniel: Shock Absorption

Hunter's 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.

3.1.2 Student 2: Katherine Riffle: Wheels

Katherine's 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 2. 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.

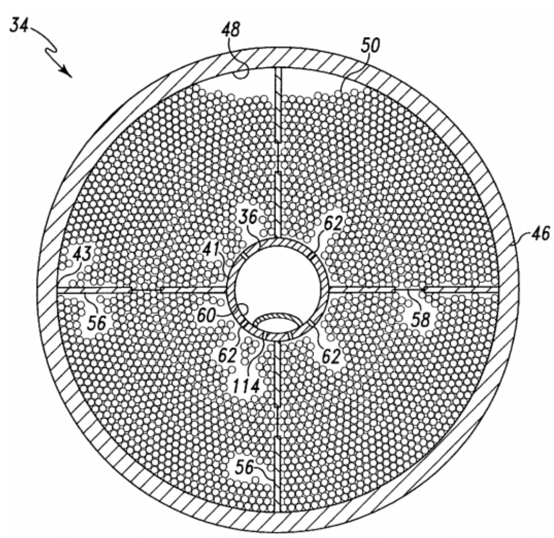


Figure 2: Beads Within the Medical Bed

Brake For Castered 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 3. 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.

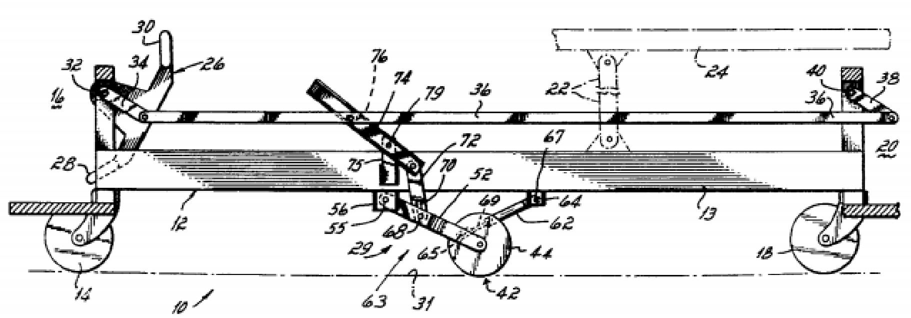


Figure 3: Deployable Center Wheels

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.

3.1.3 Student 3: Kenyon Rowley: Tabletop

Focusing on the tabletop, Kenyon primarily 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-ray's 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 is 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.

3.2 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.

3.2.1 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.

3.2.1.1 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 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 in the bench. There is no storage provided in the table design, which would also need to be addressed to meet the bench requirements.

3.2.1.2 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.

3.2.1.3 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 4. 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 4: Dr. Becker's Current Cart

3.2.2 Subsystem Level Benchmarking

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

3.2.2.1 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.

3.2.2.1.1 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.

3.2.2.1.2 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.

3.2.2.1.3 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.

3.2.2.2 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.

3.2.2.2.1 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.

3.2.2.2.2 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.

3.2.2.2.3 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.

3.2.2.3 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.

3.2.2.3.1 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.

3.2.2.3.2 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.

3.2.2.3.3 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.

3.3 Functional Decomposition

3.3.1 Black Box Model

When deciding on the direction needed for the design generation process, the team uses the black box model concept to better understand what was going to be put into the project and what was going to come out as system characteristics. The team decided to split the model into three sections. Shock absorption, storage, and tabletop design. In doing so, our team was able to understand how each subsystem would function.

Figure 5: Shock Absorption BlackBox Model

Figure 5 illustrates the black box model created for shock absorption. The inputs decided by the team are material, force, and design. The current material used on the wheel is rubber and does not provide much shock absorption. The force comes from the user needing to push the bench. The design will play a part in how shock absorption is achieved. The outputs are the system characteristics the team hopes to accomplish through design. The wheels need to reduce impact, create less noise, and be easier to push and turn. Out of all these outputs, the most important is the reduced impact.

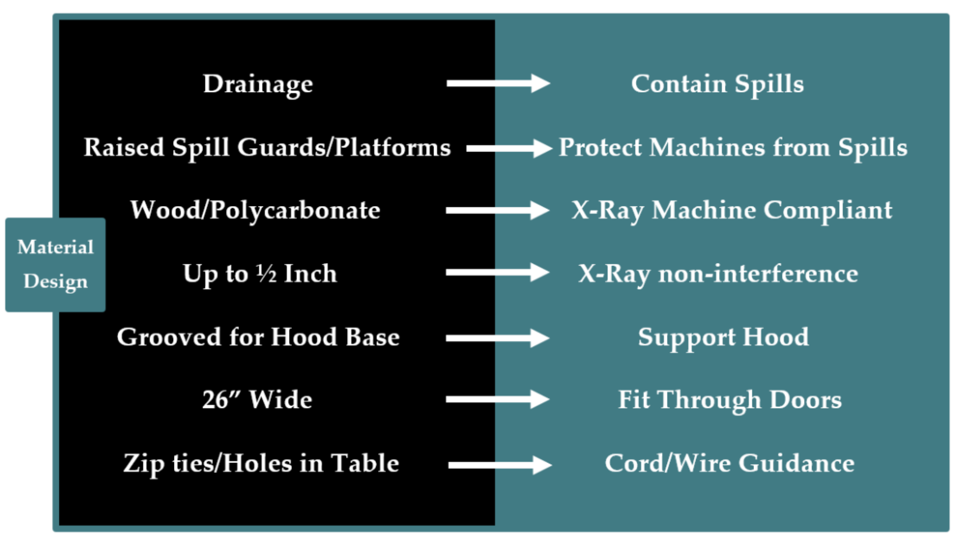


Figure 6: Tabletop BlackBox Model

Figure 6 illustrates the black box model created for the tabletop concept. Going into the box are material and design. Some designs specifics given by the client include dimensions, adding zip ties, making a piece out of polycarbonate, and drainage. The characteristics of the concept the team wants to come out of design are containing spills, x-ray compliant, and fit through doors.

Figure 7: Storage BlackBox Model

Figure 7 illustrates the black box model created for the storage concept. Going into the box are material and design. The material chosen for the storage part of the bench will be wood since it is not needed to be x-ray compatible. As for the design aspect, the team will have flanges incorporated as well as a pull out drawer.

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

The team used a decomposition model to evaluate the generated concepts. The decomposition model organizes the many different concepts. The team tried to evaluate each concept through the customer and engineering requirements as well as the client's preference. Similar to the black box model, the decomposition model is separated into three parts.

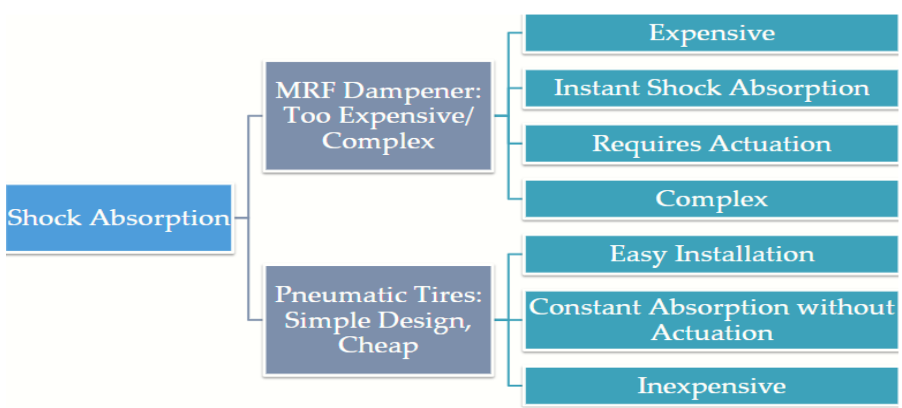


Figure 8: Decomposition Model Wheels

Figure 8 shows the decomposition model constructed for the shock absorption concept. In the model, two designs are being evaluated. One being the MRF damper and the other is the pneumatic tire design. As the model shows, the damper offers a high shock absorption but is expensive, requires actuation, and is complex. The pneumatic tire design is easy to install, offers constant shock absorption without actuation, and is cheap.

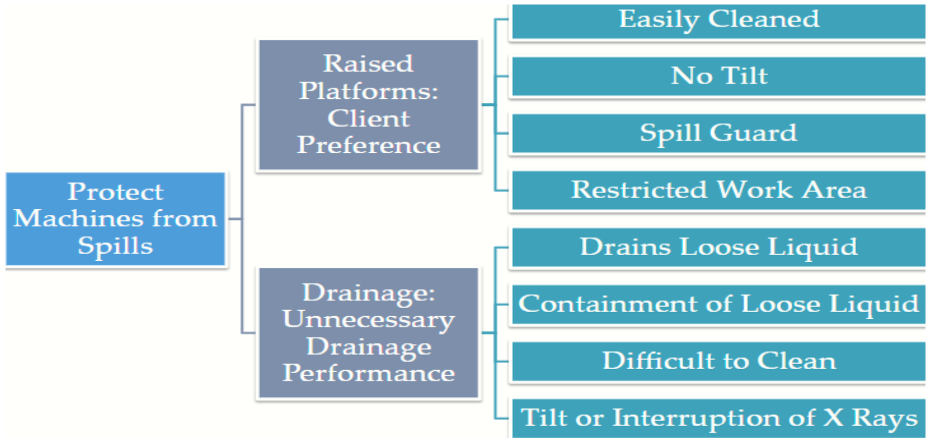


Figure 9: Decomposition Model Tabletop

Figure 9 details the decomposition model constructed for the tabletop. This model is comparing the concepts of a raised platform and adding drainage in order to protect the medical devices from spills. Raised platforms are easily cleaned but do restrict the working environment. Drainage is effective in removing excess fluid but is difficult to clean.

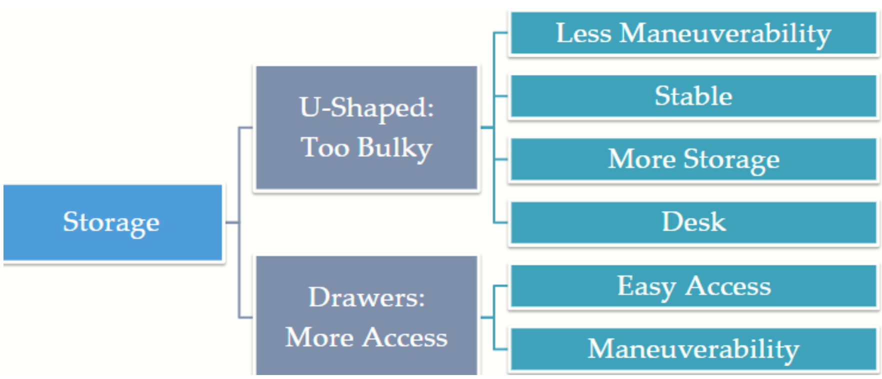


Figure 10: Decomposition Model Storage

Figure 10 illustrates the decomposition model used for the storage designs. The two designs being evaluated are U-shaped design and drawers. The U-shape design is less maneuverable, but is stable and offers more space. The drawers are more easy to access.

4 CONCEPT GENERATION

There are three full system concepts and ten subsystem concepts.

4.1 Full System Concepts

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

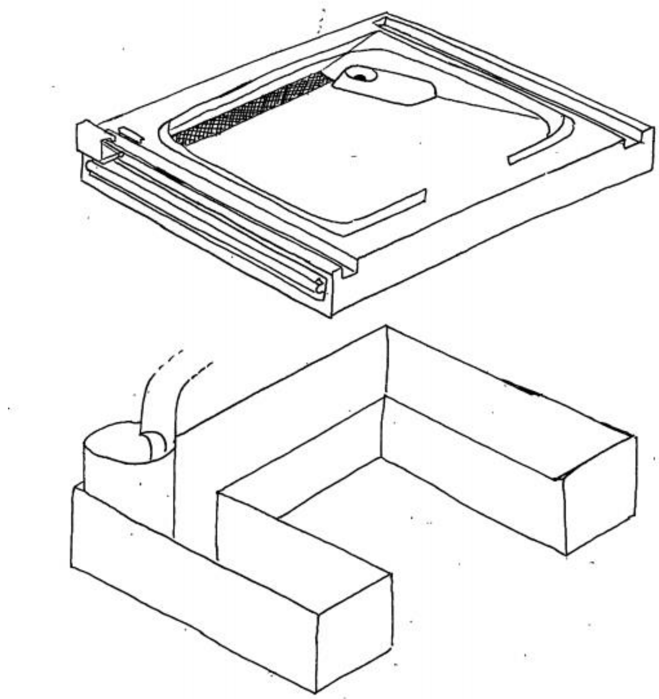


Figure 11: Tabletop (and) Access to U-Shaped Storage

Figure 11 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 1: 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	

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

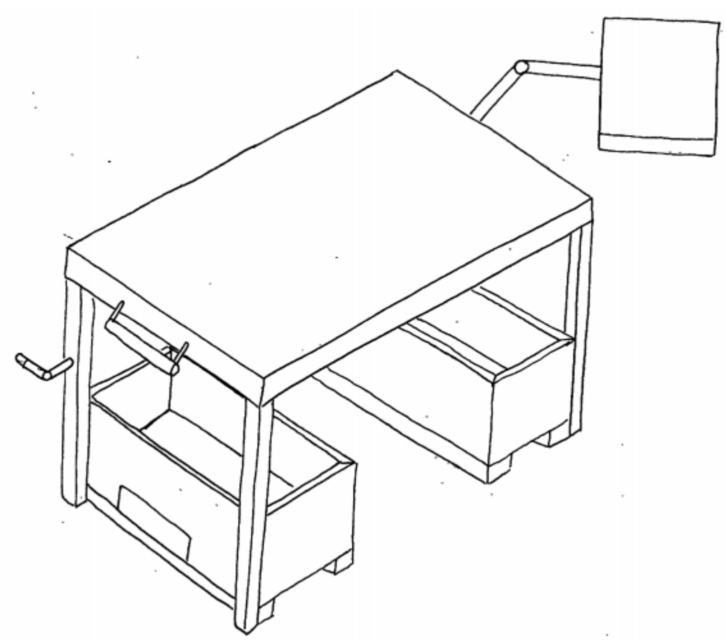


Figure 12: Drawer Storage and Tabletop Features

This design, shown in Figure 12, 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 2: 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	

4.1.3 Full System Design #3: Complete Storage Assembly

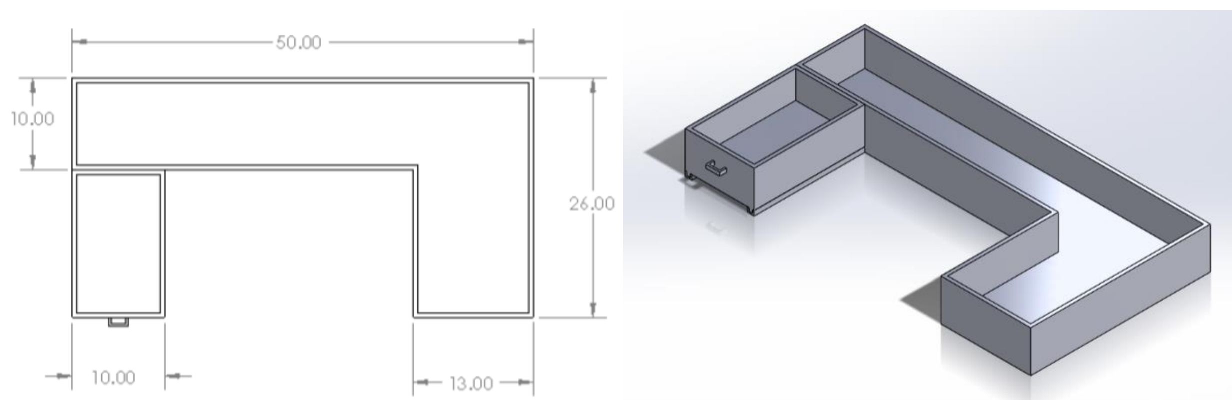


Figure 13: Complete Storage Assembly

The design, shown in Figure 13 is compatible with the tabletop base subsystem elevated devices, Figure 18, 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 3: 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	

4.2 *Subsystem Concepts*

4.2.1 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.

4.2.1.1 *Design #1: MRF Damper*

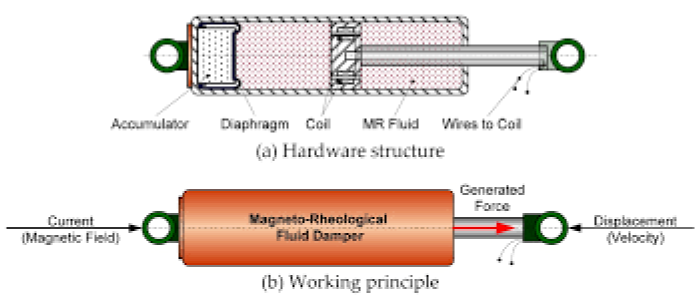


Figure 14: MRF Damper

Figure 14 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.

4.2.1.2 Design #2: Honeycomb Tire

Figure 15: Honeycomb Tire Design

Figure 15 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.

4.2.1.3 Design #3: Descriptive Title

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.

4.2.2 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.

4.2.2.1 *Design #1: Grate Drainage*

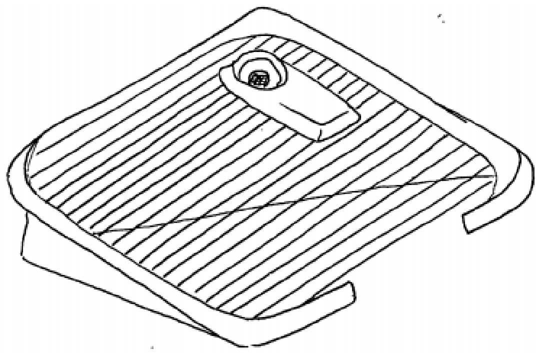


Figure 16: Grate Drainage Workspace Design

The Grate Drainage option shown in Figure 16 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 11. 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 4: 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

4.2.2.2 *Design #2: Basin Drainage*

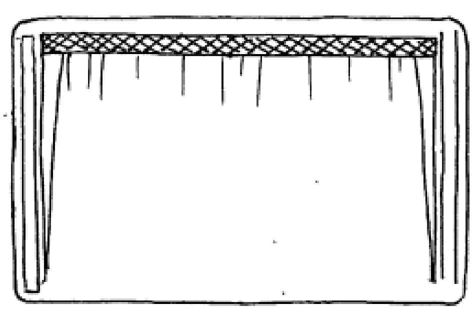


Figure 17: Basin Drainage Tabletop Design

The Basin Drainage design shown in Figure 17 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 11. 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 5: 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	

4.2.2.3 *Design #3: Elevated Platforms (No Drainage)*

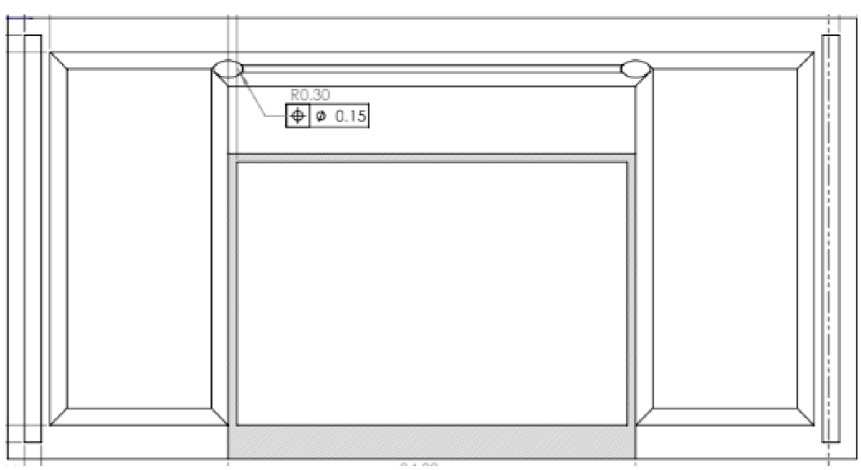


Figure 18: Elevated Platforms (No Drainage) Tabletop Design

This Elevated Platforms design shown in Figure 18 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 6: 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	

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

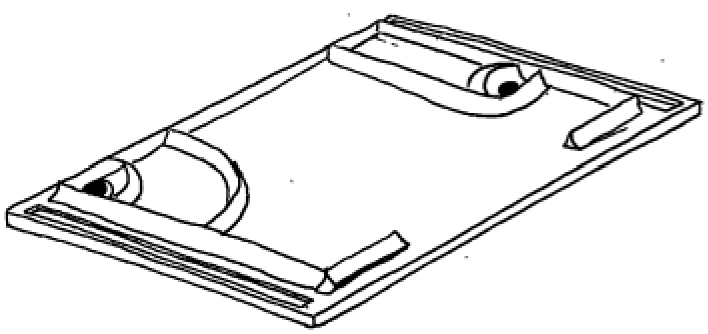


Figure 19: Partitions with Cord Holes Tabletop Design

This Partitions with Cord Holes design, shown in Figure 19, 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 7: 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	

4.2.3 Subsystem #3: Storage

The storage system has few purposes it should be designed for. They are described in the storage blackbox model, Figure 7. 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.

4.2.3.1 Design #1: U-Shaped Storage

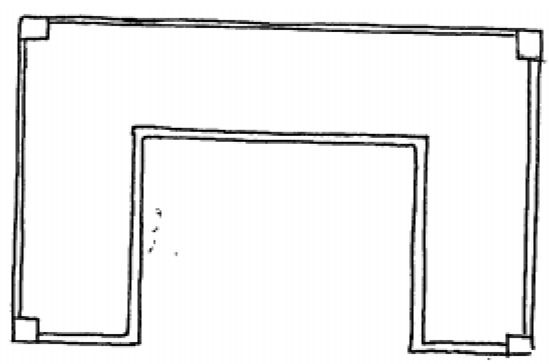


Figure 20: U-Shaped Storage Design

This U-Shaped Storage design, illustrated by an aerial view in Figure 20, 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 8: 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	

4.2.3.2 Design #2: Drawer Storage

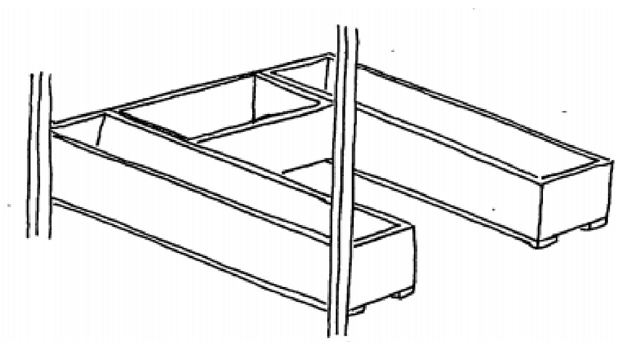


Figure 21: Drawer Storage Design

This design, shown in Figure 21, 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 9: 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	

4.2.3.3 *Design #3: Asymmetrical Storage Design*

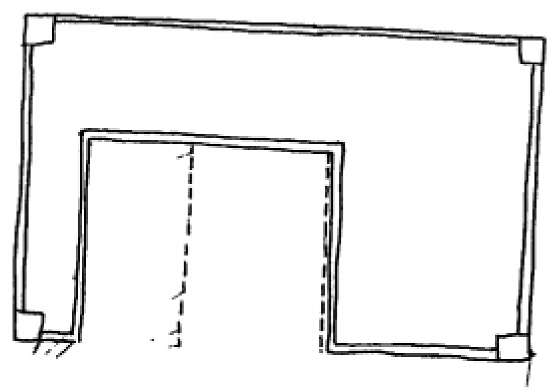


Figure 22: Asymmetrical Storage Design

The asymmetrical storage design, illustrated by an aerial view in Figure 22, 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 22 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 10: 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

5 DESIGNS 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.

5.1 *Technical Selection Criteria*

The technical criteria used for comparing designs are: material cost, reliability, installation, portability, and compatibility. Material cost is important because the design must be economical while also not compromising integrity. Reliability is selected because one of the main purposes of this device is to be more reliable than the current setup, which is a combination of a desk and a cart. Installation is addressed because of the device's need to be versatile and easy to setup and use. The device's portable aspect is important due to the fact that the current setup is not very portable, which causes many problems when the device needs to be transported to the x-ray room. The device must be compatible with the hood placed on top of the portable bench along with all the hardware that will make use of the bench.]

5.2 *Rationale for Design Selection*

Table 11: Decision Matrix

Criterion	Weight	MRF Dampner	Pneumatic Tire	Raised Platform	Drainage	Zipties	Holes in Table	U-Shape	Drawers
Material Cost	0.25	5	15	12.5	12.5	12.5	11.25	12.5	12.5
Reliability	0.25	12.5	15	12.5	12.5	16.25	15	15	12.5
Instalation	0.1	3	6	6	5	5.5	5	5	5
Portability	0.15	7.5	7.5	7.5	7.5	6.75	6.75	9	9
Compatablity	0.25	7.5	15	15	12.5	12.5	12.5	12.5	15
Totals		35.5	58.5	53.5	50	53.5	50.5	54	54

Raw Scores	MRF	Pnematic	Raised	Drainage	Zipties	Holes	U	Drawer
	20	60	50	50	50	45	50	50
	50	60	50	50	65	60	60	50
	30	60	60	50	55	50	50	50
	50	50	50	50	45	45	45	60
	30	60	60	50	50	50	50	60

Figure 9 shows the decision matrix used to evaluate the concepts made through the project. In evaluating these concepts, a weight was assigned to the criteria. Through the Customer and Engineering Requirements, cost, reliability, and compatibility are weighted the highest. Raw scores are then given to each concept to be evaluated. The decision matrix adds up the scores to assist in deciding what designs were going to be used going forward. The Pneumatic Tire design is chosen due to its dramatic difference in cost compared to the MRF damper. Raised platforms are chosen for the tabletop due to its ease of installation and compatibility. Zip ties are chosen because of being more reliable. In the storage concept evaluation, the U-shape design as well as the drawer design scored evenly. The next section details the selected design.

5.3 Selected Design

The top level design for each of the three aspects (shock absorption, tabletop, and storage) are Pneumatic Tires, and otherwise shown in the Appendices A and B. Appendix A shows the tabletop base SolidWorks, so it does not include some of the decided sub-systems. Appendix B shows the final SolidWorks storage, but the measurements are estimates because the medical devices have not arrived to Dr. Becker at this point. The tabletop and storage fit together vertically. These are the systems and subsystems are chosen or were already decided for the design:

- Pneumatic Tires – Shock Absorption
- Elevated Platforms – Tabletop
- Zip Ties – Tabletop
- Polycarbonate Workspace – Tabletop
- Coated Wood Tabletop – Tabletop
- Handles on the side – Tabletop
- Clean-Room Diffuser Storage – Tabletop (underside)
- Grooves for Clean-Room Hood Insertion – Tabletop
- Clamps for Clean-Room Hood Securement - Tabletop
- Asymmetrical U-Shape – Storage
- Office Supply Drawer – Storage

The finalization has not been confirmed yet by the client, Dr. Becker.

6 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.

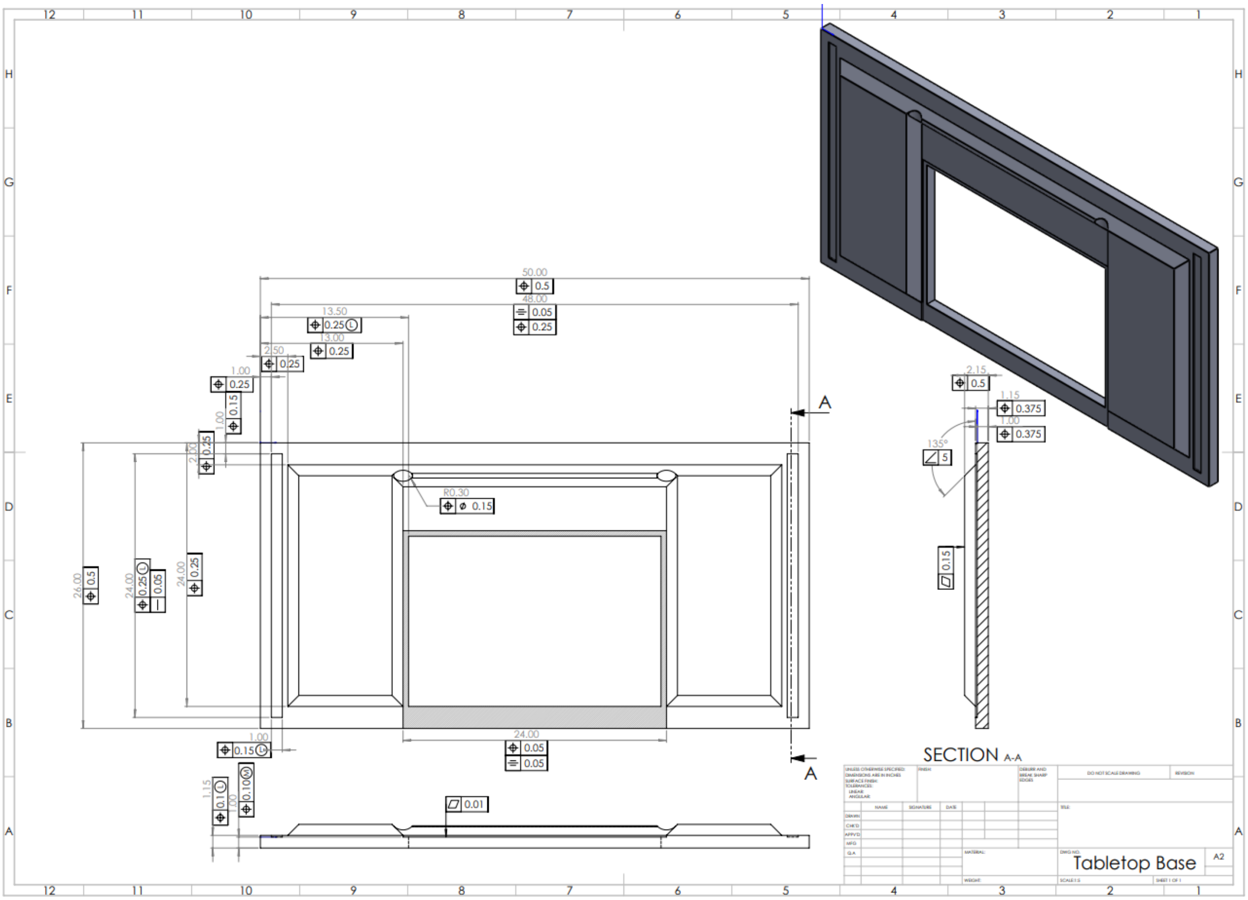
[19] E.D. Davis, "Scrub Sink," U.S. Patent 3 992 730, November 23, 1976.

[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.

7 APPENDICES

7.1 *Appendix A: Final Tabletop SolidWorks*



7.2 *Appendix B: Final Storage SolidWorks*