University of Manitoba

Faculty of Engineering

Department of Mechanical and Manufacturing Engineering

Procedural Table Equipment Retrofit

MECH 4860 – Engineering Design

Sponsoring Company:
Winnipeg Regional Health Authority (WRHA)

Project Advisor
Dr. Paul Labossiere, P.Eng

Submission Date
December 1st, 2014

Team 24

Cody Bjornsson ____ __

Olivia Essex ____ __

Thomas Sawadski ____ __

Devin Windeatt ____ ____

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

As a team, Cody Bjornsson, Olivia Essex, Thomas Sawadski, and Devin Windeatt, are responsible for the Procedural Table Equipment Retrofit project sponsored by the Winnipeg Regional Health Authority. Specifically, the team is tasked with designing a fast deploying footrest and a fluid collection system for the mobile padded procedural table used for dilation and curettage at the Women's Hospital at the Health Sciences Centre. With the aforementioned features installed, the staff at the Women's Hospital will gain access to a mobile procedural table capable of being used for dilation and curettage. Having access to said equipment will increase the overall efficiency of operations within the hospital.

The footrest the team has designed is made out of 14 Ga. stainless steel wrapped around a support structure composed of welded bar stock. The footrest is attached to the table at the rails of the backrest where a sliding pin mechanism is located to lock the footrest in place. The footrest is light weight (10kg, ~ 25% lighter than the original) and takes three seconds to deploy the footrest in three simple steps: lift, pull and lower. The sliding pin mechanism consists of two engagement pins and one sliding pin (shoulder bolt), where all three pins are 9.5 mm in diameter. Using FEA and analytical tools, we confirmed that the footrest can safely support the maximum weight of a patient (137 kg) sitting on the footrest, and withstand 25 years of service when subjected to 18.5% of a 137 kg person's body weight.

The fluid collection system the team has designed is composed of a purchased pan that is supported and deployed by C-channels. The fluid collection system is located relative to the patient's uterus and provides a working surface for the doctor to place his/her tools during surgery. Using FEA and analytical tools, we confirmed that the pan can safely support the maximum weight of 6 kg which includes 2L of fluid and the weight of the surgical tools.

Our proposed retrofit design is made entirely of 304 stainless steel, except the shoulder bolts, which are made of 316 stainless. The retrofit will cost $1754.15, which is under budget by $1245.85. 304 and 316 stainless steel can be disinfected with Oxivir and sterilized in an autoclave. The retrofit has been designed with a minimum number of components that can either be purchased or are simple to manufacture. Additionally, the retrofit has been designed to assemble and disassemble easily with the use of components like shoulder bolts.

1.0 PROJECT DEFINITION

In order for our group to begin solving the problem of our project, we first had to ensure we understood the context in which the problem exists, and the problem itself. Our sponsor for this project is the Winnipeg Regional Health Authority, and our client works in the Clinical Engineering Department at the Health Sciences Centre. In this section of the report, the background of our sponsor and our client's department at the Health Sciences Centre will be provided. An explanation of how our project fits into the overall company operation will also be presented, along with a clear statement of the problem itself and the purpose of our project.

Once we understood the problem we were solving, a list of expectations for the design and the project management aspects of the project were established. Furthermore, the team determined the following main constraints and limiting factors for our project: time, budget, size, strength of the design, material, medical device regulation standards, and retrofitting the design to the existing procedural table. In this section of the report, a detailed list of our group's expectations, and constraints and limitations, will also be presented.

Next, a list of needs to ensure the satisfaction of our customer were established. We determined how we were going to measure each of our needs, and in what units, by making a list of metrics. We then proceeded to create a list of technical specifications for each metric; this list provided us, as well as the client, with a clear idea of measurable goals that we were striving to achieve. In this section of the report, our customer's needs will also be presented and ranked in terms of importance. A list of metrics and their corresponding units, as well as their technical specifications, will conclude this section.

1.1 BACKGROUND

The Winnipeg Regional Health Authority (WRHA) is the governing body responsible for providing health care to the population of the City of Winnipeg, the Town of Churchill, and the surrounding Rural Municipalities of East and West St. Paul. The WRHA funds over two hundred health service facilities and programs, including the Health Sciences Centre (HSC) in Winnipeg [1].

There are hundreds of departments and services available at the HSC, including the Clinical Engineering Department [2]. The Clinical Engineering Department is in charge of assessing existing equipment and technology for all of the HSC; they determine what needs replacement or refurbishment, and implement the replaced or refurbished equipment or technology at the HSC. The WRHA and the Clinical Engineering Department are committed to innovation that fosters improved care, health, and general well-being; excellence in the care and services they provide; and stewardship [3].

At the Women’s Hospital at the HSC, a stationary padded procedural table is used for dilation and curettage. Dilation and curettage is a procedure that involves removing tissue from the uterus. Currently, a pan system is used to collect fluids from the uterus during the procedure; this system is attached to the stationary table and is located below the patient’s uterus during surgery, as pictured in Figure 1.

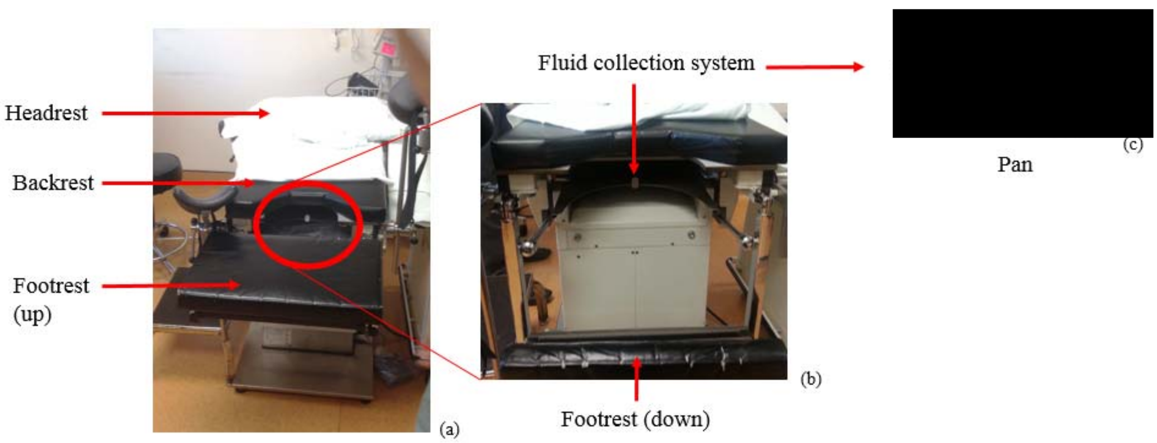


Figure 1: Stationary padded procedural table: (a) overview of table [4], (b) envelope support for pan [5], (c) pan [6]

The Clinical Engineering Department has identified that the stationary table used for dilation and curettage fulfills all the basic needs of those operating it, except that the table is non-mobile. A mobile table provides the opportunity to move a patient, without having to transfer the patient from one table to another.

Currently, there exists a padded procedural table at the hospital which is mobile, but it cannot be used. This mobile table is out of service because it lacks a fluid collection system and a fast deploying footrest, which the stationary padded procedural table currently provides. The mobile table that is currently out of service at the HSC is pictured in Figure 2.

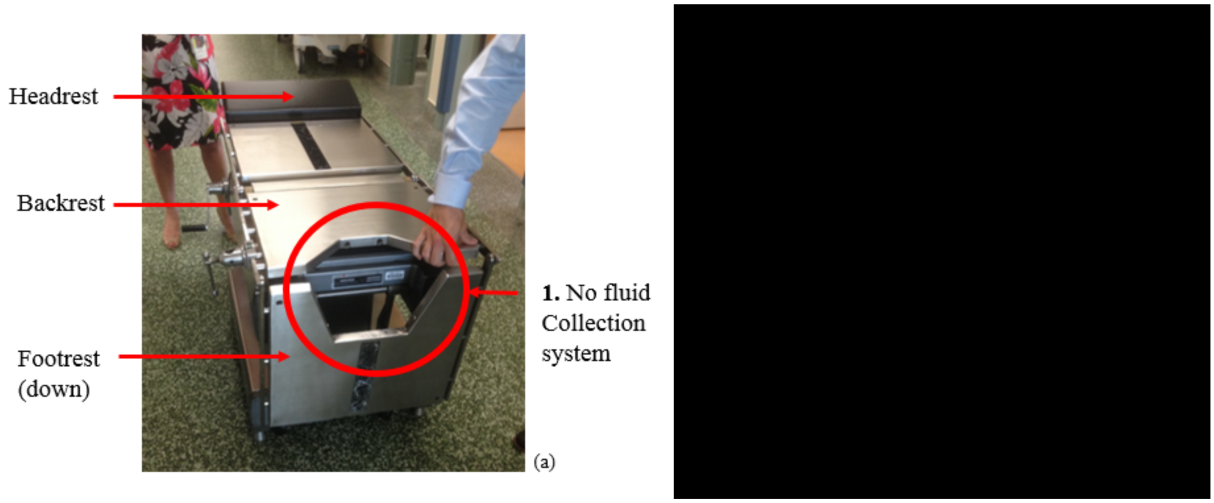


Figure 2: Mobile padded procedural table lacks a fluid collection system and fast deploying footrest: (a) isometric view of table [7], (b) side view of table [8]

It should be noted that the mobile table pictured in Figure 2 is a different table model than the stationary table pictured in Figure 1. As such, one cannot directly apply the design of the fluid collection system and footrest from the stationary table to the mobile table without some adjustments.

The Clinical Engineering Department would like to refurbish the mobile procedural tables to have a fluid collection system, as well as a fast deploying footrest. Our group is tasked with designing the aforementioned features for the mobile padded procedural tables at the Women's Hospital at the HSC. Our design must be ready to take to fabrication at the machine shop at the HSC. With these features made and installed by the technicians at the machine shop at HSC, the staff at the Women's Hospital will gain access to a mobile procedural table capable of being used for dilation and curettage. Having access to said equipment will increase the overall efficiency of operations within the hospital.

1.2 Project Expectations

Our team's expectations of the retrofit are as follows:

- To create a footrest that can be deployed quickly and is easy to use.
- To create a fluid collection system that contains and supports fluid from a procedure.

- To have a fluid collection system that is always accessible, regardless of the footrest's position.
- To deliver a design that can be disinfected with Oxivir and/or sterilized in an autoclave without degrading.
- To deliver a design that is ready to take to fabrication by the machine shop at the HSC.
- To deliver a design that does not interfere with the current functionality of the table.
- To deliver a design that decreases the limitations the nurses experience with the current procedural table.
- To instill confidence in the nurses who use the procedural table regularly.
- To achieve a design that is under the allocated budget provided by the HSC.
- To follow the medical regulatory standards for the table in Canada.
- To create a design that is marketable.
- To satisfy all stakeholders' expectations.

The expectations listed above have been approved by our client. It should be noted that the technical specifications associated with our group's expectations of the retrofit are defined in Section 1.5. Our team's expectations in terms of managing the project are as follows:

- To communicate frequently with our client and one another.
- To respond to all forms of communication in a timely manner.
- To send regrets if one cannot attend a meeting.
- To have all work required for a meeting completed, even if you are absent.
- To submit work that is of high standard and quality.
- To submit work on time.
- To monitor and control our progression against the work schedule.
- To monitor and control risks associated with the project.
- To meet all deliverables and deadlines of MECH 4860.

In order to meet the deliverables and deadlines of this course and for our client, the team needed to be constantly monitoring and controlling the progression of the project through time and risk management. All work pertaining to monitoring and controlling the progression of the project can be found in Appendix A.

1.3 CONSTRAINTS AND LIMITATIONS

Constraints and limitations are pieces of information that restrict one's solutions to a problem. The constraints and limiting factors for this project include time, budget, size, strength of the design, material, medical device regulation standards, and retrofitting the design to the existing procedural table. A more detailed list of our project's constraints and limitations is provided next.

Time:

- The deadline for completion of the project is December 1st, 2014.
- Duration of time team members, the client, and the advisor to work on the project.

Budget:

- The budget for labour and materials to manufacture the final design must not exceed $3000.

Size:

- The size of the table must be capable of fitting through all standard hospital doors which are approximately 3 feet wide by 7 feet tall.
- The size of the table must be capable of fitting in the hospital elevators which are approximately 4 feet wide, 6 feet deep, and 8 feet tall.
- The fluid collection system is limited to a space of 12 inches wide by 9 ¾ inches deep due to the space available underneath the procedural table.
- The bottom of the fluid collection system must be located a distance of 6 ¾ inches from the bottom of the backrest to ensure that the tools used during the procedure do not interfere with the fluid collection system.

Strength:

- The strength of the footrest must be capable of supporting the weight of a patient: 137 kilograms.
- The strength of the fluid collection system must contain and be capable of supporting the estimated weight of fluid for the procedures performed: 4 to 12 kilograms.

Material:

- The material of the footrest and fluid collection system must be able to be disinfected with the cleaning agent Oxivir.
- The material of the footrest and fluid collection system must be able to withstand temperatures of 140 degrees Celsius when being sterilized in an autoclave [9].

Regulatory Standards:

- Regulatory codes and standards of a class 1 medical device in Canada must be met by the design of the fluid collection system and the footrest.

Retrofitting the Design:

- The retrofit design of the fluid collection system and the footrest must attach to the frame of the existing table.
- The retrofit design of the fluid collection system and the footrest must not hinder the procedural table's mobility.
- The retrofit design of the fluid collection system and the footrest must not hinder the procedural table's current functionality.

1.4 NEEDS

Customer needs are independent of any solution, concept, or product; we established our needs by first gathering information from our stakeholders. The stakeholders of our project include the following people:

i. Clinical Engineer: Kyle Eckhardt, EIT
ii. Clinical Engineer: Michael Hamilton, EIT
iii. Surgical Instrument Technician: Nhien Tu
iv. OR Manager: Lynn Kurylko
v. Sponsor: WRHA
vi. Users: nurses, doctors, patients
vii. Team: Cody Bjornsson, Olivia Essex, Thomas Sawadski, Devin Windeatt
viii. Advisor: Dr. Paul Labossiere, P.Eng

After meeting with the project stakeholders and gaining a better understanding of the project, we made a list of our project's needs. We then proceeded to organize our needs into a hierarchy, and then prioritize the needs based on level of importance. Next, we met with our client to review the hierarchy we established. The list of our project's needs and their level of importance are presented in Table I; this list was approved by the client. The star system located beside each need indicates its level of importance. One star represents the lowest level of importance, while four stars represents the highest.

TABLE I: NEEDS RANKED IN TERMS OF LEVEL OF IMPORTANCE

Label	Needs	Importance
	The footrest is easy to use	
1.	• The mechanism for deployment of the footrest is easily found	***
2.	• The mechanism for deployment of the footrest is straight-forward to use	***
3.	• The footrest is ergonomic for the person moving it	**
4.	• The footrest can be deployed quickly	****
5.	• The footrest is lightweight	***
	The footrest coexists with the fluid collection system	
6.	• The fluid system is always accessible during any part of the procedure	***
7.	The footrest is able to safely support the patient's weight	***
	The footrest can move	
8.	• The footrest can be positioned at 0 and 90 degrees relative to the backrest	***
	The footrest is durable	
9.	• The footrest can withstand cyclic loading	**
10.	• The footrest is able to be cleaned with Oxivir (a disinfectant)	****
11.	The footrest is easy to manufacture	****
	The fluid collection system contains and supports fluid	
12.	• The fluid collection system contains the fluid from a procedure	****
13.	• The fluid collection system supports the fluid from a procedure	****
	The fluid collection system is easy to use	
14.	• The fluid collection system can be deployed quickly	****
15.	• The fluid collection system is ergonomic for the person interacting with it	***
16.	• The fluid collection system is lightweight	**
17.	• The fluid collection system is located relative to the patient's pertinent anatomy (uterus)	****
	The fluid collection system is durable	
18.	• The fluid collection system is able to be sterilized using an autoclave	****
19.	• The fluid collection system is able to be cleaned with Oxivir	****
20.	The fluid collection system is easy to manufacture	****
21.	The fluid collection system and footrest are easy to clean	***
	The fluid collection system and the footrest are easy to set-up and maintain	
22.	• The fluid collection system is easy to install/uninstall	**
23.	• The footrest is easy to install/uninstall	**
24.	• The fluid collection system can be maintained with readily available tools	*
25.	• The footrest can be maintained with readily available tools	**
	The fluid collection system and the footrest are marketable	
26.	• The fluid collection system and the footrest are affordable to produce	***

TABLE I: NEEDS RANKED IN TERMS OF LEVEL OF IMPORTANCE

Label	Needs	Importance
	The fluid collection system and the footrest are marketable	
27.	• The fluid collection system and the footrest do not interfere with the current functionality of the table	***
28.	• The fluid collection system and the footrest are aesthetically pleasing	***
29.	• The fluid collection system and the footrest are attached to the frame of the existing table	****
30.	• The fluid collection system and the footrest do not hinder the mobility of the procedural table	****
31.	The fluid collection system and the footrest meet the codes and standards of a class 1 device in Canada	****

All needs presented in Table I must be met in order to deliver a successful design to our client. However, those rated with four stars require the most attention, as they were deemed most important by the team and our client. For example, both the footrest and fluid collection system must be able to be deployed quickly, attached to the existing frame of the table, easily manufactured, and able to be disinfected with Oxivir and/or sterilized in an autoclave. Additionally, the design of both the footrest and fluid collection system must meet the codes and standards of a class 1 device in Canada. The fluid collection system also needs to contain and support the fluid from a procedure, and be located relative to the patient's pertinent anatomy (uterus). All changes made to the table must also not hinder the mobility of it.

1.5 Metrics and Technical Specifications

Once our needs were identified, we devised a list of metrics. After we determined our metrics, we proceeded to determine units and precise technical specifications for each metric. Precise technical specifications were determined by consulting with our stakeholders in detail about their expectations for the design. In Table II, the list of metrics for our project and their corresponding units, along with rough and precise technical specifications are shown. Technical specifications are not listed for metrics that have units of list, schematic, or subjective. Technical specifications are also not listed for metrics that are dependent on the material chosen for the design of either the footrest or fluid collection system.

TABLE II: METRICS & TECHNICAL SPECIFICATIONS

Label	Metric	Unit	Precise Technical Specifications
1.	Average time to find mechanism for deployment	s	1
2.	Average time required to determine how to use	s	5
3.	Duration of time the worker operates the footrest for each patient	s	6
4.	Number of times a worker operates the footrest in a day	cycles	16
5.	Position of worker's body during operation of the footrest	schematic	-
6.	Minimum descent/ascent time of the footrest	s	2
7.	Total mass of the footrest	kg	10
8.	Access the fluid collection system during every part of the procedure	subjective	-
9.	Total mass the footrest can safely withstand	kg	137
10.	Angle between the footrest and backrest	degree	0 and 90
11.	Cycles to failure	cycles	300 000
12.	Strength of material after being cleaned with Oxivir	MPa	-
13.	Thickness of material after being cleaned with Oxivir	mm	-
14.	Time to manufacture the footrest	hours	24
15.	Total volume of the fluid	litres	2
16.	Total mass of the fluid*	kg	2
17.	Minimum deployment time of the fluid collection system	s	2
18.	Duration of time the worker operates the fluid collection system for each patient	s	14
19.	Number of times a worker operates the fluid collection system in a day	cycles	16
20.	Position of worker's body during operation of the fluid collection system	schematic	-
21.	Total mass of the fluid collection system	kg	2
22.	Position of the patient’s body during the procedure	schematic	-
23.	Strength of material after being put in an autoclave	MPa	-
24.	Thickness of material after being put in an autoclave	mm	-
25.	Time to manufacture the fluid collection system	hours	8
26.	Minimum radii of corners	mm	10
27.	Surface finish of material [10]	μm	0.8
28.	Time to assemble/disassemble the fluid collection system for maintenance	min	30
29.	Time to assemble/disassemble the footrest for maintenance	min	30
30.	Tools required for maintenance of the fluid collection system	list	-
31.	Tools required for maintenance of the footrest	list	-
32.	Cost of materials and labour	$ (CDN)	3000
*Assume the fluid from the procedure has the same density of water at atmospheric conditions			

TABLE II: METRICS & TECHNICAL SPECIFICATIONS

Label	Metric	Unit	Precise Technical Specifications
33.	Current functionality of the table is maintained	list	-
34.	The fluid collection system and the footrest look aesthetically pleasing	subjective	-
35.	The fluid collection system and the footrest attach to the frame	schematic	-
36.	Speed at which the table moves with a patient	m/s	0.25
37.	Speed at which the table moves without a patient	m/s	0.5
38.	Canadian codes and standards for a class 1 device	list	-
*Assume the fluid from the procedure has the same density of water at atmospheric conditions			

As Table II does not offer any explanation on the specifications listed, technical specifications requiring some background information will be described now. For example, for every patient the nurse encounters he/she will have to move the footrest from an angle of 0 to 90 degrees (measured between the footrest and backrest) and from 90 to 0 degrees once on average. As such, if the average time to find the mechanism for deployment is specified at 1 second and the minimum ascent/descent time of the footrest is specified at 2 seconds, the total time the nurse interacts with the footrest per patient is 6 seconds.

Lynn Kurylko, the OR Manager at the HSC, has specified that the Women's Hospital does not need the footrest to be at any other position but 0 and 90 degrees between the footrest and backrest. Also, the manufacturer of the current table specifies that the table can withstand 137 kilograms [8]. As the probability of a patient sitting on the footrest is very low, as indicated by the OR Manager at the Women's Hospital at the HSC, we have considered a safety factor of approximately 1 for our design. This factor was approved by Michael Hamilton, the Clinical EIT overseeing the project.

As also indicated by Lynn, there are 16 procedures performed on average during one working day and each patient supports their feet with the footrest twice for one given procedure. Assuming 16 procedures are performed 7 days a week, 52 weeks in a year, for 25 years, the footrest will undergo approximately 300 000 cycles.

It should also be noted that for every patient the nurse encounters he/she will have to deploy the fluid collection system twice on average. A cleaner will also come in between each patient and clean the pan and surrounding area. As such, if the minimum deployment time of the fluid collection system is specified at 2 seconds, and cleaning takes approximately 10 seconds, the total time workers interact with the fluid collection system is 14 seconds per patient.

To better understand the relationship between our needs and metrics, Table III was created. A black dot indicates that the metric can be used to determine if the need is met. As shown in Table III, some metrics, like 21, can be used to determine if multiple needs are met. Table III also shows that some needs, like 3, require more than one metric to determine if the need is met.

TABLE III: NEEDS AND METRICS COMPARISON

Metrics / Needs	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.
1.	•		•																																			
2.		•																																				
3.			•	•	•																																	
4.						•																																
5.							•																															
6.								•												•																		
7.									•																													
8.										•																							•					
9.											•																											
10.												•	•																									
11.														•																								
12.															•						•																	
13.																•					•																	
14.																	•																					
15.																		•	•	•																		
16.																					•																	
17.																						•																
18.																							•	•														
19.												•	•																									
20.																									•													
21.																										•	•											
22.		•																										•										
23.																													•									
24.																														•								
25.																															•							
26.																																•						
27.																																	•					
28.																																		•				
29.																																			•			
30.																																				•	•	
31.																																						•

In summary, we are responsible for the Procedural Table Equipment Retrofit project sponsored by the Winnipeg Regional Health Authority. Specifically, we are tasked with designing a fluid collection system and fast deploying footrest for the mobile padded procedural tables used for dilation and curettage at the Women's Hospital at the Health Sciences Centre. Through designing these aforementioned features, the Women's Hospital will gain access to a mobile procedural table that they can use for dilation and curettage. Our design must be ready to take to fabrication by the machine shop at the Health Sciences Centre.

Our team is primarily constrained by time, budget, size, strength of the design, material, medical device regulation standards, and retrofitting the design to the existing procedural table. The team expected to create a footrest and fluid collection system that is easy to manufacture and does not hinder the mobility of the table. The footrest and fluid collection system must both be deployed in 2 seconds, be attached to the existing frame of the table, be able to be disinfected with Oxivir and/or sterilized in an autoclave. In addition, the footrest and fluid collection system must meet the codes and standards of a class 1 device in Canada, and cost a total of $3000 to implement. The footrest must also be designed to support a weight of 137 kilograms, and all changes made to the table must not hinder the mobility of it. The fluid collection system also needs to contain and support 2 litres of fluid from a procedure, and be located relative to the patient's pertinent anatomy (uterus).

2.0 CONCEPT GENERATION

Once our project was defined, we were able to proceed to the concept generation phase of the project. Concept generation can be thought of as a five-step method, as illustrated in Figure 3 [11].

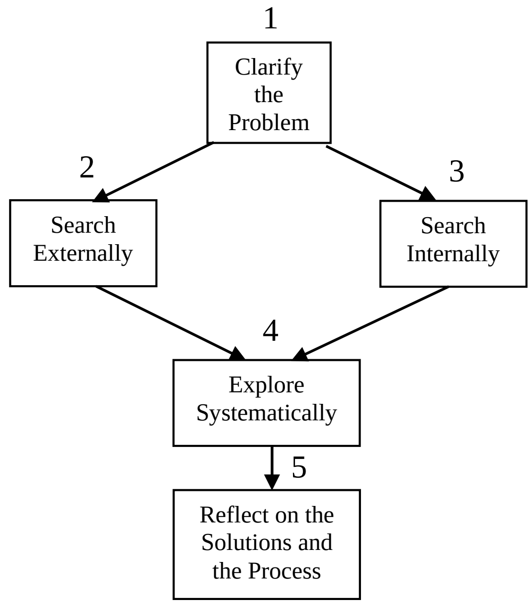


Figure 3: Five-step method for concept generation

As Step 1 has already been completed, our group was able to move on to step 2 and 3. As depicted in Figure 3, step 2 and 3 of concept generation involves external and internal search results, respectively. External search results include any information obtained from lead users, experts, competitors, codes and standards, and patents [11]. Internal search results include any information obtained from an individual's or a group's own knowledge or experience. In the case of our project, an internal search is brainstorming. It should be noted that step 2 and 3 can be done in parallel to one another. Step 4 of the five-step method for concept generation involves exploring ideas systematically to generate new ideas and fuse developed ideas. For our group, step 4 was approached using the following tools: a morphologic box and a contradiction matrix. Step 5 was performed before our team moved on to the concept screening and scoring phase.

In this section of the report, our external search results are presented, along with all concepts that will be moving on to the concept screening and scoring phase. A complete list of our generated concepts can be found in Appendix B. The tools used to explore our ideas systematically are discussed in detail in Appendix B as well.

2.1 EXTERNAL SEARCH RESULTS

By meeting with experts Michael Hamilton, a clinical engineer in training, and Nhien Tu, a mechanical technician, on a biweekly basis, we have been able to understand their expectations and needs on a technical and manufacturing level. We had the privilege to dissemble the mobile procedural table with Nhien during one visit to the HSC. Disassembly of the table allowed us to quantify how limited we were by space, and see how difficult it would be to mount any mechanism to the table due to a thick layer of casting.

Meeting with Lynn Kurylko, the OR Manager at the Women's Hospital, and her staff has also been very helpful. Lynn has provided us with a lot of information regarding the dilation and curettage procedure, and how she would like the procedure to operate with the mobile padded procedural table we are retrofitting. One particular visit with Lynn allowed us to understand the needs associated with the table. During the visit, Lynn went through the entire procedure step by step, particularly outlining where the patient would be positioned throughout the procedure. Lynn also explained the doctor's position with respect to the patient, the nurse's position, the tools used, the location of the tools, and the disposal of the patients fluid.

Meeting with our advisor, Dr. Paul Labossiere, has also been very helpful. He has emphasized the necessity of staying open minded during brainstorming and avoiding excessive influence by our stakeholders.

In addition to meeting with experts and lead users, competitors' products were also researched. Due to the nature of the design, there were very few products from other designers and manufactures that we looked at. In our research we found one operating table that had a removable pan attached to it; this table was made by OPT SurgiSystems Model OPT30/1 [12]. The OPT30/1 did not include a footrest when the fluid collection system was in use. Since the procedural table that we are working on includes a footrest, which is a critical part of the design, the design from OPT SurgiSystems was not very helpful in concept generation.

To get a thorough understanding of the requirements and limitations that we face in the design process, we researched the regulations for the region of application of footrest and fluid collection system designs. The clinical engineers at the HSC informed us that the surgical table would be classified as a Class I device in Canada. This was confirmed by researching classification of hospital equipment. According to the draft guidance document, Risk-based Classification System, the surgical table is classified as a Class I device [13]. The Medical Devices Regulations of Canada were then researched, and the registration and design requirements were studied for Class I devices [14]. According to the Medical Devices Regulations, there are no specific set of requirements to the manufacturing or design of a Class I Medical device. However, according to Section 75 of the Medical Device Regulations, if the device is a custom manufactured device and is to be sold, it requires labelling specifying the name of the manufacturer, the name of the device, and whether the device is custom made.

In addition to the code and standard research conducted, patents were also researched for surgical tables, as well as footrest deployment methods. This was done to ensure the design that we develop does not use an idea that is covered by any patent. This was an extremely important part of the research phase because the Clinical Engineering Department has requested that our design must be marketable. Since our design must be marketable, it is critical that it does not violate any patent covered designs.

The first patents that were researched were folding footrests. Under this category, one patent was found. This patent has a patent number of 2,093,455 and was registered with the United States Patent Office on September 21, 1937 [15]. Since this patent is much older than 20 years, it has expired and does not restrict our design. The patent research was expanded and patents on birthing beds were researched. The United States Patent Office has a patent registered under patent number 5,157,800; this patent was filed on October 27, 1992 titled "Foot Section for Birthing Bed" [16]. Since the patent is also over 20 years old, it has also expired. Lastly, patents for general surgery tables were researched. Once again a patent was found that had expired – it has a patent number of 3,411,766, which was filed on February. 23, 1966 [17]. Based on our search results, we found that we were not limited to any specific designs due to patent rights, and could proceed with the concept development.

2.2 INTERNAL SEARCH RESULTS

During this stage of the project, our team decided to isolate the footrest and fluid collection system problem we were tasked with solving. During our group's brainstorming session, the members of our team came prepared with ideas they generated individually. This preparation led to a productive meeting with many ideas being generated. After this initial concept generation session, our team began to generate ideas using a more systematic approach. Particularly, our team used the following tools: a morphologic box and a contradiction matrix. Through the use of a morphologic box and the contradiction matrix connected to TRIZ, we were able to generate a number of fused concepts for the footrest and fluid collection system.

Once the concept generation phase was complete, the team reviewed the concepts generated to see if any ideas could be eliminated before screening. Concepts were eliminated based on the group's intuition and known customer needs. After this initial screening, a number of concepts were chosen to take into a more in depth screening and scoring process.

A complete list of all concepts our team generated for the table design can be found in the Appendix B, along with a more detailed description of the tools we used for the systematic exploration of our ideas. Table IV and V present the 14 footrest and 10 fluid collection system concepts we have chosen for in depth screening and scoring, respectively. Advantages and disadvantages of each design are listed in Table IV and V as well.

TABLE IV: FOOTREST CONCEPT GENERATION

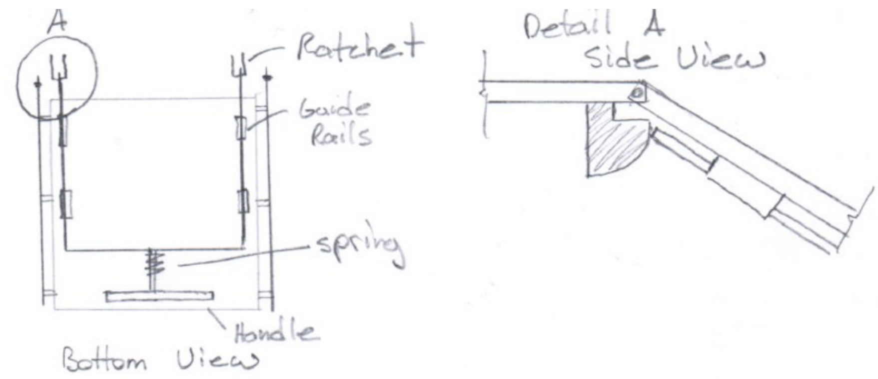
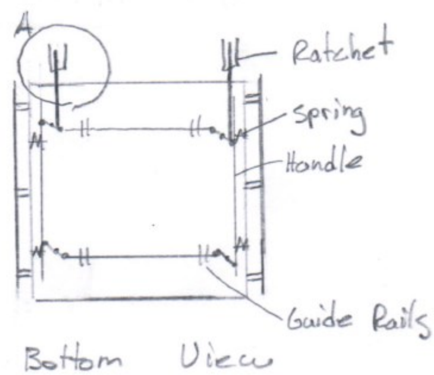
<table>
<tr><td rowspan="3">Concept 1:
Lever-Ratchet
Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Can be operated with one hand and would be very smooth to operate.
- Fast deployment time.</td><td>- Complex to manufacture.
- Contains a spring.
- Difficult to clean.
- Mechanism could become off centered due to single spring.
- All the patient’s weight relies on two pins in a ratchet.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 2:
Double
Lever-Ratchet
Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Good accessibility from both sides of the table.
- User friendly and easy to operate.</td><td>- Complex to manufacture.
- Contains multiple springs.
- High risk of jamming during operation.
- Operation is from the side of the table, not the end.
- All the patient’s weight relies on two pins in a ratchet.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE IV: FOOTREST CONCEPT GENERATION

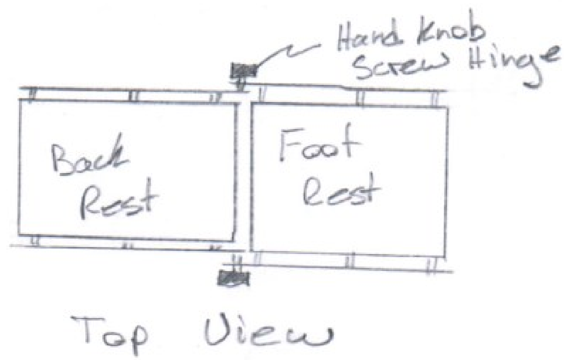
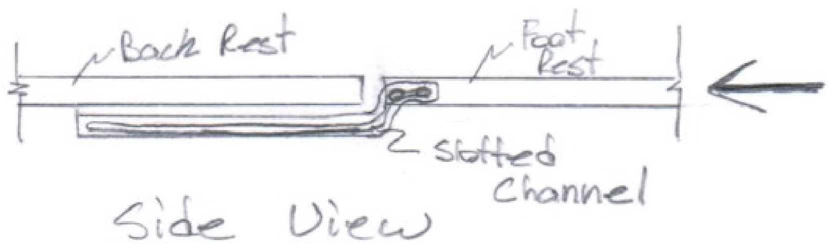
Concept 5: Screw Hinge Footrest		
	Advantages	Disadvantages
	- Easy to manufacture and install. - Simple to operate. - Easy to understand.	- Not ergonomic for nurses. - Short expected life cycle of screw. - Lack of support strength.
Concept 8: Hidden Slide-in Footrest		
	Advantages	Disadvantages
	- Easy to use. - Aesthetically pleasing. - Quick to operate.	- Difficult to manufacture. - Space restriction under the table. - Difficult to clean slide tracks.

TABLE IV: FOOTREST CONCEPT GENERATION

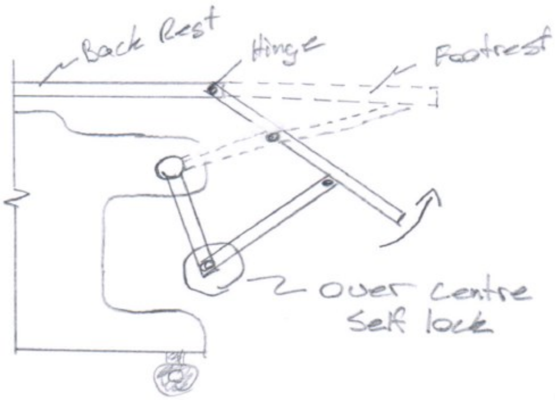
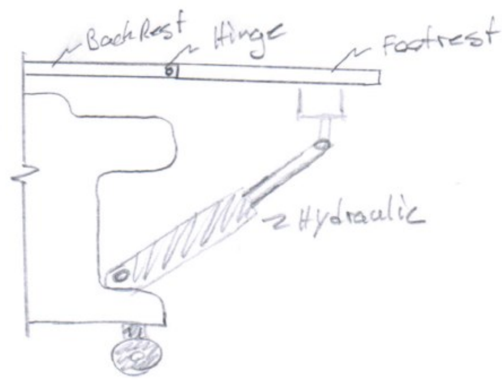
Concept 10: Lever Arm Assembly Over Center Footrest		
	Advantages	Disadvantages
	- Uses current support system (low cost). - Provides good support for required weight specification. - Quick to operate.	- Difficult to provide simple locking mechanism for lever arm assembly.
Concept 11: Hydraulic Powered Footrest		
	Advantages	Disadvantages
	- Easy to use. - Requires no physical effort from nurses.	- Would take too long to deploy footrest. - Difficult to implement.

TABLE IV: FOOTREST CONCEPT GENERATION

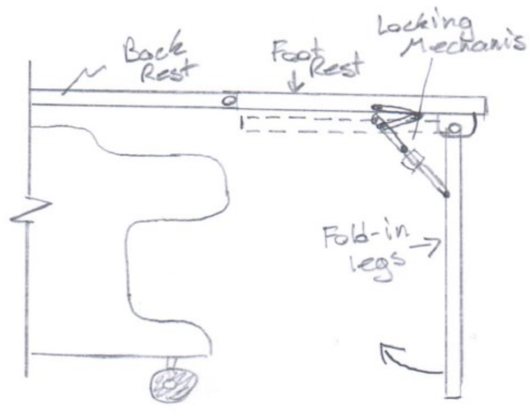
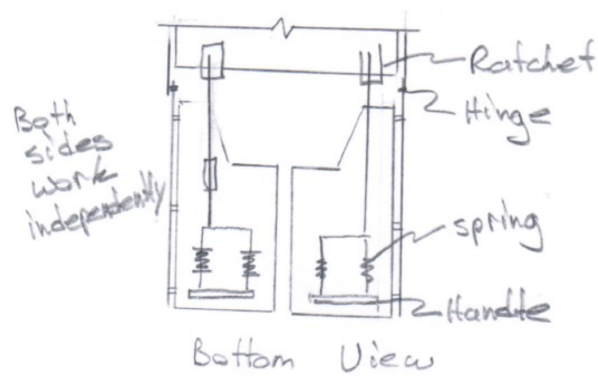
<table>
<tr><td rowspan="4">Concept 12:
Fold out legs
Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Provides solid support for footrest.</td><td>- Long deployment time.</td></tr>
<tr><td>- Easy to manufacture.</td><td>- Cumbersome to operate.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="6">Concept 13:
Two-piece
Footrest with
Ratchets</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Not a lot of effort required for deployment.</td><td>- Deployment is a two-step procedure (longer deployment time).</td></tr>
<tr><td>- Ergonomic.</td><td>- Contains multiple springs.</td></tr>
<tr><td>- Easy to understand/operate.</td><td>- Complex to manufacture.</td></tr>
<tr><td>- Option to keep one leg supported.</td><td></td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE IV: FOOTREST CONCEPT GENERATION

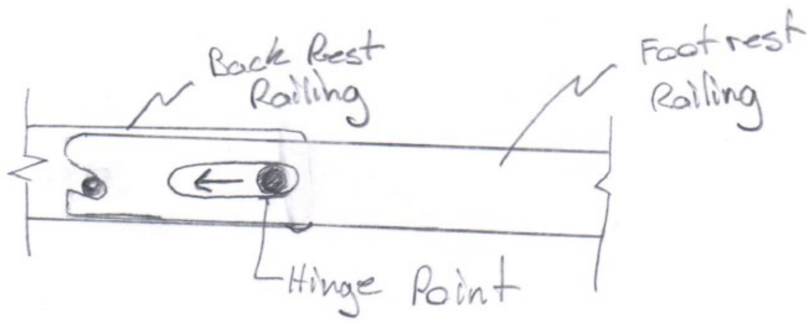
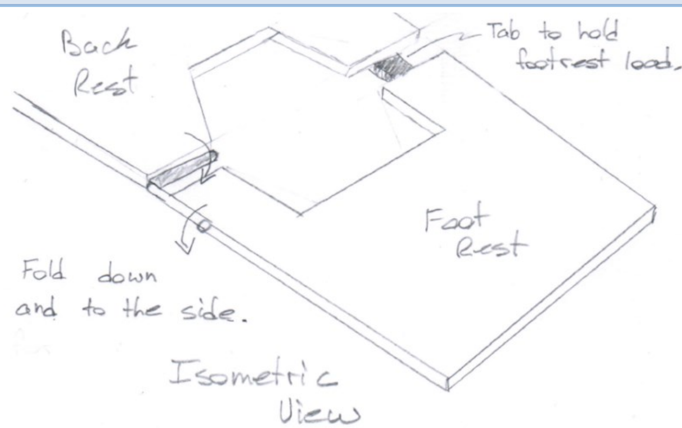
Concept 14: Slide Pin Footrest		
	Advantages	Disadvantages
	- Easy to manufacture. - Simple to operate.	- Difficult to design to support required weight specifications. - Risk of footrest falling if not properly engaged.
Concept 17: Side Hinged Footrest		
	Advantages	Disadvantages
	- Footrest is out of the immediate vicinity where the procedure will be performed.	- Big sweeping movements of the footrest is required. - Difficult to design to support required load. - Not ergonomic.

TABLE IV: FOOTREST CONCEPT GENERATION

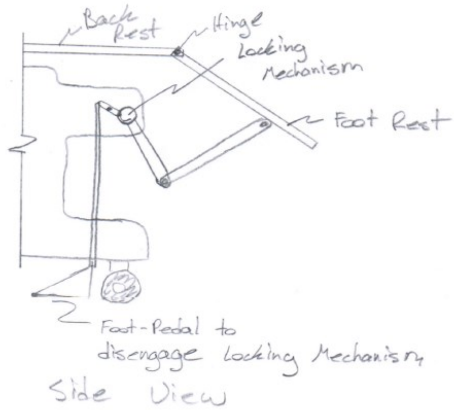
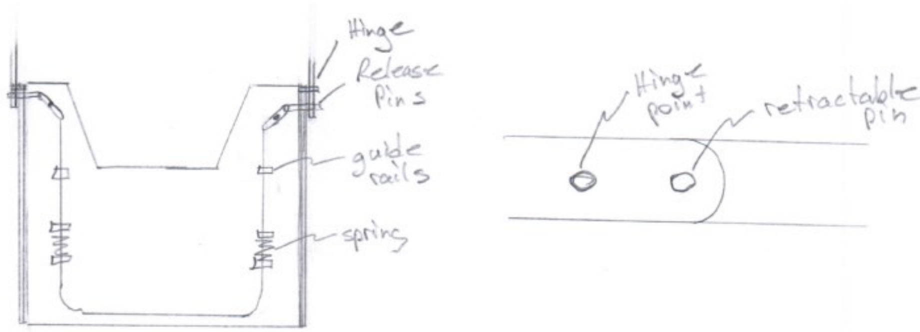
<table>
<tr><td rowspan="3">Concept 18: Pedal Operated Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Simple and quick to operate.
- Uses current support system (low cost).
- Provides good support for required weight specification.</td><td>- Only accessible from one side.
- Operation is from the side of the table, not the end.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 22: Horizontal Spring Loaded Pin with Handle on Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Fast deployment.
- User friendly and easy to operate.
- Requires minimal change to current footrest.</td><td>- May result in jamming of rods between handle and pin.
- X-motion needs to be converted to Y-motion.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE IV: FOOTREST CONCEPT GENERATION

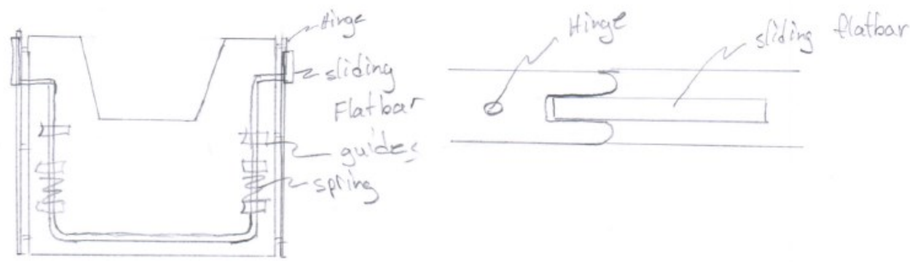
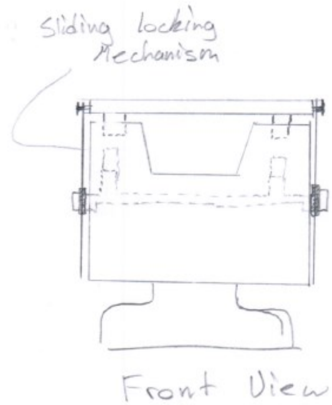
<table>
<tr><td rowspan="3">Concept 23: Spring Loaded Flat-bar with Handle on Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Fast deployment.
- User friendly and easy to operate.
- Requires minimal change to current footrest.</td><td>- May result in jamming of rods between flat-bar and handle.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 24: Sliding Bar Locking Mechanism Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to manufacture and cheap.
- Easy to install.</td><td>- Could be cumbersome to operate.
- Will add additional weight to footrest.
- Handles would be interfere with side rails.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE V: FLUID COLLECTION SYSTEM CONCEPT GENERATION

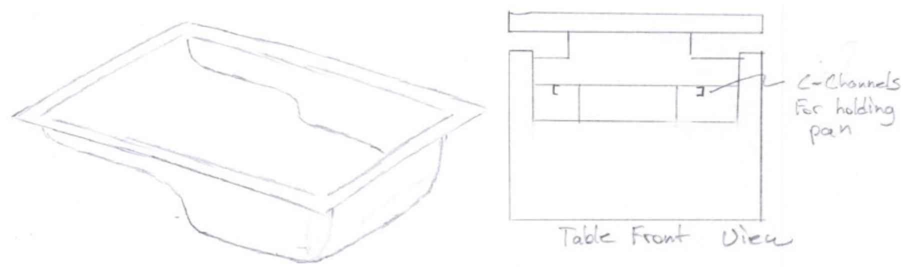
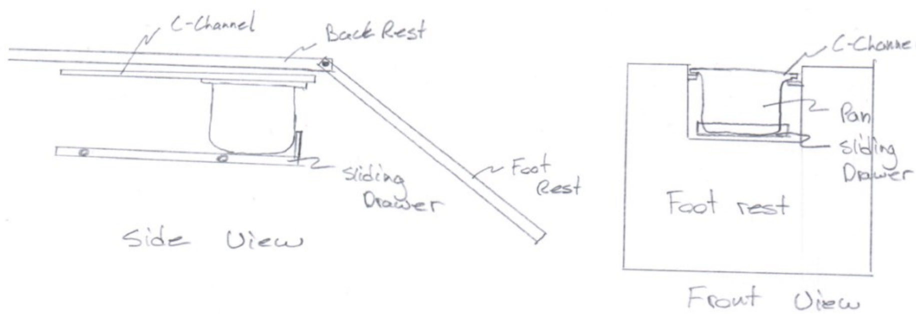
<table>
<tr><td rowspan="3">Concept 1: Custom Fluid Collection Pan on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Keeps the current volume specifications.
- Fits around the gearbox located underneath the table.</td><td>- Difficult to manufacture.
- More costly than a pre-made pan.
- Could have 90 degree corners, which are difficult to clean.
- Cannot store pan under the table.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 2: Small Fluid Collection Pan with Sliding Drawer on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to deploy.
- Simple to manufacture/modify purchased pan.
- Could store pan under the table.</td><td>- Total volume is less than current pan.
- Deployment mechanism may be quite complicated to install.
- Fluid could get inside bearings.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE V: FLUID COLLECTION SYSTEM CONCEPT GENERATION

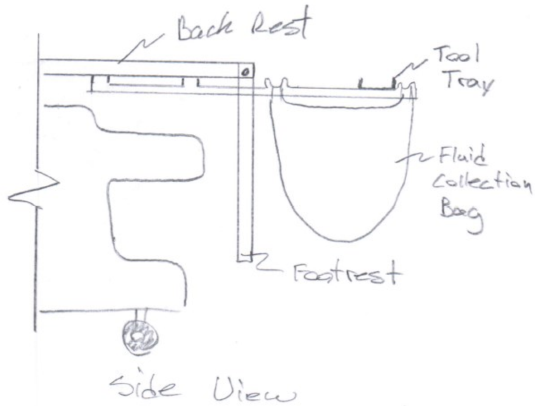
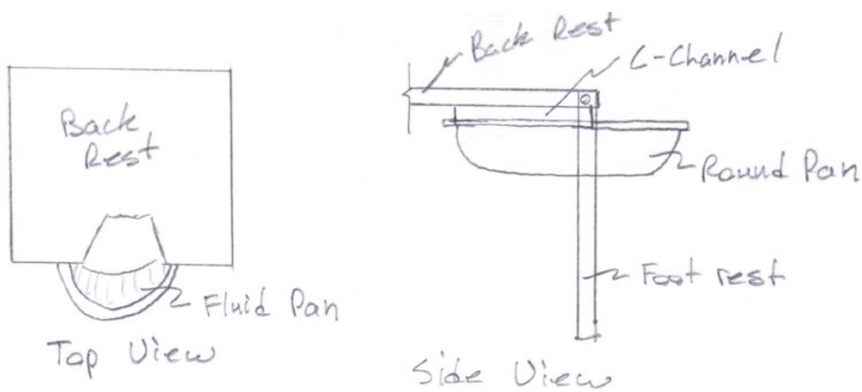
<table>
<tr><td rowspan="3">Concept 3: Fluid Collection Bag on Rails with Hooks</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Eliminates need to clean pan.
- Fast deployment.</td><td>- Fluid bag is unsupported.
- Need to find pre made bags that they can purchase.
- Tools are not in the location where surgeons are used to them.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 4: Round Fluid Collection Pan on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to deploy.
- Easy to manufacture.
- Pan is premade, so cheap to purchase.
- Could store pan under the table.</td><td>- Will not contain volume the same volume as the current pan.
- Could have cleaning issues in deploying railings.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE V: FLUID COLLECTION SYSTEM CONCEPT GENERATION

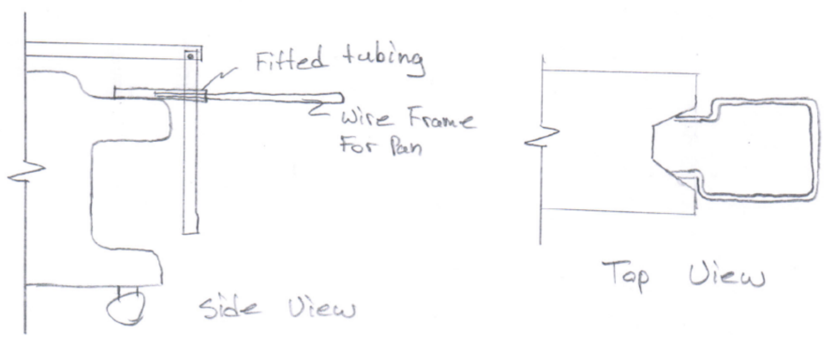
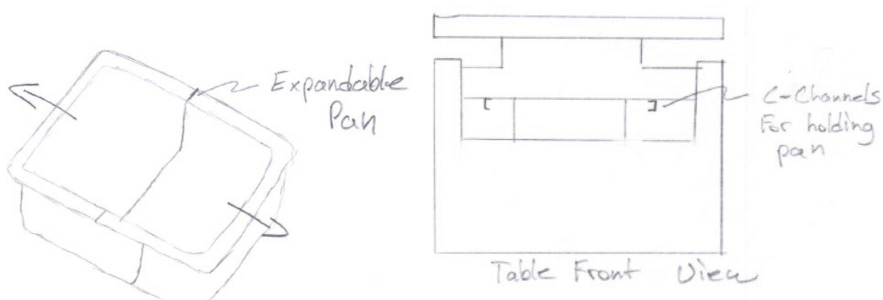
<table>
<tr><td rowspan="3">Concept 5: Rod Frame Fluid Collection Pan Holder with Fitted Tubing</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Not restricted to pan size (rod can be bent to fit any pan shape).
- Easy to install.
- Easy to remove pan after procedure.
- Easy and cheap to manufacture.</td><td>- Cannot store tray under the procedural table as currently practiced.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 7: Expandable Fluid Collection Pan on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Could store pan under the table.
- Expand pan for fluid capacity during procedure.</td><td>- Difficult to have an expandable pan that will seal well.
- Difficult to clean sealed edges.
- Difficult to manufacture</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE V: FLUID COLLECTION SYSTEM CONCEPT GENERATION

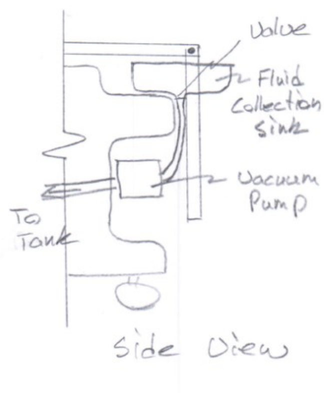
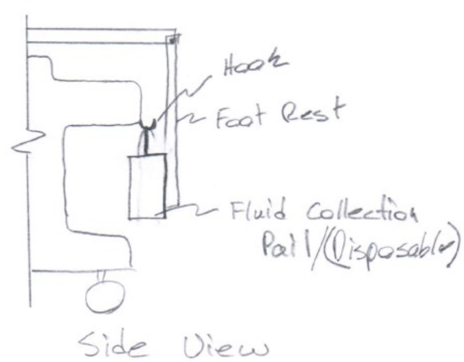
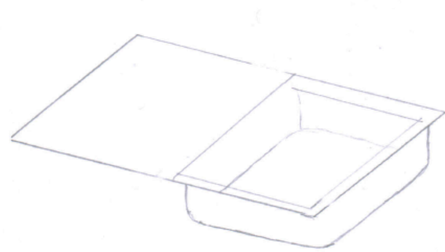
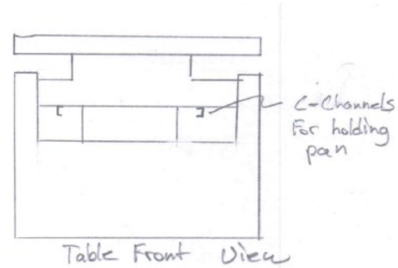
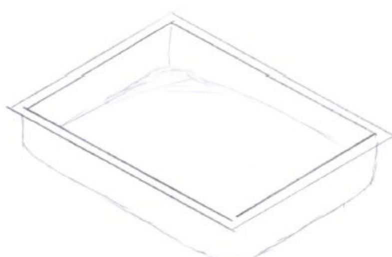
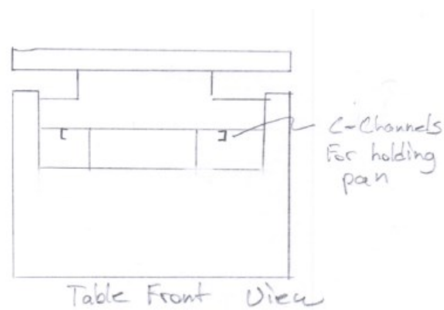
Concept 10: Small Fluid Collection Pan with Vacuum Pump		
	Advantages	Disadvantages
	- Fluid would be pumped into larger waste container immediately. - Not limited to size due to volume requirements.	- Noisy. - Expensive to implement.
Concept 12: Disposable Hanging Fluid Collection Pail		
	Advantages	Disadvantages
	- No cleaning required of the pan. - All-in-one system used for collecting and disposing of fluids.	- No working surface for surgeon. - Difficult to find supplier. - Long term costs.

TABLE V: FLUID COLLECTION SYSTEM CONCEPT GENERATION

<table>
<tr><td rowspan="3">Concept 13: Extended Flange Fluid Collection Pan on C-channels</td><td colspan="2">



</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Provides additional deployment distance.
- Easy to manufacture/modify purchased part.</td><td>- Decreased pan volume.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 16: Regular Fluid Collection Pan on C-channels</td><td colspan="2">



</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Pan can be purchased/easily modified to meet size constraints.
- Same as current design.</td><td>- Hard to fit purchased pan into designated area.
- May require frame modifications to make pan fit.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

In summary, 14 footrest concepts and 10 fluid collection concepts were chosen for in depth screening; they are listed in Table VI and Table VII, respectively.

TABLE VI: FOOTREST CONCEPTS FOR SCREENING PHASE

Concept Number	Concept Description
Concept 1	Lever-Ratchet Footrest
Concept 2	Double Lever-Ratchet Footrest
Concept 5	Screw Hinge Footrest
Concept 8	Hidden Slide-in Footrest
Concept 10	Lever Arm Assembly Over Center Footrest
Concept 11	Hydraulic Powered Footrest
Concept 12	Fold out legs Footrest
Concept 13	Two-piece Footrest with Ratchets
Concept 14	Slide Pin Footrest
Concept 17	Side Hinged Footrest
Concept 18	Pedal Operated Footrest
Concept 22	Horizontal Spring Loaded Pin with Handle on Footrest
Concept 23	Spring Loaded Flat-bar with Handle on Footrest
Concept 24	Sliding Bar Locking Mechanism Footrest

TABLE VII: FLUID COLLECTION SYSTEM CONCEPTS FOR SCREENING PHASE

Concept Number	Concept Description
Concept 1	Custom Fluid Collection Pan on C-channels
Concept 2	Small Fluid Collection Pan with Sliding Drawer on C-channels
Concept 3	Fluid Collection Bag on Rails with Hooks
Concept 4	Round Fluid Collection Pan on C-channels
Concept 5	Rod Frame Fluid Collection Pan Holder with Fitted Tubing
Concept 7	Expandable Fluid Collection Pan on C-channels
Concept 10	Small Fluid Collection Pan with Vacuum Pump
Concept 12	Disposable Hanging Fluid Collection Pail
Concept 13	Extended Flange Fluid Collection Pan on C-channels
Concept 16	Regular Fluid Collection Pan on C-channels

3.0 CONCEPT SCREENING AND SCORING

In order to determine which generated concept(s) met the client's needs best, a systematic approach was developed. This approach included screening and scoring our concepts, as well as a sensitivity analysis. Concept screening is a quick evaluation process that produces a few alternatives for further evaluation. Concept scoring is a detailed evaluation of the concepts that made it through the screening process. The purpose of concept screening and scoring is to determine the concept(s) most likely to create product success [18]. A sensitivity analysis is used to determine how sensitive the overall scores of concepts are to changes within the concept scoring matrix. Within this section of the report, our screening and scoring matrices will be presented, along with a sensitivity analysis.

3.1 CONCEPT SCREENING

In the screening phase, each concept listed in Table VI and VII was compared against the current stationary table's design to see if the design was better, worse, or the same at meeting the selection criteria. The selection criteria used to screen concepts for both the footrest and the fluid collection system are as follows: speed of deployment, ease of deployment, manufacturability, safety, durability user friendly, and cost concerns. If the concept met the selection criteria better, worse, or the same, it was given a '+', '-', or '0' rating, respectively. The scores were then totaled to determine which concepts improved upon the current stationary tables design. Concepts that improved upon the design were carried on to the concept scoring phase. The concept screening tables reduced the number of footrest and fluid collection system concepts from 14 to 7, and 10 to 4, respectively. The concept screening phase matrix for the footrest and fluid collection system are shown in Table VIII and IX, respectively. Concepts that improved upon the existing design are highlighted in yellow.

TABLE VIII: FOOTREST CONCEPT SCREENING

	Footrest Mechanism Concepts														
	1	2	5	8	10	11	12	13	14	17	18	22	23	24	Current Table
Description / **Selection Criteria**	Single Ratchet	Double Ratchet	Screw Support	Sliding Hidden	Lever Arm Over Center	Hydraulic	Fold Out Legs	Two Legs - Ratchet	Slide Pin	Side Hinge	Lever Arm with Pedal	Horizontal Spring Pin	Spring Loaded Flat Bar	Sliding Bar	Rod in Rod
Speed of Deployment	+	+	-	+	0	-	-	+	0	-	+	+	+	+	0
Ease of Deployment	+	+	0	+	0	+	-	+	0	0	0	+	+	+	0
Manufacturability	-	-	+	-	+	-	0	-	+	0	-	-	-	-	0
Ergonomic	+	+	-	+	0	+	-	+	0	-	-	+	+	-	0
Safety	+	+	-	-	-	-	0	0	-	0	0	-	+	+	0
Durability	0	0	-	-	+	+	0	0	+	0	0	0	0	0	0
Cost	-	-	+	-	+	-	0	-	+	0	-	-	-	-	0
User Friendly	+	0	-	+	0	+	-	+	0	-	-	+	+	0	0
Sum +'s	5	4	2	4	3	4	0	4	3	0	1	4	5	3	
Sum -'s	2	2	5	4	1	4	4	2	1	3	4	3	2	3	
Sum 0's	1	2	1	0	4	0	4	2	4	5	3	1	1	2	
Net Score	3	2	-3	0	2	0	-4	2	2	-3	-3	1	3	0	
Rank	1	2	5	4	2	4	6	2	2	5	5	3	1	4	
Continue?	Yes	Yes	No	No	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	

TABLE IX: FLUID COLLECTION SYSTEM CONCEPT SCREENING

Description / **Selection Criteria**	**Fluid Collection System Concepts**										
	1	2	3	4	5	7	10	12	13	16	Current Table
	Custom Pan on C-channels	Sliding Drawer with Bottom Support	Bag on Rails	Round Pan on C-channels	Rod Frame Holder with Fitted Tubes	Expandable Pan on C-channels	Small Pan with Vacuum	Disposable Pail	Extended Flange on C-channels	Regular Pan (C-channels)	Pan with Envelope Support
Speed of Deployment	+	+	+	+	+	-	+	+	+	+	0
Ease of Deployment	+	+	0	+	+	-	+	+	+	+	0
Manufacturability	-	0	-	-	+	-	-	0	0	0	0
Ergonomic	0	0	0	0	0	0	+	0	0	0	0
Safety	-	0	-	0	0	-	-	-	0	0	0
Durability	0	0	-	0	0	-	-	-	0	0	0
Cost	-	0	+	-	0	-	-	-	-	0	0
User Friendly	0	0	-	-	0	0	+	-	0	+	0
Sum +'s	2	2	2	2	3	0	4	2	2	3	
Sum -'s	3	0	4	3	0	6	4	4	1	0	
Sum 0's	3	6	2	3	5	2	0	2	5	5	
Net Score	-1	2	-2	-1	3	-6	0	-2	1	3	
Rank	5	2	6	5	1	7	4	6	3	1	
Continue?	No	Yes	No	No	Yes	No	No	No	Yes	Yes	

Concepts selected to move on to the concept scoring phase were chosen if they scored higher than a net score of zero. For the footrest, Concept 1, 2, 10, 13, 14, 22, and 23 were chosen for further evaluation, while for the fluid collection system, Concept 2, 5, 13, and 16 were chosen for further evaluation.

3.2 CONCEPT SCORING

As concept scoring is a more detailed analysis of concept feasibility, a more thorough list of selection criteria was needed for the concept scoring phase, compared to the concept screening phase. The new set of selection criteria was created by breaking down the list of criteria from the screening phase into more specific areas. In concept scoring, the criteria are also weighted. The weight of each criteria is established by comparing each criteria in a weighting matrix against one another, to determine which criteria is more important. The criteria weighting matrix for the footrest and fluid collection system is shown in Table X and XI, respectively.

As shown in Table X and XI, each selection criteria was given a letter. The letter of the criteria which the team deemed to be more important at satisfying the client's needs was recorded in the matrix. The number of times each criteria prevailed over the others was tallied and divided by the total number of comparisons. This gave each criteria a weighting of importance for meeting the design requirements and client needs.

TABLE X: FOOTREST SELECTION CRITERIA WEIGHTING MATRIX

	Footrest Mechanism Selection Criteria	Speed of deployment	Support patients weight	Maintains current tables functionality	Easy to manufacture	Lightweight	Durable	Aesthetically pleasing	Easy to install/uninstall	Safe to Use	Ergonomic for the person moving it	Will withstand cyclic loading	Mechanism for deployment is lightweight	Affordable to produce	Easily cleanable	Deployment mechanism is easily found	Straight-forward to use	The retrofit is affordable to produce
	Footrest Mechanism Selection Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
A	Speed of deployment		B	A	A	A	F	A	A	I	A	K	A	A	N	A	A	A
B	Support patients weight			B	B	B	B	B	B	I	B	B	B	B	B	B	B	B
C	Maintains current tables functionality				C	E	F	C	C	I	J	K	C	M	N	O	C	Q
D	Easy to manufacture					E	F	D	D	I	J	K	D	M	N	O	P	Q
E	Lightweight						F	E	E	I	J	K	E	E	N	E	E	E
F	Durable							F	F	I	J	K	F	F	N	F	F	F
G	Aesthetically pleasing								H	I	J	K	L	M	N	O	P	Q
H	Easy to install/uninstall									I	J	K	L	M	N	O	P	Q
I	Safe to Use										I	I	I	I	I	I	I	I
J	Ergonomic for the person moving it											K	J	J	N	O	P	J
K	Will withstand cyclic loading												K	K	N	K	K	K
L	Mechanism for deployment is lightweight													M	N	O	P	Q
M	Affordable to produce														N	O	P	Q
N	Easily cleanable															N	N	N
O	Deployment mechanism is easily found																O	O
P	Straight-forward to use																	P
Q	The retrofit is affordable to produce																	
	Total Hits	11	15	5	3	9	11	0	1	16	9	13	2	5	14	9	7	6
	Weightings	0.08	0.11	0.04	0.02	0.07	0.08	0.00	0.01	0.12	0.07	0.10	0.01	0.04	0.10	0.07	0.05	0.04

TABLE XI: FLUID COLLECTION SYSTEM SELECTION CRITERIA WEIGHTING MATRIX

	Fluid Collection System Selection Criteria	System can be quickly deployed	Contains fluid from a procedure	Supports fluid and tools from a procedure	Components are easily cleanable	Accessible during entire procedure	Affordable to produce	Maintains current tables functionality	Durability	Easy to manufacture	Lightweight	Aesthetically pleasing	Easy to install/uninstall	Safe to operate	Ergonomic for the person using it
	Fluid Collection System Selection Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
A	System can be quickly deployed		B	C	D	E	F	G	H	A	A	A	A	M	A
B	Contains fluid from a procedure			B	B	B	B	B	B	B	B	B	B	B	B
C	Supports fluid and tools from a procedure				C	C	C	C	C	C	C	C	C	C	C
D	Components are easily cleanable					D	D	D	D	D	D	D	D	M	D
E	Accessible during entire procedure						F	G	H	E	E	E	E	M	E
F	Affordable to produce							G	H	F	F	F	F	M	N
G	Maintains current tables functionality								H	G	G	G	G	M	G
H	Durability									H	H	H	H	M	H
I	Easy to manufacture										I	I	I	M	I
J	Lightweight											J	J	M	N
K	Aesthetically pleasing												L	M	N
L	Easy to install/uninstall													M	N
M	Safe to operate														M
N	Ergonomic for the person using it														
	Total Hits	5	13	12	10	6	6	8	9	4	2	0	1	11	4
	Weightings	0.05	0.14	0.13	0.11	0.07	0.07	0.09	0.10	0.04	0.02	0.00	0.01	0.12	0.04

Once the weighting of each selection criteria was determined from the criteria weighting matrices, each concept could then be analyzed against one another. A concept scoring table was created to determine which conceptual designs met the selection criteria best. Using the selection criteria and its weighting of importance, each concept was given a score between 0 and 3 based on how well the team felt it met the criteria; a description for each score is presented in Table XII.

TABLE XII: CONCEPT RATING LEGEND FOR SCORING MATRICES

Rating Number	Rating Description
0	Poor
1	Average
2	Strong
3	Exceptional

The ratings determined by the team were multiplied by the weight of that criteria to give each concept a weighted score. Weighted scores for each concept were then added and a total score for each concept was attained. The team compared the total scores of each concept and ranked the concepts accordingly. Using these ratings, concept scoring tables were created to determine which concepts will be selected for further analysis.

Concepts selected through the concept screening phase are rated in Table XIII and XIV, respectively. The results of the concept scoring tables for the footrest and fluid collection system show that the footrest Concept 14 and the fluid collection system Concept 16 scored higher than the others. It should be noted that although the rated score for footrest Concept 14 was highest, it only scored 0.05 higher than footrest Concept 23. It should also be noted that although the rated score for the fluid collection system Concept 16 was highest, it only scored 0.02 higher than the fluid collection system Concept 5.

TABLE XIII: FOOTREST CONCEPT SCORING

	Description	Concepts													
		1 Single Ratchet		2 Double Ratchet		10 Lever Arm Over Center		13 Two Legs - Ratchet		14 Slide Pin		22 Horizontal Spring Pin		23 Spring Loaded Flat Bar	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Speed of deployment	0.08	3	0.24	3	0.24	2	0.16	2	0.16	3	0.24	3	0.24	3	0.24
Support patients weight	0.11	2	0.22	2	0.22	2	0.22	2	0.22	2	0.22	2	0.22	3	0.33
Maintains current tables functionality	0.04	2	0.07	2	0.07	3	0.11	2	0.07	2	0.07	2	0.07	2	0.07
Easy to manufacture	0.02	2	0.04	1	0.02	3	0.07	1	0.02	3	0.07	2	0.04	3	0.07
Lightweight	0.07	2	0.13	1	0.07	3	0.20	3	0.20	3	0.20	3	0.20	2	0.13
Durable	0.08	3	0.24	3	0.24	2	0.16	3	0.24	2	0.16	3	0.24	3	0.24
Aesthetically pleasing	0.00	2	0.00	2	0.00	2	0.00	3	0.00	2	0.00	2	0.00	2	0.00
Easy to install/uninstall	0.01	1	0.01	1	0.01	3	0.02	1	0.01	3	0.02	1	0.01	2	0.01
Safe to Use	0.12	2	0.24	2	0.24	1	0.12	2	0.24	2	0.24	2	0.24	2	0.24
Ergonomic for the person moving it	0.07	3	0.20	3	0.20	2	0.13	3	0.20	2	0.13	3	0.20	3	0.20
Will withstand cyclic loading	0.10	2	0.19	2	0.19	3	0.29	2	0.19	3	0.29	2	0.19	2	0.19
Mechanism for deployment is lightweight	0.01	1	0.01	1	0.01	3	0.04	1	0.01	3	0.04	1	0.01	1	0.01
Affordable to produce	0.04	3	0.11	3	0.11	3	0.11	2	0.07	3	0.11	2	0.07	3	0.11
Easily cleanable	0.10	1	0.10	1	0.10	2	0.21	1	0.10	3	0.31	1	0.10	1	0.10
Deployment mechanism is easily found	0.07	3	0.20	3	0.20	1	0.07	3	0.20	3	0.20	3	0.20	3	0.20
Straight-forward to use	0.05	3	0.15	3	0.15	1	0.05	3	0.15	1	0.05	3	0.15	3	0.15
The retrofit is affordable to produce	0.04	3	0.13	3	0.13	3	0.13	3	0.13	3	0.13	3	0.13	3	0.13
TOTAL SCORE		2.30		2.21		2.09		2.23		2.49		2.33		2.44	
RANK		4		6		7		5		1		3		2	
Continue?		No		No		No		No		Develop		No		No	

TABLE XIV: FLUID COLLECTION SYSTEM CONCEPT SCORING

		Concepts							
	Description	2 Sliding Drawer with Bottom Support		5 Rod Frame Holder with Fitted Tubes		13 Extended Flange on C-channels		1 Regular Pan on C-channels	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Wighted Score**	**Rating**	**Wighted Score**	**Rating**	**Wighted Score**
System can be quickly deployed	0.05	3	0.16	3	0.16	3	0.16	3	0.16
Contains fluid from a procedure	0.14	2	0.29	3	0.43	3	0.43	3	0.43
Supports fluid and tools from a procedure	0.13	3	0.40	3	0.40	3	0.40	3	0.40
Components are easily cleanable	0.11	1	0.11	3	0.33	3	0.33	3	0.33
Accessible during entire procedure	0.05	3	0.16	3	0.16	3	0.16	3	0.16
Affordable to produce	0.05	2	0.11	3	0.16	2	0.11	3	0.16
Maintains current tables functionality	0.08	2	0.15	0	0.00	0	0.00	0	0.00
Durability	0.10	2	0.20	3	0.30	3	0.30	3	0.30
Easy to manufacture	0.08	2	0.15	3	0.23	2	0.15	3	0.23
Lightweight	0.02	3	0.07	2	0.04	3	0.07	3	0.07
Aesthetically pleasing	0.00	2	0.00	3	0.00	3	0.00	3	0.00
Easy to install/uninstall	0.01	2	0.02	3	0.03	3	0.03	3	0.03
Safe to operate	0.12	2	0.24	3	0.36	3	0.36	3	0.36
Ergonomic for the person using it	0.04	2	0.09	2	0.09	2	0.09	2	0.09
TOTAL SCORE		2.15		2.70		2.59		2.73	
RANK		4		2		3		1	
Continue?		No		No		No		Develop	

3.3 SENSITIVITY ANALYSIS

After presenting the preliminary concepts to the client, the team discovered that the weighting of the “easy to manufacture” selection criteria was more important than originally predicted. The team revisited the criteria weighting matrices to address the comments made by the client. This helped to check the sensitivity of the weighting matrix, as well as the concept scoring matrix. The weighted criteria “easy to manufacture” increased from 2 to 5% for the footrest and from 4 to 8% for the fluid collection system. After altering the ease of manufacturing selection criteria, the team analyzed the new rankings from the concept scoring tables. The altered weightings due to ease of manufacturability had no effect on the concept rankings.

The team further analyzed the concept scoring table and realized that the total scores for the footrest concepts 14 and 23, as well as for the fluid collection system concepts 5 and 16, only varied slightly. During the concept scoring phase there were a number of instances where the team deliberated extensively on which rating a concept should receive for meeting certain selection criteria. Due to the extensive deliberation, and the uncertainty of some of the ratings given, the team decided to further check the sensitivity of the concept scoring matrices by altering the ratings of Concept 5 and 23.

First, the sensitivity of the footrest concepts was analyzed. By increasing any one of the following criteria for Concept 23 by one point, a higher total score when compared to Concept 14 is obtained: lightweight, withstand cyclic loading, safety and easy to clean. Changing any of the selection criteria by one point for Concept 22, the third ranked concept, did not alter the concept rankings. An example of the sensitivity of the scoring of Concept 14 and 23 is shown in Table XV, with the altered rating highlighted. In Table XV, the “safe to use” selection criteria was altered because it produced the most drastic total score change. In fact, Concept 23’s total score increased from 2.44 to 2.56, putting it 0.06 points ahead of Concept 14.

TABLE XV: FOOTREST CONCEPT SCORING SENSITIVITY ANALYSIS

	Description	Concepts													
		1 Single Ratchet		2 Double Ratchet		10 Lever Arm Over Center		13 Two Legs - Ratchet		14 Slide Pin		22 Horizontal Spring Pin		23 Spring Loaded Flat Bar	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Speed of deployment	0.08	3	0.24	3	0.24	2	0.16	2	0.16	3	0.24	3	0.24	3	0.24
Support patients weight	0.11	2	0.22	2	0.22	2	0.22	2	0.22	2	0.22	2	0.22	3	0.33
Maintains current tables functionality	0.04	2	0.07	2	0.07	3	0.11	2	0.07	2	0.07	2	0.07	2	0.07
Easy to manufacture	0.05	2	0.10	1	0.05	3	0.15	1	0.05	3	0.15	2	0.10	3	0.15
Lightweight	0.07	2	0.13	1	0.07	3	0.20	3	0.20	3	0.20	3	0.20	2	0.13
Durable	0.08	3	0.24	3	0.24	2	0.16	3	0.24	2	0.16	3	0.24	3	0.24
Aesthetically pleasing	0.00	2	0.00	2	0.00	2	0.00	3	0.00	2	0.00	2	0.00	2	0.00
Easy to install/uninstall	0.01	1	0.01	1	0.01	3	0.02	1	0.01	3	0.02	1	0.01	2	0.01
Safe to Use	0.12	2	0.24	2	0.24	1	0.12	2	0.24	2	0.24	2	0.24	3	0.35
Ergonomic for the person moving it	0.07	3	0.20	3	0.20	2	0.13	3	0.20	2	0.13	3	0.20	3	0.20
Will withstand cyclic loading	0.10	2	0.19	2	0.19	3	0.29	2	0.19	3	0.29	2	0.19	2	0.19
Mechanism for deployment is lightweight	0.01	1	0.01	1	0.01	3	0.04	1	0.01	3	0.04	1	0.01	1	0.01
Affordable to produce	0.03	3	0.09	3	0.09	3	0.09	2	0.06	3	0.09	2	0.06	3	0.09
Easily cleanable	0.10	1	0.10	1	0.10	2	0.21	1	0.10	3	0.31	1	0.10	1	0.10
Deployment mechanism is easily found	0.06	3	0.18	3	0.18	1	0.06	3	0.18	3	0.18	3	0.18	3	0.18
Straight-forward to use	0.04	3	0.13	3	0.13	1	0.04	3	0.13	1	0.04	3	0.13	3	0.13
The retrofit is affordable to produce	0.04	3	0.11	3	0.11	3	0.11	3	0.11	3	0.11	3	0.11	3	0.11
TOTAL SCORE		2.27		2.15		2.12		2.18		2.50		2.31		2.56	
RANK		4		6		7		5		2		3		1	
Continue?		No		No		No		No		Develop		No		Develop	

Since the concept scoring table is sensitive when changing the ratings between the top two concepts (14 and 23), both Concept 14 and 23 have been selected to be taken through to the final design phase for further analysis.

The same sensitivity analysis was performed for the fluid collection system. Increasing the rating by one point for the lightweight or ergonomic selection criteria for Concept 5, resulted in a change in the rankings of the concept scoring table. It is important to note that changing the ranking of any one selection criteria of Concept 13 (the third ranked concept) resulted in no change of the overall concept rankings. An example of the sensitivity of the scoring of Concept 5 and 16 is shown in Table XVI, with the altered rating highlighted. In Table XVI, the "ergonomic for the person using it" selection criteria was altered because it produced the most drastic total score change. In fact, Concept 5's total score increased from 2.70 to 2.75, putting it 0.02 points ahead of Concept 16. Since the fluid collection system concept scoring table is also sensitive for the top two concepts (5 and 16), Concept 5 and 16 have been selected to be taken through to the final design phase for further analysis.

TABLE XVI: FLUID COLLECTION SYSTEM CONCEPT SCORING SENSITIVITY ANALYSIS

		Concepts							
	Description	2 Sliding Drawer with Bottom Support		5 Rod Frame Holder with Fitted Tubes		13 Extended Flange on C-channels		1 Regular Pan on C-channels	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Wighted Score**	**Rating**	**Wighted Score**	**Rating**	**Wighted Score**
System can be quickly deployed	0.05	3	0.16	3	0.16	3	0.16	3	0.16
Contains fluid from a procedure	0.14	2	0.29	3	0.43	3	0.43	3	0.43
Supports fluid and tools from a procedure	0.13	3	0.40	3	0.40	3	0.40	3	0.40
Components are easily cleanable	0.11	1	0.11	3	0.33	3	0.33	3	0.33
Accessible during entire procedure	0.05	3	0.16	3	0.16	3	0.16	3	0.16
Affordable to produce	0.05	2	0.11	3	0.16	2	0.11	3	0.16
Maintains current tables functionality	0.08	2	0.15	0	0.00	0	0.00	0	0.00
Durability	0.10	2	0.20	3	0.30	3	0.30	3	0.30
Easy to manufacture	0.08	2	0.15	3	0.23	2	0.15	3	0.23
Lightweight	0.02	3	0.07	2	0.04	3	0.07	3	0.07
Aesthetically pleasing	0.00	2	0.00	3	0.00	3	0.00	3	0.00
Easy to install/uninstall	0.01	2	0.02	3	0.03	3	0.03	3	0.03
Safe to operate	0.12	2	0.24	3	0.36	3	0.36	3	0.36
Ergonomic for the person using it	0.04	2	0.09	3	0.13	2	0.09	2	0.09
TOTAL SCORE		2.15		2.75		2.59		2.73	
RANK		4		1		3		2	
Continue?		No		Develop		No		Develop	

3.4 RECOMMENDATIONS

During the conceptual design phase of the project, our team decided to approach the project by isolating the two problems we are tasked with solving: the presence of a fast deploying footrest and a fluid collection system. Through screening and scoring our concepts, a total of two concepts addressing each problem were found to score very closely: Concept 14 and 23 for the footrest problem, and Concept 5 and 16 for the fluid collection system problem. Recall that Concept 14 incorporates a sliding pin mechanism, Concept 23 incorporates a spring loaded flat-bar with a handle, Concept 5 incorporates a purchased pan with a lip that is supported and deployed with a rod frame, and Concept 16 incorporates a purchased pan with a lip that is supported and deployed with C-channels.

As our scoring process did not produce a clear winner, the team met with the client to see if one of the two ideas for each solution was preferred. Footrest Concept 14 was ultimately selected by the client over Concept 23 because of the fewer pieces involved. Having fewer pieces makes the idea easy to manufacture, install, and clean. As Concept 16 closely represents what they currently use, and it is easy to manufacture and install, the client has asked us to pursue Concept 16, rather than Concept 5, for the fluid collection system problem. Brief descriptions and initial renders of the footrest Concept 14 and the fluid collection system Concept 16 are presented next.

As mentioned previously, Concept 14 incorporates a sliding pin mechanism. This design consists of adding a 9.5 mm (0.375 inches) pin to the railings of the backrest, approximately 25.4 mm (1 inch) back from the end of the backrest. The footrest would have a hinge point in a slot milled into the railings of the footrest; this would give the footrest a rotating/sliding functionality, allowing it to be lifted and slid into a locking position. An isometric view and a detailed view of Concept 14 is presented in Figure 4 and 5, respectively.

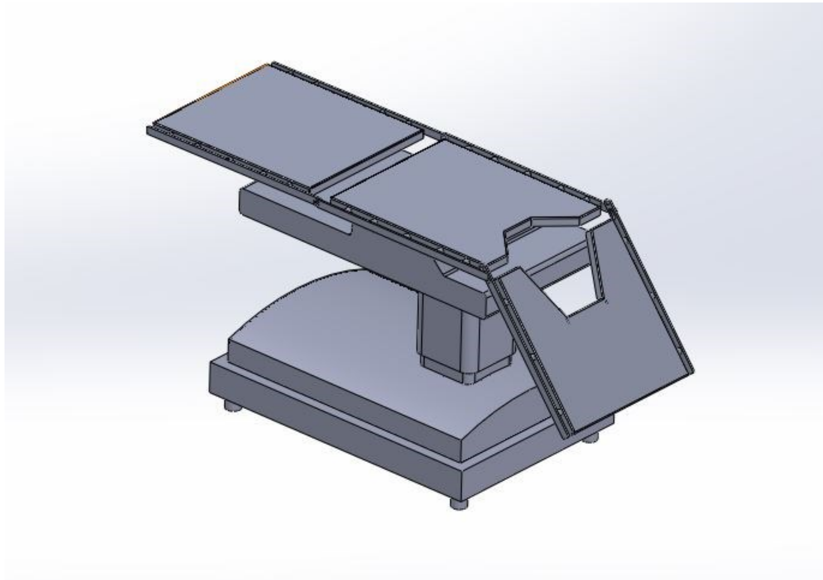


Figure 4: Isometric view of Concept 14 – sliding pin mechanism

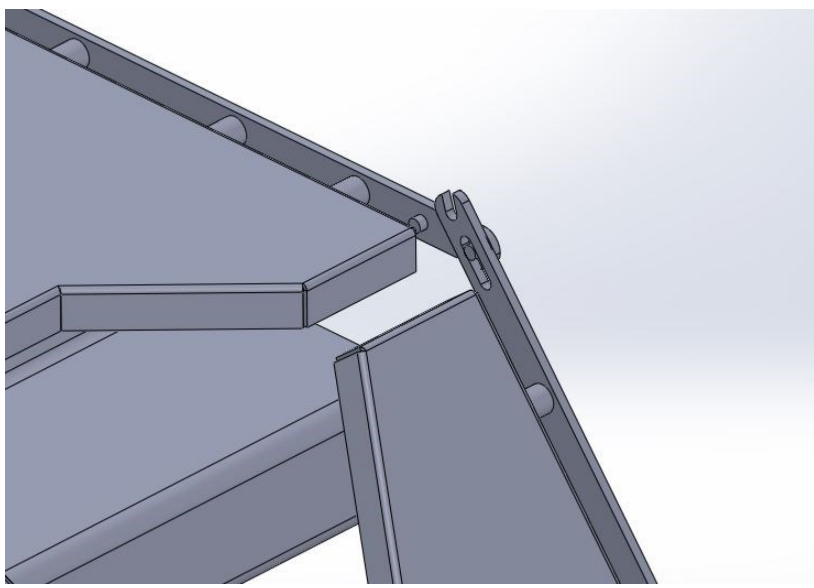


Figure 5: Detailed view of Concept 14 – sliding pin mechanism

Concept 16 incorporates a purchased pan with a lip that is supported and deployed with C-channels. The C- channels will be mounted using self-tapping flat head screws. An isometric view and a detailed view of Concept 16 is presented in Figure 6 and 7, respectively.

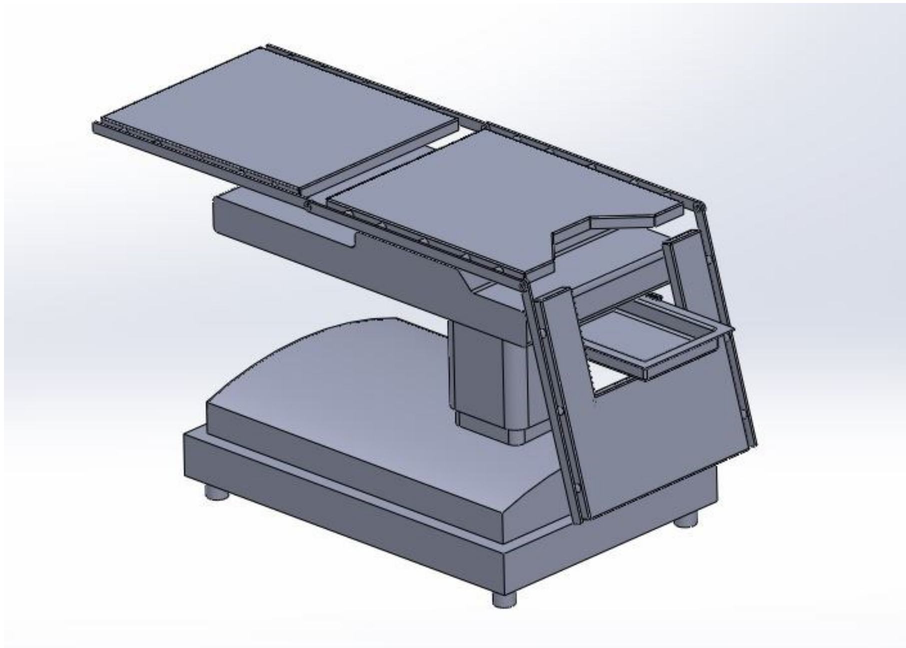


Figure 6: Isometric view of the procedural table and Concept 16 – purchased pan with a lip that is supported and deployed with C-channels

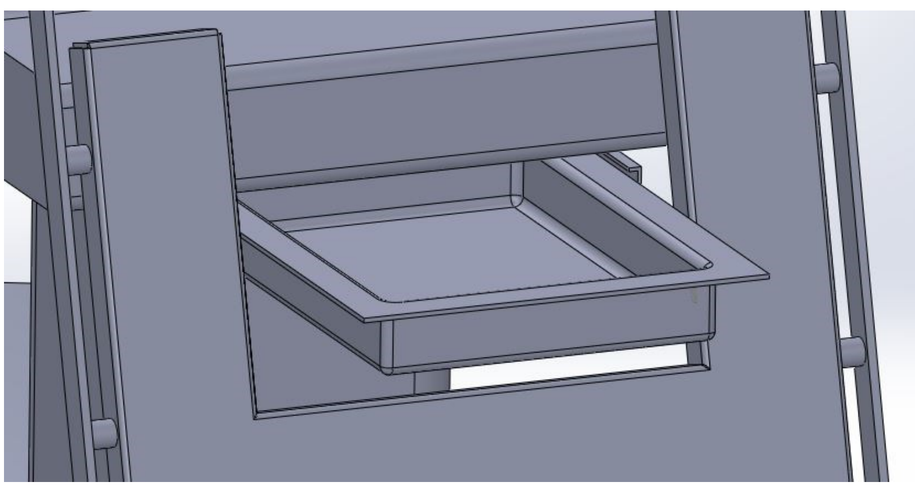


Figure 7: Detailed view of Concept 16 – purchased pan with a lip that is supported and deployed with C-channels

In Figure 4 and 5, the current footrest shape is presented. As one can see in Figure 6 and 7, a portion of the footrest must be cut away in order to access the pan size needed by our client. If space was available underneath the backrest of the mobile table, the pan could be slid away so as not to interfere with the footrest during operation. Unfortunately, the space is not available and the pan size is fixed based on our clients' needs. After talking with our client about the space constraints, it was agreed upon that a newly manufactured footrest design would cost less and take less time, than retrofitting our current footrest.

The design team feels that the two concepts presented within this section individually and together meet the needs, constraints, and limitations set by the team and client. In the next section of the report, our analysis on these two concepts is presented, and optimal integration between the footrest and fluid collection system is created.

4.0 FINAL DESIGN ANALYSIS

To ensure that the design of the footrest, as well as the design of the fluid collection system, perform as expected, a preliminary Finite Element Analysis (FEA) was performed. FEA is a tool used to numerically approximate solutions to engineering problems. Particularly, FEA can be used to determine the stresses experienced in an object, and can be confirmed using analytical calculations. This section of the report presents the FEA and analytical calculations for both the footrest and the fluid collection system. It should be noted that the analysis contained within this section is preliminary, and should be verified by professional engineers before implementation.

4.1 FOOTREST ACTUATING MECHANISM ANALYSIS

Three different configurations of the sliding pin actuating mechanism for the footrest were modelled in the SolidWorks environment to perform FEA. Using SolidWorks FEA, a stress analysis was performed on all three configurations of the actuating mechanism to ensure that the footrest could support the maximum allowable weight of a patient, 137 kg (300 lbs). Although only the weight of a patient's legs is acting on the footrest during a typical procedure, we needed to design the footrest to safely support the entire weight of a patient in case the patient sat down on the footrest. Since the nurses at the Women's Hospital have never seen a patient sit on the footrest, it was determined that the probability of this happening was very low. Based on this, Michael Hamilton, the clinical engineer in training that is overseeing our project, informed us to design the footrest without a safety factor. In addition to the FEA performed, analytical calculations were done to validate the FEA results.

In addition to the stress analysis performed for the maximum weight capacity subjected to the footrest, a fatigue analysis was also performed on the footrest actuating mechanism. Fatigue was considered as the footrest is subjected to repeated loading on a daily basis. In fact, there are 16 procedures performed on average during one working day and each patient supports their feet with the footrest twice for one given procedure [19]. Assuming 16 procedures are performed 7 days a week, 52 weeks in a year, for 25 years, the footrest will undergo approximately 300 000 cycles. An analysis was done to ensure that aforementioned criteria is met.

The following assumptions were made while completing the FEA analysis for the footrest actuating mechanism:

1. The weight of the members of the structure is considered negligible.
2. The mass of the patient is equally distributed between both sides of the table.
3. The railings are made of 304 stainless steel with a yield strength of 240 MPa.
4. The sliding pins are shoulder bolts, but will be modeled as pins, and are made of 316 stainless steel with a yield strength of 207 MPa.
5. The pins for engagement and the spacers are made of 304 stainless steel.
6. The material is isotropic and homogeneous.
7. The spacers are fixed.
8. The load was applied to the end of the footrest railing and equally distributed over a distance of 0.2794 m (11 inches).
9. The pins are considered a part of the railings, not separate.

The weight of the members of the structure is considered negligible, as it will produce smaller loads than the other external loads being applied to the structure. In reality, the weight of the footrest corresponds to 5% of the maximum weight applied. As the weight of the footrest is a small percentage of the applied weight, our assumption is valid.

Since the footrest is supported by a railing on each side of the table, and the footrest is symmetrical in design, the weight was assumed to be split evenly between both the railings.

Since the most commercially available stainless steel is the 304 grade, the material used for the railings in FEA was assumed to be AISI 304. The properties of 304 stainless are very similar to those of 316 stainless, with the only major difference being the yield strength; this was taken into consideration for the analysis. Since the pins for engagement and spacers are subjected to high shear stresses, 304 was specified over 316 due to its higher yield strength. As the sliding pin was found to only be available in 316 stainless, we assumed the sliding pins are made of 316 for the FEA. All components of the design were assumed to be made out of material that is isotropic and homogeneous to simplify our design calculations.

The spacers between the table and the railing were considered a fixed geometry for the FEA performed, as shown in Figure 8. The spacers were considered fixed because theoretically they are fixed to the table and should not move.

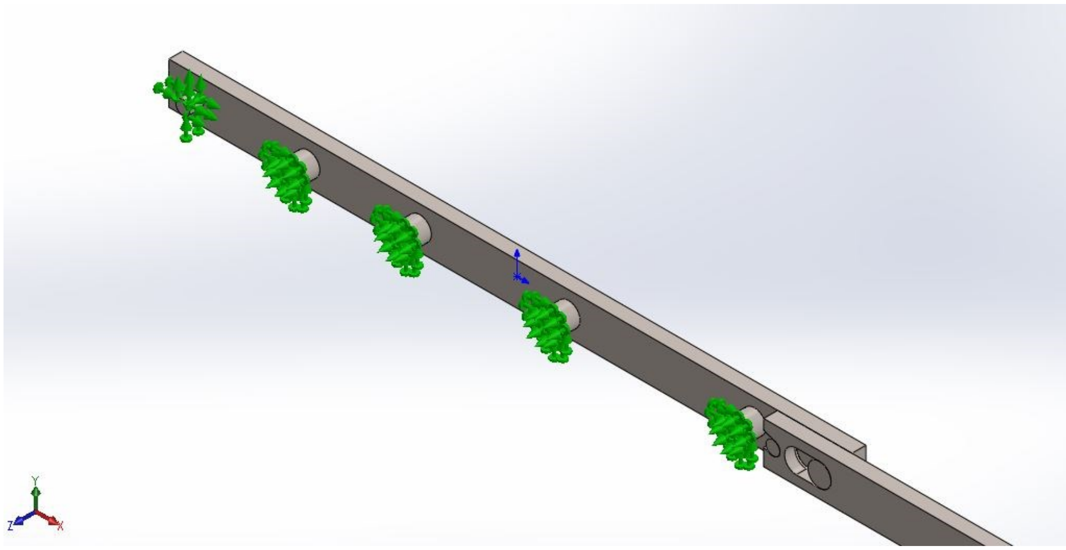


Figure 8: Fixed spacers on the backrest for FEA on the footrest mechanism design

The load was applied to the end of the railing of the footrest and equally distributed over the width of the padding, a distance of 0.2794 m (11 inches). Equal distribution of the load was assumed for simplicity purposes. Figure 9 shows the applied load.

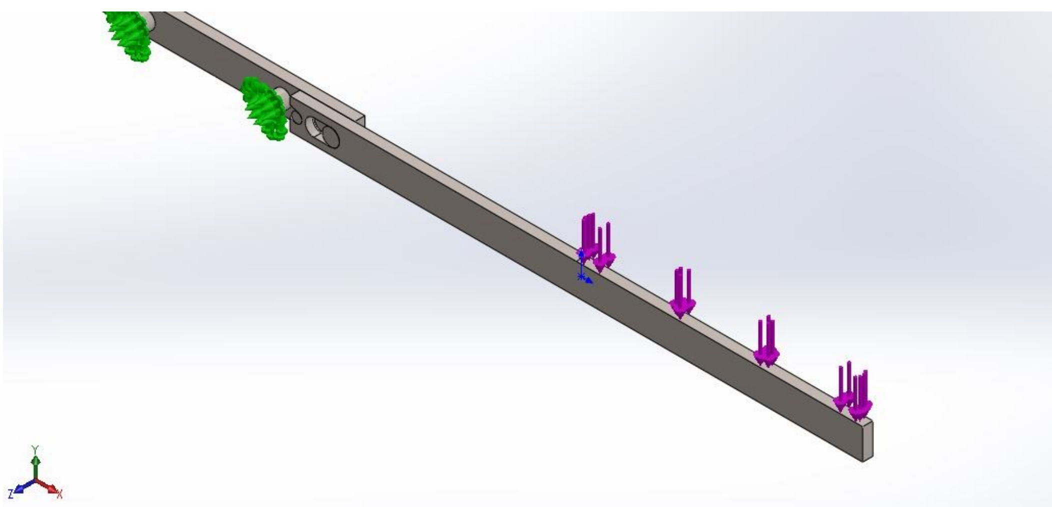


Figure 9: Applied load on the footrest railings for FEA on the footrest mechanism design

The rails were modelled as parts and an FEA was performed on the assembly of these parts. As such contact was established between the pins and the railing, but no movement was established between these elements because they were considered as one assembly. We can assume due to tight tolerances that the pins involved will not move a significant amount to warrant an assembly FEA where the pins are separate from the railings. If the parts were modelled as an assembly where the pins are separate from the railings, the model would have multiple free parts that would produce large sources of error, due to increased complexity of the geometry and surface interfacing.

4.1.1 SLIDING PIN DESIGN 1

The initial sliding pin design consists of two pins mounted on the backrest railing. The pins are centered in the y-plane. The sliding pin is 15.9 mm (0.625 inches) in diameter and the engagement pin is 9.53 mm (0.375 inches) in diameter. Figure 10 shows a drawing of Pin Design 1. It should be noted that the circle on the far left in Figure 10 represents a spacer which attaches the railing to the backrest. It should also be noted that although this design was modelled in SolidWorks with the pins mounted onto the backrest railing and the slot milled into the footrest railing, these features of the sliding pin design could be swapped and the design would still be feasible. In other words, the pins could be mounted onto the footrest railings and the slot milled into the backrest railing.

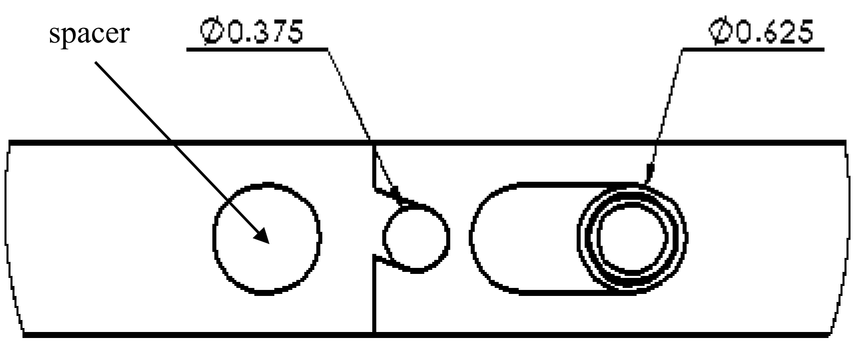


Figure 10: Sliding Pin Design 1 drawing

If a 137 kg (300 lb) person were to sit on the edge of the footrest, 68.5 kg would be applied on each side, as we have assumed that the load is equally distributed between the rails on either side of the table. The stress distribution produced from performing an FEA analysis for an applied weight of 68.5 kg is shown in Figure 10. The stress distribution was found to be much higher than expected. In fact, the maximum was determined to be 690 MPa. However, this maximum stress was a mathematical maximum at the 90 degree corner where the engagement pin meets the railing. The engagement and sliding pin were found to experience a maximum stress of 189 and 119 MPa, respectively, which is less than the yield strength of 304 and 316 stainless steel, respectively. The railings were found to experience a maximum stress of 244 MPa located on top of the rail above the location of the sliding pin. As the stress in the railings exceeds the yield strength of 304 stainless, Pin Design 1 would begin to plastically deform and fail. Figure 11 shows the associated stress distribution of Pin Design 1 calculated using FEA.

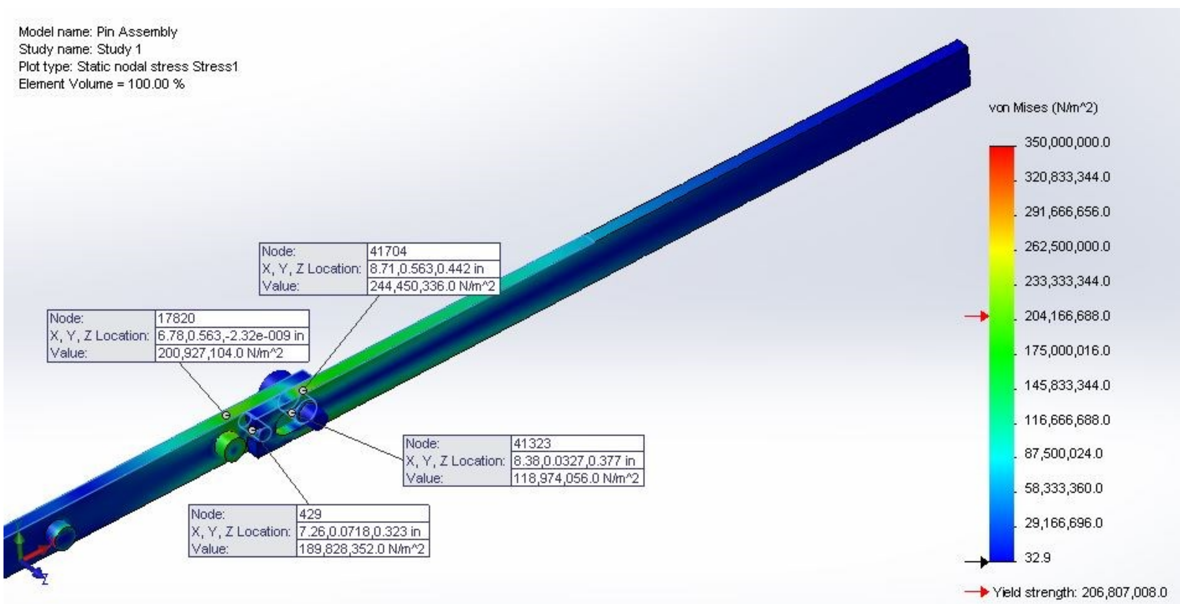


Figure 11: Stress analysis for Pin Design 1 subjected to a weight of 68.5 kg

The maximum areas of stress are not pictured in Figure 11, as they are located at the 90 degree corners where the stresses tend to infinity. The mesh details for the analysis shown in Figure 11 are summarized in Table XVII.

TABLE XVII: MESH DETAILS FOR PIN DESIGN 1

Mesh type	Solid mesh
Mesher used	Curvature based mesh
Jacobian points	At nodes
Maximum element size	0.103731 inches
Minimum element size	0.0207462 inches
Mesh quality	High
Remesh failed parts with incompatible mesh	Off
Total nodes	181792
Total elements	117487
Maximum aspect ratio	53.782
% of elements with aspect ratio < 3	99.8
% of elements with aspect ratio > 10	0.0102
% of distorted elements (Jacobian)	0
Time to complete mesh (hh;mm;ss)	00:00:25

Although Pin Design 1 would fail when subjected to the maximum allowable load, we must ensure that the analysis we performed was accurate. To ensure the obtained data was accurate, a convergence plot was generated. Figure 12 shows the convergence graph for the FEA study for the Pin Design 1.

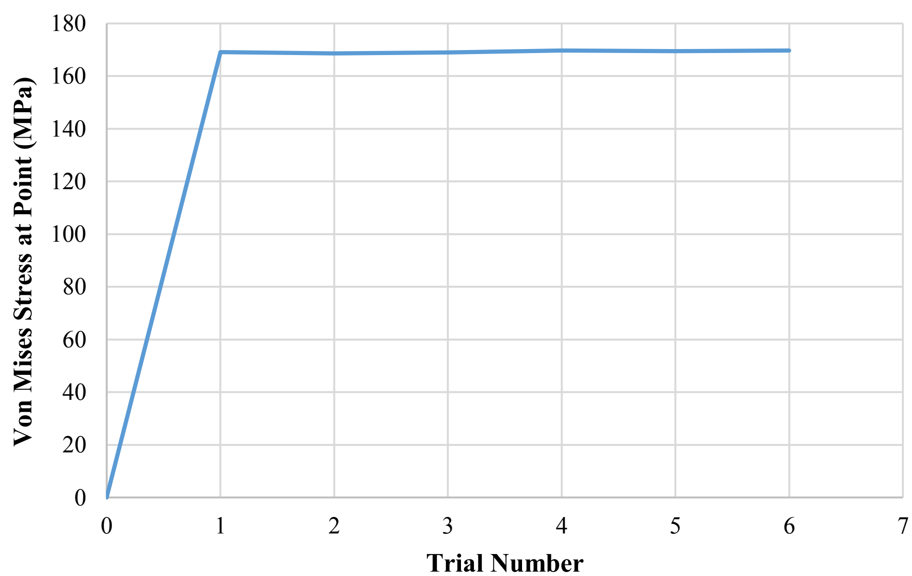


Figure 12: Von Mises stress convergence graph for Pin Design 1

In addition to confirming the accuracy of our FEA stress plots with convergence, we must also validate our results with manual calculations. For our calculations, the railing can be considered as a beam in bending. Figure 13 shows the basic loading scenario for Pin Design 1. It should be noted that Figure 13 is not to scale.

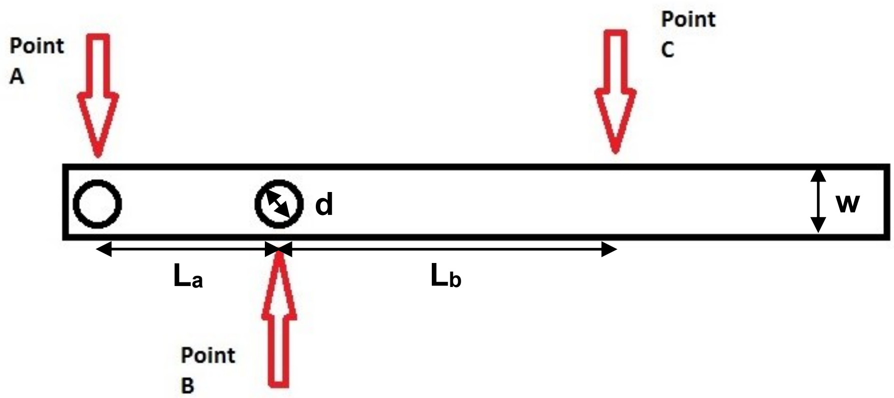


Figure 13: Free body diagram for Pin Design 1

Point A and B in Figure 13 represent the position of the engaging pin and the sliding pin, respectively. Point C in Figure 13 represents the location where the resulting force from a person's legs is applied. This resulting force is the summation of the distributed load due to the weight of a person's legs. A summary of specifications regarding the dimensional parameters for Pin Design 1 are shown in Table XVIII.

TABLE XVIII: DIMENSIONAL PARAMETERS SUMMARY FOR PIN DESIGN 1

Description	Symbol	Value (m)
Length of beam	L	0.535
Length between point A and B	L_a	0.03175
Length between point B and C	L_b	0.21625
Height	w	0.0287
Diameter of sliding pin	d	0.0159
Thickness	t	0.0094

To determine the forces seen in the beam, the equations of static equilibrium must be applied: the sum of the forces and the sum of the moments. The sum of the forces in the x-direction, the forces in the y-direction, and the moments are shown in equations 1, 2, and 3, respectively.

$$\sum F_x = 0 \tag{1}$$

$$\sum F_y = 0 \tag{2}$$

$$\sum M_b = 0 \tag{3}$$

Using the free body diagram pictured in Figure 13 and equation 1, 2, and 3, the following equations can be determined.

$$F_b = F_a + F_c \tag{4}$$

$$M_b = F_a \times L_a = F_c \times L_b \tag{5}$$

Through knowing the applied load F_c, and the lengths L_a and L_b, equation 4 and 5 can be used to determine that F_a, F_b, and M_b are 5287 N, 5955 N, and 167 Nm, respectively.

Intuitively, it can be seen that the beam is in bending. To validate our FEA results, we must choose a point in our analysis for comparison purposes. We have chosen to analyze point B, as it is subjected to the highest reaction force along the rail. For Pin Design 1, the stress at point B can be determined using equation 6.

$$\sigma = \frac{Mc}{I} \tag{6}$$

Where *I* is the moment of inertia and *c* is the distance from the centroid. For a beam in bending with a rectangular cross section, *I* and *c* are defined as per equation 7 and 8, respectively.

$$I = \frac{bw^3}{12} \tag{7}$$

$$c = \frac{w}{2} \tag{8}$$

Using equations 7 and 8, the values for *I* and *c* were found to be 17.73×10^{-9} m^4 and 0.01435 m, respectively. Using equation 6 and the calculated values for *I* and *c*, we find that the stress at point B is 135.88 MPa. The computed stress of 135.88 MPa is the stress at point B if the beam does not contain the slot for the sliding pin. As our railing design does have a slot, a stress concentration factor, *K,* needs to be considered to calculate the true stress in the beam. *K* is defined as per equation 9.

$$K = \frac{\sigma_{max}}{\sigma_{nom}} \quad (9)$$

Where σ_{max} is the maximum stress experienced in a member, and σ_{nom} is the nominal stress experienced in a member.

The equation for the nominal stress for a plate with a hole subjected to in plane bending is defined as follows [20].

$$\sigma_{nom} = \frac{6Mw}{(w^3 - d^3)t} \quad (10)$$

Where *w* is the height of the beam, *t* is the thickness of the beam, and *d* is the diameter of the hole. As *w*, *t*, and *d* of the beam are 0.0287 m, 0.0094 m, and 0.0159 m, the nominal stress is found to be 156 MPa using equation 10. If we assume that the maximum stress is the yield strength of 304 stainless steel (240 MPa), according to equation 9, the stress concentration factor is 1.5. Taking into account the stress concentration due to the slot, the true stress at B can be determined using equation 11.

$$\sigma_b = K\sigma = (1.5)(135.88\ MPa) = 209\ MPa \quad (11)$$

Once we determined the true stress at point B, we were able to compare our analytical result with that from the FEA. A close-up of the locking mechanism for Pin Design 1 for a loading of 68.5 kg on the rails is shown in Figure 14.

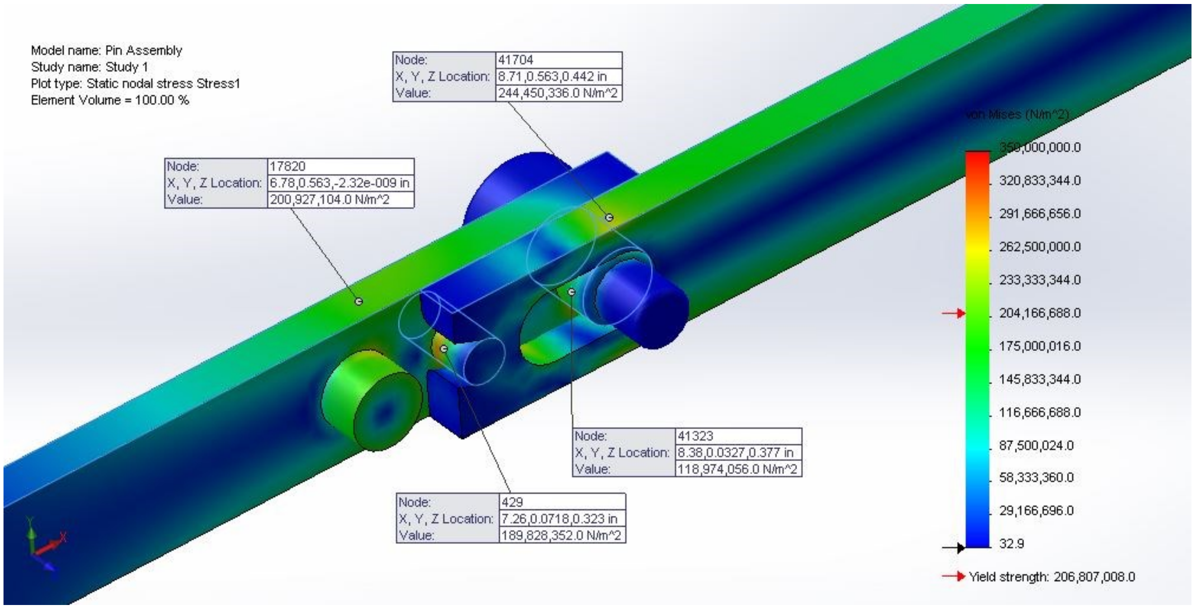


Figure 14: Close-up of locking mechanism for Pin Design 1 subjected to a weight of 68.5 kg

As shown in Figure 14, the stress at point B is 244 MPa. As the stress we have determined analytically is within the same magnitude as that shown using FEA, our FEA results have been validated. A summary of the analytical calculations performed within this section can be found in Table XIX.

TABLE XIX: SUMMARY OF ANALYTICAL RESULTS FOR PIN DESIGN 1

Description	Symbol	Value	Unit
Stress at point B	σ_B	209	MPa
Yield stress	σ_Y	240	MPa
Force at point A	F_a	5287	N
Force at point B	F_b	5955	N
Force at point C	F_c	667.23	N
Moment at point B	M_B	167	N-m
Distance from centroid	c	0.01435	m
Moment of inertia	I	17.73×10^{-9}	m^4

In summary, Pin Design 1 experiences stresses in the railings that exceed the yield strength of 304 stainless steel. Therefore, a new pin design is required.

4.1.2 Sliding Pin Design 2

Pin Design 2 incorporates that of Pin Design 1, but includes a modification intended to help reduce the stress in the railings. This modification involves moving the engagement pin to the top of the railing. By doing so, the diameter of the sliding pin was decreased by 3.18 mm (0.125 inches) to avoid interference with the cut-out for the engagement pin on the rail. It should be noted that although Pin Design 2 was modelled in SolidWorks with the pins mounted onto the footrest railing and the slot milled into the backrest railing, these features of the sliding pin design could be swapped and the design would still be feasible. Figure 15 shows a drawing of Pin Design 2.

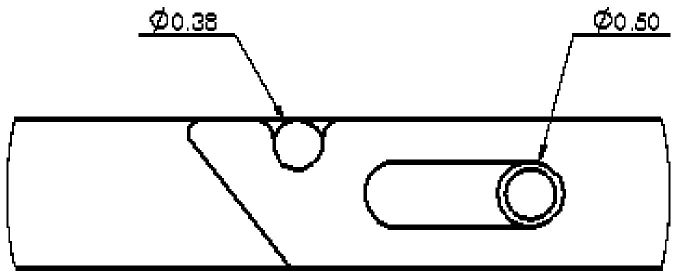


Figure 15: Pin Design 2 drawing

An FEA analysis with an applied load due to the weight of 68.5 kg was performed on Pin Design 2. The results were found to be similar to those of Pin Design 1. Once again, the maximum stress exceeded the yield strength of 316 stainless at the location where the engagement pin meets the railing. The engagement and sliding pin were found to experience a maximum stress of 70 and 123 MPa, respectively, which is less than the yield strength of 304 and 316 stainless steel, respectively. The stresses in the railings were found to experience a maximum stress of 289 MPa. As shown in Figure 16, the maximum stress in the railings is located on the top of the rail above the location of the sliding pin. This maximum stress is also above the maximum yield strength of 304 stainless steel, and is higher than the maximum stress experienced in Pin Design 1. The increase in stress in the rail between Pin Design 1 and 2 may be attributed to the use of a sliding pin of smaller diameter. A smaller diameter hole gives rise to an increase in stress because the radius of curvature is smaller. Figure 16 shows the associated stress distribution of Pin Design 2 computed using FEA.

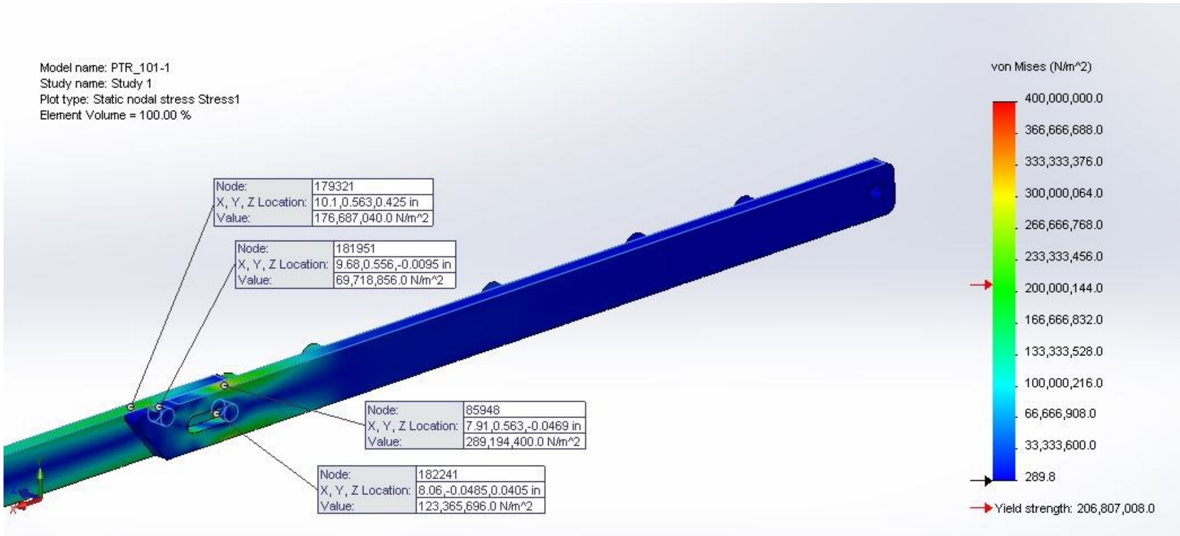


Figure 16: Stress analysis for Pin Design 2 subjected to a weight of 68.5 kg

The maximum areas of stress are not pictured in Figure 16, as they are located at the 90 degree corners where the stresses tend to infinity. The mesh details for the analysis shown in Figure 16 are summarized in Table XX.

TABLE XX: MESH DETAILS FOR PIN DESIGN 2

Mesh type	Solid mesh
Mesher used	Curvature based mesh
Jacobian points	At nodes
Maximum element size	0.265538 inches
Minimum element size	0.0531075 inches
Mesh quality	High
Remesh failed parts with incompatible mesh	Off
Total nodes	182805
Total elements	117446
Maximum aspect ratio	32.233
% of elements with aspect ratio < 3	99.8
% of elements with aspect ratio > 10	0.0196
% of distorted elements (Jacobian)	0
Time to complete mesh (hh;mm;ss)	00:00:07

Despite the stress is the rails exceeding the yield stress, causing plastic deformation and ultimately failure, the FEA results for Pin Design 2 must be validated using convergence and analytical calculations. The convergence graph for the stress analysis for Pin Design 2 is shown in Figure 17.

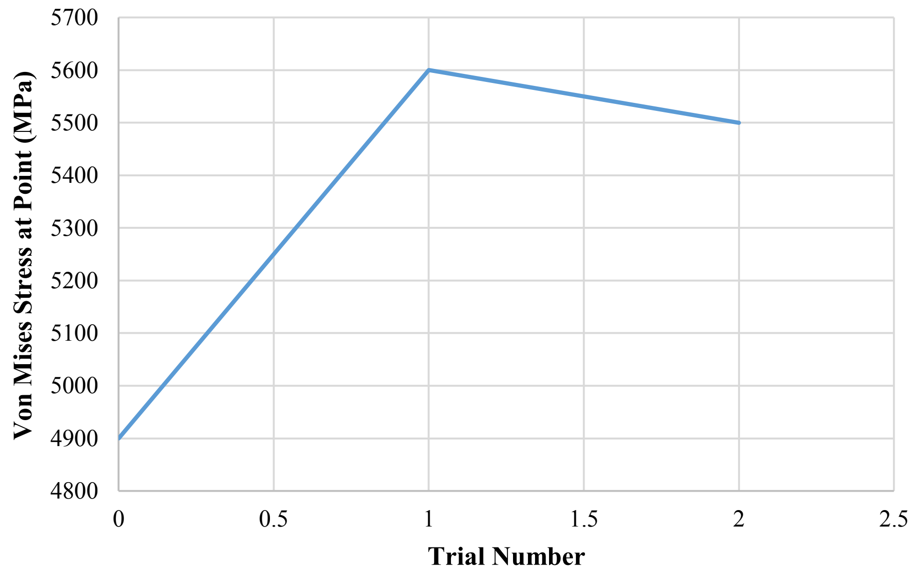


Figure 17: Von Mises stress convergence graph for Pin Design 2

In order to validate that the FEA results are accurate, manual calculations must be performed. As the free body diagram for Pin Design 2 is identical to Pin Design 1, the process for validating Pin Design 2 would be identical to that done for Pin Design 1. The only difference between the results for Pin Design 1 and 2 is the value for the stress concentration factor. As *w*, *t*, and *d* of the beam for Pin Design 2 are 0.0287 m, 0.0094 m, and 0.0127 m, the nominal stress is found to be 156 MPa using equation 10. If we assume that the maximum stress is the yield strength of 304 stainless steel (240 MPa), according to equation 9, the stress concentration factor is 1.7. Taking into account the stress concentration due to the slot, the true stress at B can be determined using equation 12.

$$\sigma_b = K\sigma = (1.7)(135.88\ MPa) = 230\ MPa \quad (12)$$

Having determined the true stress at point B, the analytical result was able to be compared with the FEA. The FEA plot for a loading of 68.5 kg on the rails for Pin Design 2 is shown in Figure 18.

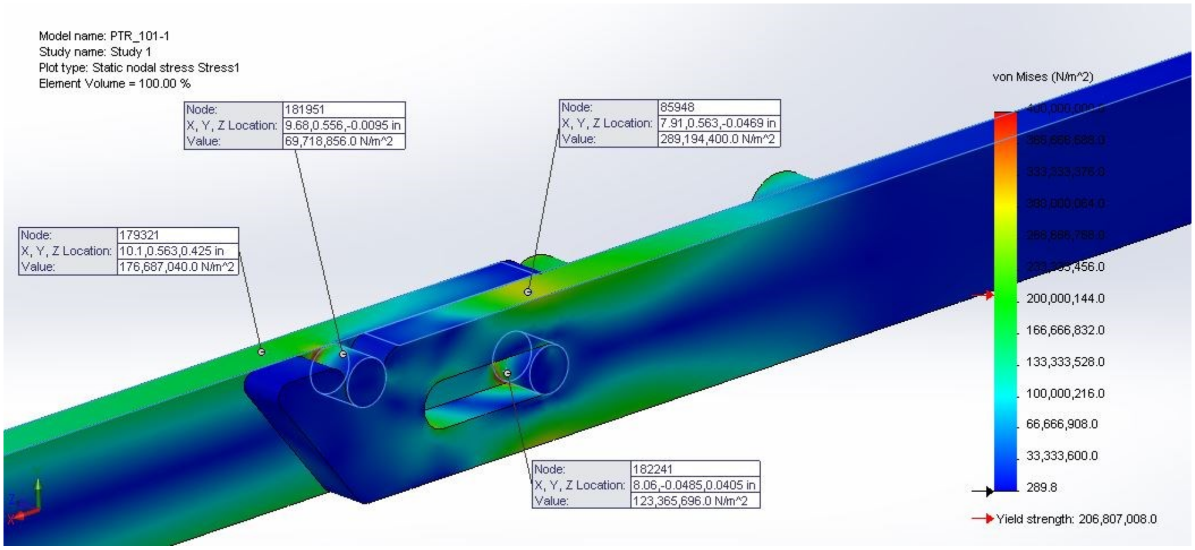


Figure 18: Close-up of locking mechanism for Pin Design 2 subjected to a weight of 68.5 kg

As shown in Figure 18, the stress at point B is 289 MPa. As the stress we have determined analytically is within the same magnitude as that using FEA, our FEA results have been validated. In summary, Pin Design 2, like Pin Design 1, experiences stresses in the railings that exceed the yield strength of 304 stainless steel. Therefore, a new pin design is required.

4.1.3 Sliding Pin Design 3

As the stresses in Pin Design 1 and 2 were found to both be above the yield stress, we needed to create a design that could redistribute our load so that the railings would only experience stresses below the yield stress. We determined that a second engagement pin must be added to redistribute the load, and ultimately reduce the stress in the railings. Although a second engagement pin could be added to either Pin Design 1 or 2, it was determined that altering Pin Design 2 would be best as it would be easier for the user to operate the actuating locking mechanism.

Therefore, Pin Design 3 consists of two engagement pins and one sliding pin where all three pins are 9.53 mm (0.375 inches) in diameter. As shown in Figure 19, the second engagement pin is fixed to the backrest railing behind the rotation point and engages with the slot milled out of the footrest railing.

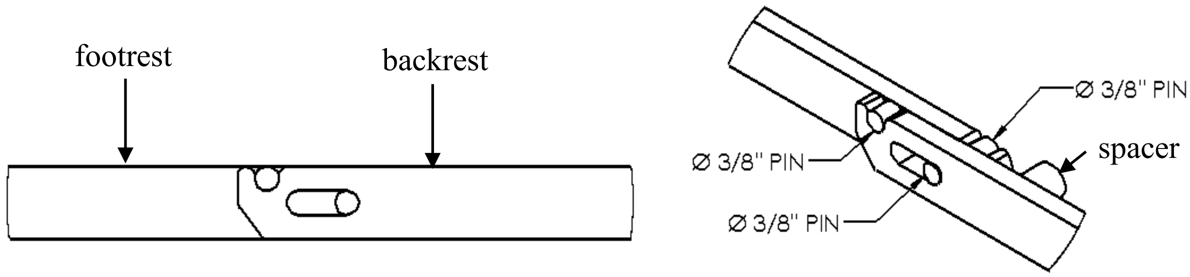


Figure 19: Pin Design 3 drawing

It should be noted that like Pin Design 1 and 2, Pin Design 3 is also feasible if the milled slot is located on the footrest or the backrest railing. However, if the slot is located on the footrest railing, the sliding pin is stationary and the milled slot in the footrest is free to move in the x- and y-direction. Having the slot free to move in two directions poses a concern as the operator is now responsible for supporting the weight of the footrest during operation. This problem can be avoided by simply having the slot in the backrest railing, as this allows the footrest to be supported by the pin during operation. As such, the design team recommends only using Pin Design 3 pictured in Figure 19.

An FEA analysis with an applied load due to the weight of 68.5 kg was performed on Pin Design 3. It was found that the modified locking pin mechanism experiences a maximum stress of 601 MPa. Once again, this was assumed to be a mathematical maximum stress point that formed at a 90 degree corner. By probing the visible maximum stress locations on the rails and pins in SolidWorks, it was determined that the maximum stress in the railing was approximately 210 MPa, which is less than 240 MPa, the yield strength of the railings. It was also found that the maximum stress in the engagement pins was 118 MPa, which is less than the yield stress of the material, and the maximum stress in the sliding pin was 122 MPa, which is less than the yield stress of the material. All pins experience a maximum stress lower than 207 MPa, the yield strength of the pin material. Figure 20 shows the associated stress distribution of Pin Design 3 calculated using FEA.

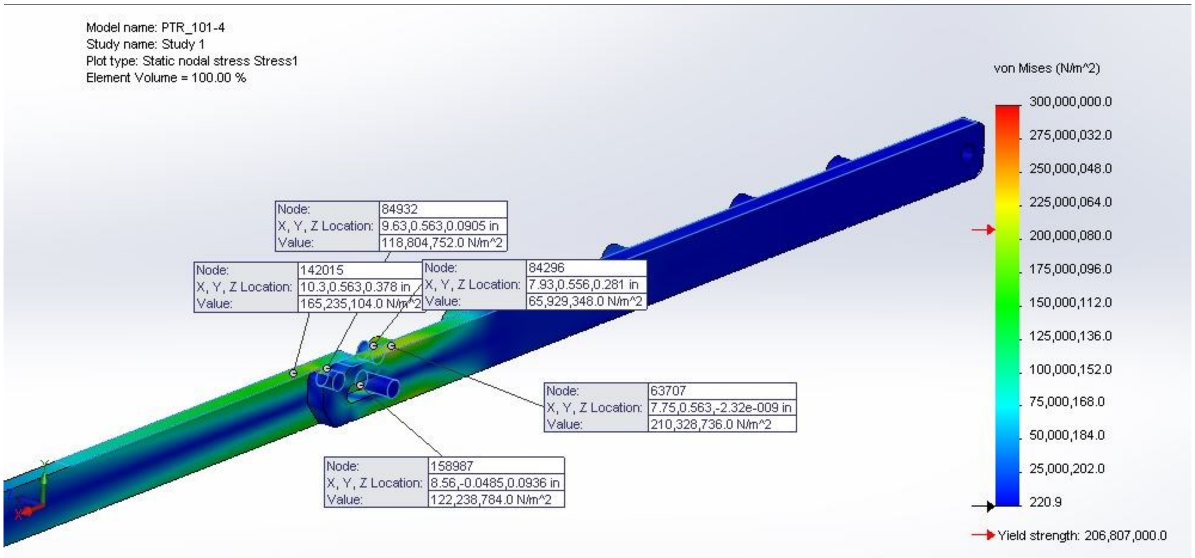


Figure 20: Stress analysis for Pin Design 3 subjected to a weight of 68.5 kg

The mesh details for the stress analysis shown in Figure 20 are summarized in Table XXI.

TABLE XXI: MESH DETAILS FOR PIN DESIGN 3

Mesh type	Solid Mesh
Mesher used	Curvature based mesh
Jacobian points	At nodes
Maximum element size	0.265538 inches
Minimum element size	0.0531075 inches
Mesh quality	High
Remesh failed parts with incompatible mesh	Off
Total nodes	131350
Total elements	82900
Maximum aspect ratio	5.5557
% of elements with aspect ratio < 3	99.8
% of elements with aspect ratio > 10	0
% of distorted elements (Jacobian)	0
Time to complete mesh (hh;mm;ss)	00:00:17

To ensure the results were accurate, a convergence study was performed on the FEA stress analysis for Pin Design 3. Initially, the SolidWorks convergence tool was used for both the h-Adaptive and p-Adaptive convergence methods. The h-Adaptive convergence method did not converge to within 2%. After some research and brainstorming, it was found that our design did not converge because of the high stress concentrations in the sharp corners of the design. As the mesh size decreased, the stress at that specific location increased. Since the SolidWorks convergence tools test the maximum von Mises stress for convergence, the stress increased with every iteration and did not converge. The p-Adaptive convergence method did converge to within 3% after two or three iterations. However, from past experience with SolidWorks FEA, we know that the maximum stress often spikes after the third or fourth iteration of FEA. For this reason, we decided to do a separate convergence study. We performed 8 finite element stress analyses each with the applied weight of 68.5 kg. The stress was measured at the same location for each of the iterations. The mesh size was decreased after each iteration and the number of nodes, maximum stress, and percentage difference between the different iterations was calculated. Table XXII summarizes the results of this study.

TABLE XXII: CONVERGENCE STUDY FOR PIN DESIGN 3 FEA

Study Number	Number of Elements	Stress at Node	% Difference
1	9384	213523904	
2	15262	212679856	-0.003952944
3	20732	207628624	-0.023750402
4	32906	211183712	0.017122341
5	53673	212304144	0.005305485
6	82900	212052864	-0.001183585
7	116106	211639296	-0.001950306
8	241854	211522176	-0.000553394
9	294332	211262272	-0.001228732

The data shown in Table XXII was plotted in a graph to give us a visual representation of whether or not the results converged. Figure 21 shows the stress convergence for the railings of the footrest for Pin Design 3.

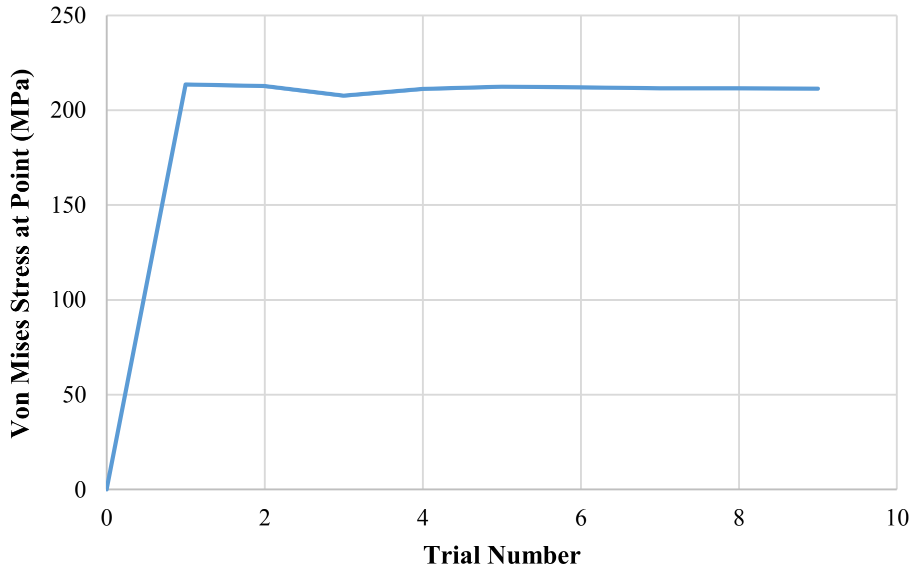


Figure 21: Von Mises stress convergence graph for Pin Design 3

As shown in Figure 21, the stress converges after nine tests.

In order to validate that the FEA results are accurate, manual calculations must be performed. Unfortunately, Pin Design 3 is complex to solve analytically, as it is a statically indeterminate to the second order. However, calculations can be performed at a point on the beam away from the pins that are not complex to determine. In Figure 22, the free body diagram for Pin Design 3 is shown. It should be noted that Figure 22 is not to scale.

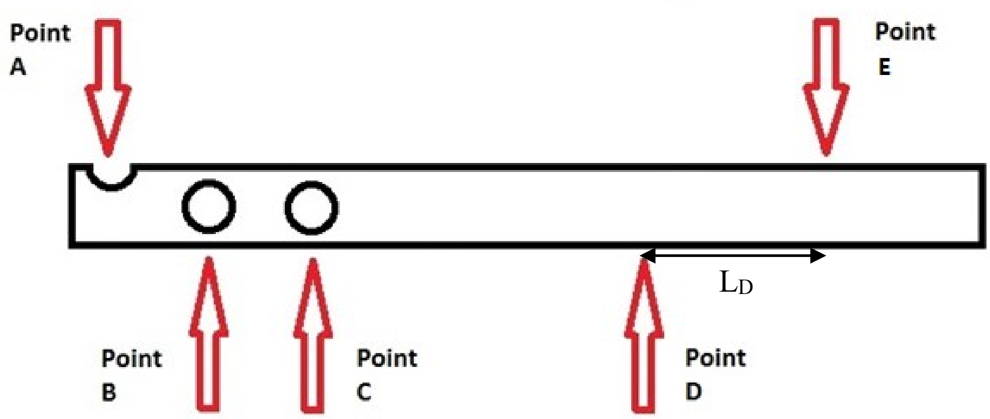


Figure 22: Free body diagram for Pin Design 3

Point A represents the position of the engagement slot, Point B represents the position of the sliding pin, Point C represents the position of the engagement pin, Point D is an arbitrary point that is centered between points C and the end of the rail of the footrest, and Point E represents the location where the resulting force from a person's legs is applied. This resulting force is the summation of the distributed load due to the weight of a person's legs.

If we assume that point C is fixed, the railing shown in Figure 22 can be modeled as a cantilever beam to the right of point C. Point D has arbitrarily been chosen to compare and validate the FEA results. Point E in Figure 22 represents the location where the resulting force from a person's legs is applied. This resulting force is the summation of the distributed load due to the weight of a person's legs. To find the stress at point D, equation 6 is used. To find the moment in equation 6, the resulting force, F_E, is multiplied by the distance between point D and E, L_D. As F_E and L_D are 667 N and 0.097 m, the resulting moment is 65 Nm. Using the resulting moment, and values of the moment of inertia and centroid from Table XIX, the stress in equation 6 is found to be 50 MPa. A summary of the analytical calculations performed within this section can be found in Table XXIII.

TABLE XXIII: SUMMARY OF ANALYTICAL RESULTS FOR PIN DESIGN 3

Description	Symbol	Value	Unit
Force at point E	F_E	667	N
Length from point D to E	L_D	0.097	m
Moment at point D	M_D	65	N-m
Stress at point D	σ_D	50	MPa
Centroid	c	0.01435	m
Moment of Inertia	I	17.73×10^{-9}	m^4

Once we determined the stress at point D, we were able to compare our analytical result with that from FEA. The FEA plot for a loading due to the weight of 68.5 kg on the rails for Pin Design 3 is shown in Figure 24.

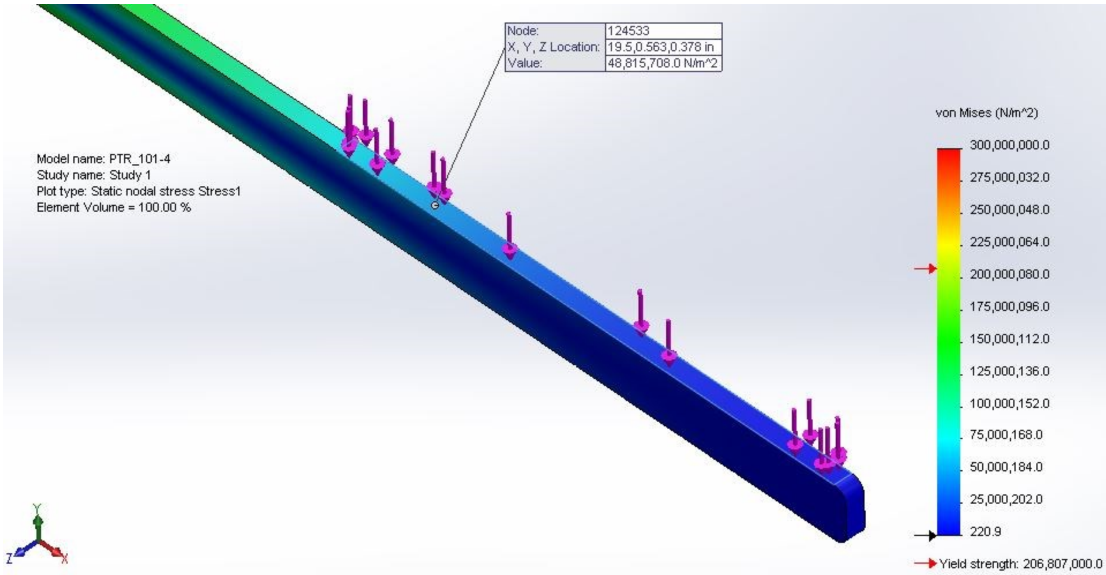


Figure 23: FEA plot of the rails for Pin Design 3 subjected to 68.5 kg

The point probed in Figure 23 is point D; at this point a stress of 48.8 MPa was found to exist. As the stress we have determined analytically is within the same magnitude as that using FEA, our FEA results have been validated.

In summary, Pin Design 3 experiences stresses that are far below the yield strength of 316 stainless steel. Once we confirmed that Pin Design 3 would not fail when subjected to the maximum weight (137 kg), we were able to perform a fatigue analysis on the design.

4.1.4 FATIGUE ANALYSIS ON PIN DESIGN 3

A fatigue analysis was performed to ensure that over the lifespan of the table the components do not fail due to repeated loading of a patient's legs acting on the footrest. 16 procedures are performed on average during one working day and each patient supports their feet with the footrest twice for one given procedure [19]. If we assume 16 procedures are performed 7 days a week, 52 weeks in a year, for 25 years, the footrest will undergo approximately 300 000 cycles. This loading cycle was completed through considering that the mass of a patient's legs are approximately 18.5% of their body weight [21]. Using the maximum weight capacity that the procedural table can safely support, 137 kg, 18.5% of this would be approximately 26 kg. Using a conservative safety factor of 2, each side of the footrest was loaded with 26 kg and a fatigue analysis in SolidWorks was performed using the Goodman approach. Based on the preliminary results obtained from the simulation, it was determined that with fully reversed loading, every part of the footrest actuating locking mechanism was capable of operating at least 300 000 cycles. No yielding was observed up to a magnitude of 1 000 000 cycles.

To validate the FEA results, analytical calculations must be performed. Using the S-N curve for 304 stainless steel, an analytical analysis was done on the expected loading life of the footrest. Based on the FEA, it was determined that for a weight of 26 kg, the maximum stress in the railings was approximately 81 MPa and the maximum stress in the 9.53 mm (3/8 inches) pins was approximately 21 MPa; this is shown in Figure 24.

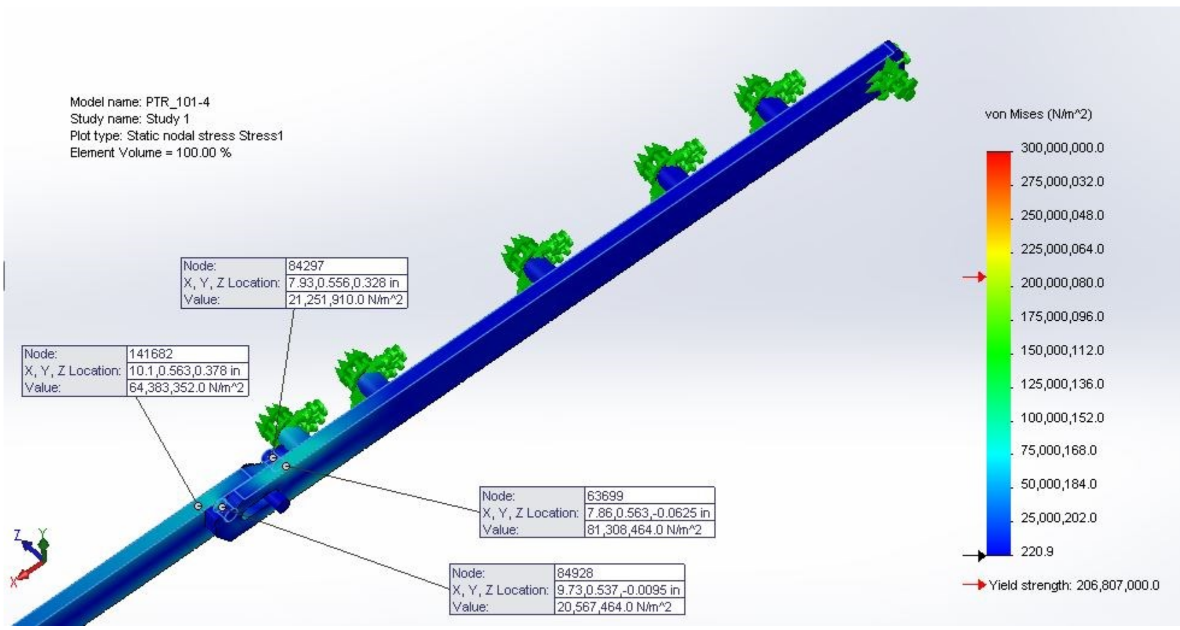


Figure 24: Stress analysis for Pin Design 3 subjected to a weight of 26 kg

To validate the fatigue analysis, the maximum stress must be determined for 300 000 cycles. In the S-N curve pictured in Figure 27, the maximum allowable stress for 300 000 cycles is approximately 210 MPa. As 210 MPa is well above the stresses seen in Figure 25, the railings will be able to withstand the cyclic loading.

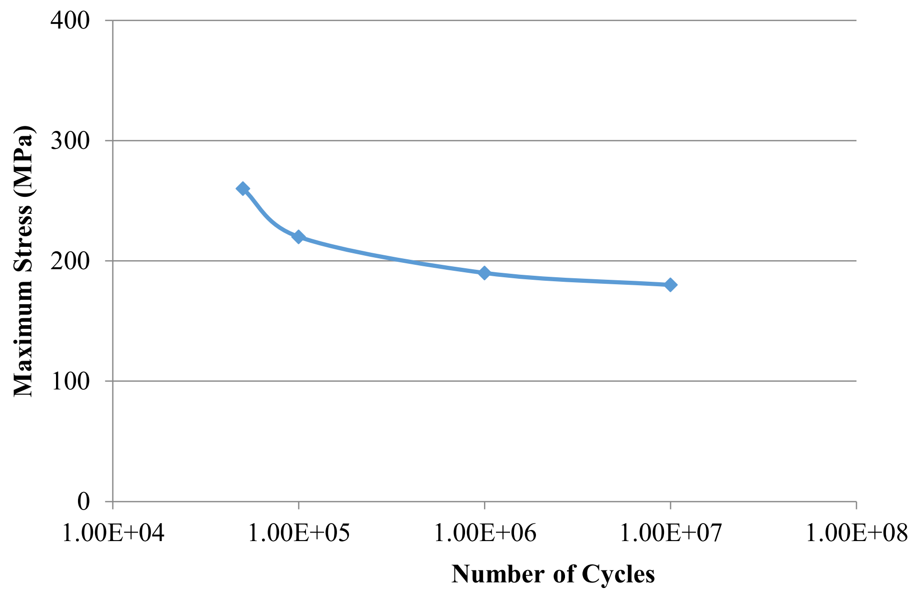


Figure 25: S-N curve for 304 stainless steel [22]

It is important to note that the endurance limit for 304 stainless steel is 180 MPa. As such, if the stresses in the structure are maintained under this limit, the structure should not fail due to fatigue.

4.2 Footrest Analysis

Since the footrest had to be re-designed, an analysis needed to be performed to determine if the proposed design was able to safely support a 137 kg person if they sat in the center of the footrest and on a corner. The footrest was designed without a safety factor, since the probability of a patient sitting on the footrest is very low.

The footrest was modelled in SolidWorks and an FEA was performed. The following assumptions were made while completing the FEA analysis for the footrest:

1. The footrest is made out of 304 stainless steel with a yield strength of 240 MPa.
2. The material is isotropic and homogeneous.
3. The locking pin mechanism is fixed.
4. The load for a patient sitting on the center of the footrest is applied as a 406 mm by 203 mm (16 inches by 8 inches) elliptical circle centered along the length and width of the footrest where the padding is located.

5. The load for a patient sitting on a corner of the footrest is applied as a 203 mm (8 inches) circle.

Since the most commercially available stainless steel is the 304 grade, the material used for the footrest in FEA was assumed to be AISI 304. It was also assumed that all components of the footrest design are made out of material that is isotropic and homogeneous to simplify our design calculations.

For FEA, the locking pin mechanism for the footrest is considered fixed because theoretically the pins that are a part of the locking mechanism are not moving when the footrest is locked in place. Figure 26 shows the fixed geometries in the FEA environment.

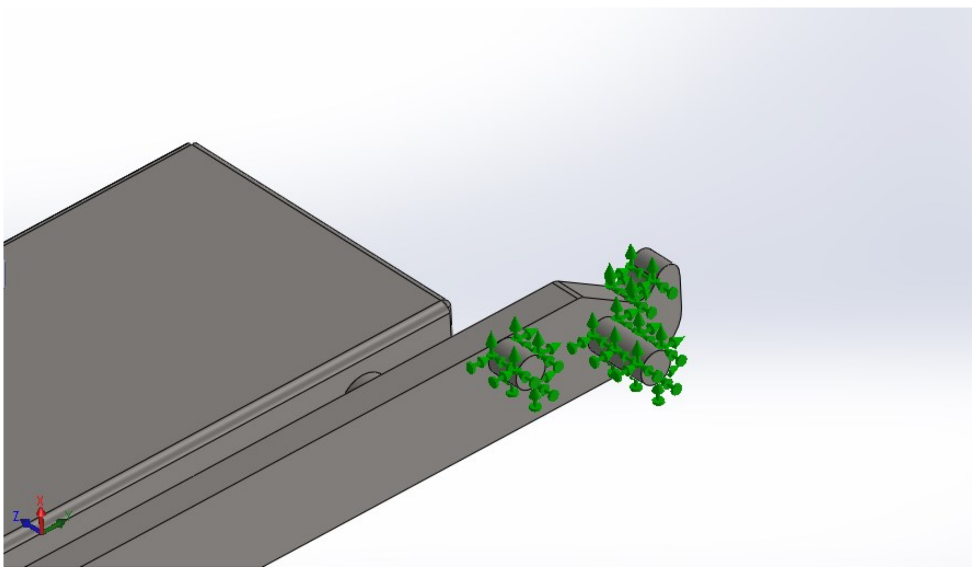


Figure 26: Fixed pin locking mechanism for footrest FEA

The load for a patient sitting on the center of the footrest is applied as a 406 mm by 203 mm (16 inches by 8 inches) elliptical circle centered along the length and width of the footrest where the padding is located. This assumption has been made due to the associated footprint of a person's body when they sit on the footrest. In Figure 27, the fixed locking pin mechanism is shown, along with the load application in the FEA environment for center loading.

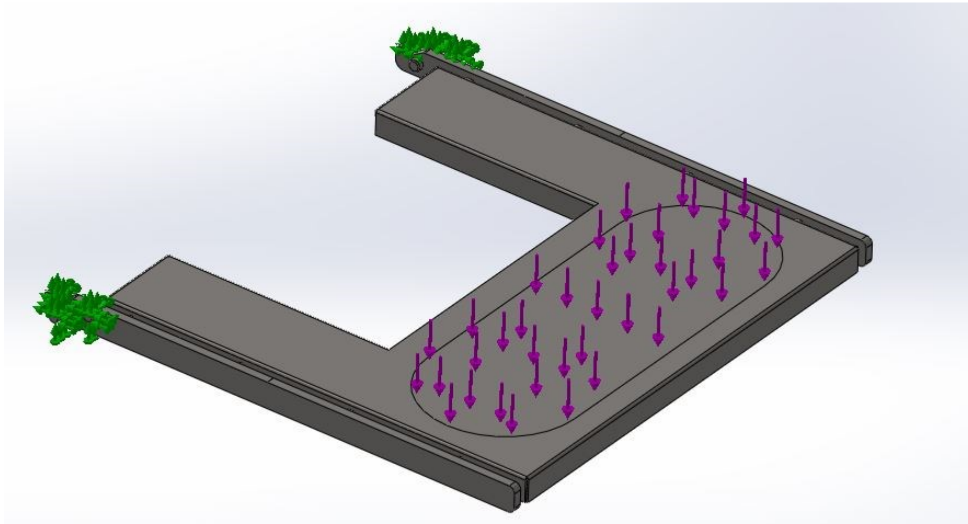


Figure 27: Fixed pin locking mechanism and applied center point load for footrest FEA

The load for a patient sitting on a corner of the footrest is applied as a 203 mm (8 inches) circle. This assumption has been made due to the associated footprint of a person's body when they sit on the corner of the footrest. In Figure 28, the load application in the FEA environment for corner loading is shown.

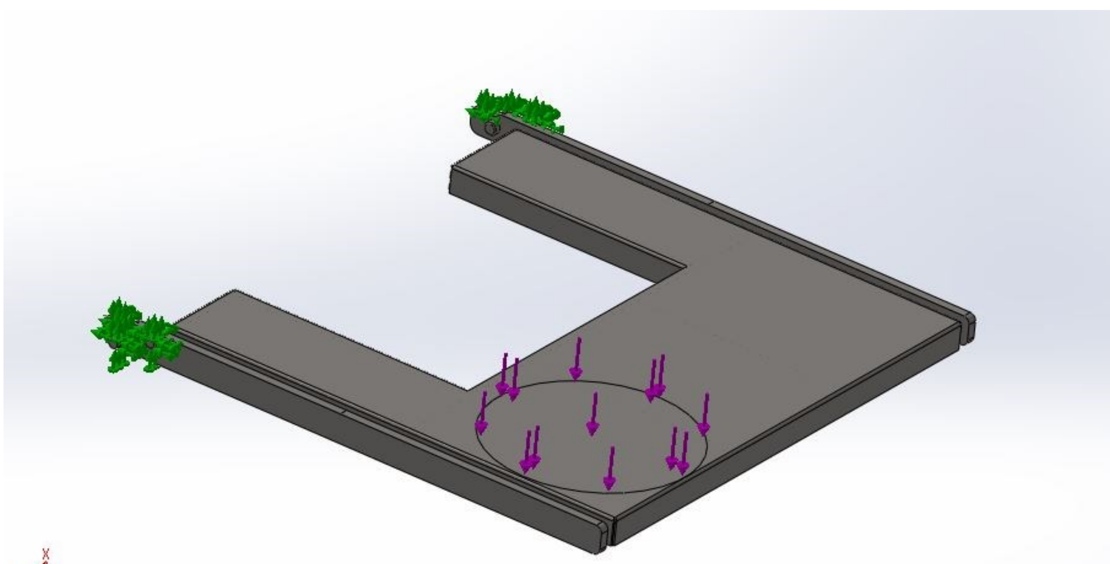


Figure 28: Fixed pin locking mechanism and applied corner point load for footrest FEA

The FEA analysis on the footrest was performed using the mesh properties summarized in Table XXIV.

TABLE XXIV: MESH DETAILS FOR FEA ON FOOTREST

Study name	Study 1 (Default)
Mesh type	Mixed mesh
Mesher used	Standard mesh
Automatic transition	Off
Include mesh auto loops	Off
Jacobian points	At nodes
Jacobian check for shell	On
Element size	0.242 inches
Tolerance	0.0121 inches
Mesh quality	High
Total nodes	80395
Total elements	41041
Remesh failed parts with incompatible mesh	Off
Time to complete mesh (hh;mm;ss)	00:00:42

Through performing FEA on the footrest, it was determined that a maximum stress of 283 MPa exists. This maximum stress exists at the 90 degree corner where the engagement pin meets the railing when subjected to 137 kg in the center of the footrest. As this stress is a mathematical maximum, it will be ignored. The next highest stress in the footrest was found to exist in the railing and it has a value of 229 MPa, which is below the yield strength of 304 stainless steel. A close-up of the rail when subjected to a weight of 137 kg in the center of the footrest is shown in Figure 29.

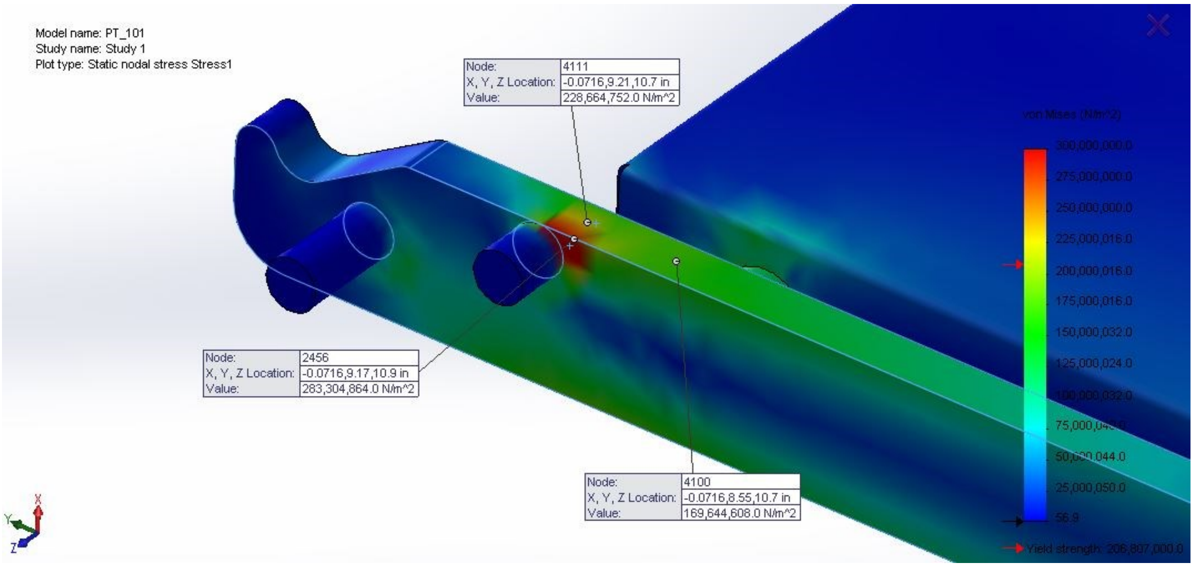


Figure 29: Maximum stress of 229 MPa in the footrest due to an applied weight of 137 kg in the center of the footrest

An overall view of the stress distribution of the footrest is shown in Figure 30.

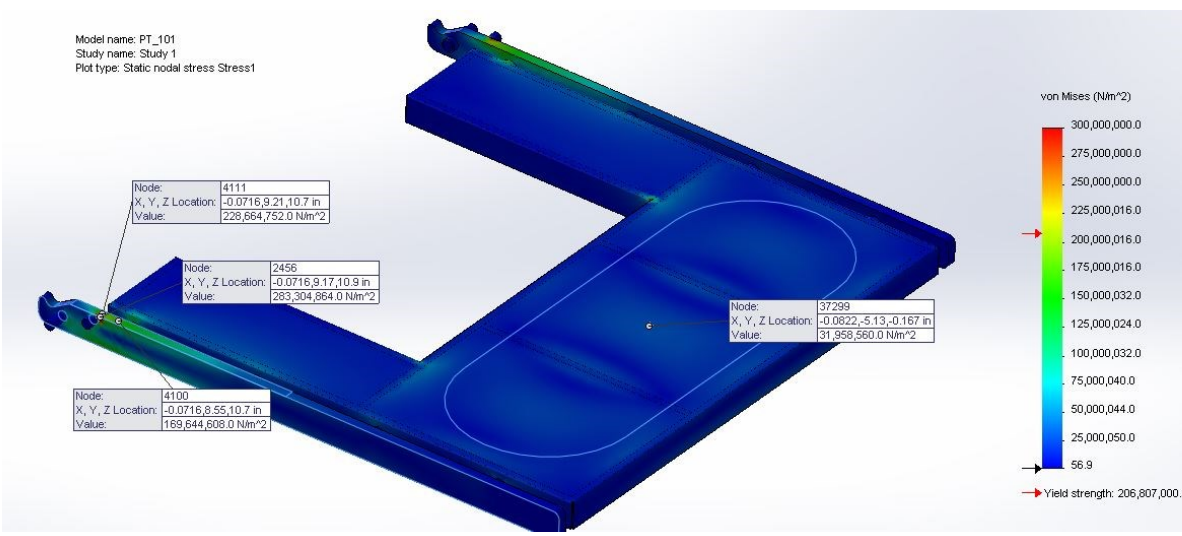


Figure 30: Stress distribution in the footrest due to an applied weight of 137 kg in the center of the footrest

As shown in Figure 30, the stresses within the footrest are generally low and do not exceed 75 MPa. In addition to the stress experienced in the footrest, the deflection was also determined for the 137 kg loading and can be seen in Figure 31 with a deformation scale of 15.5.

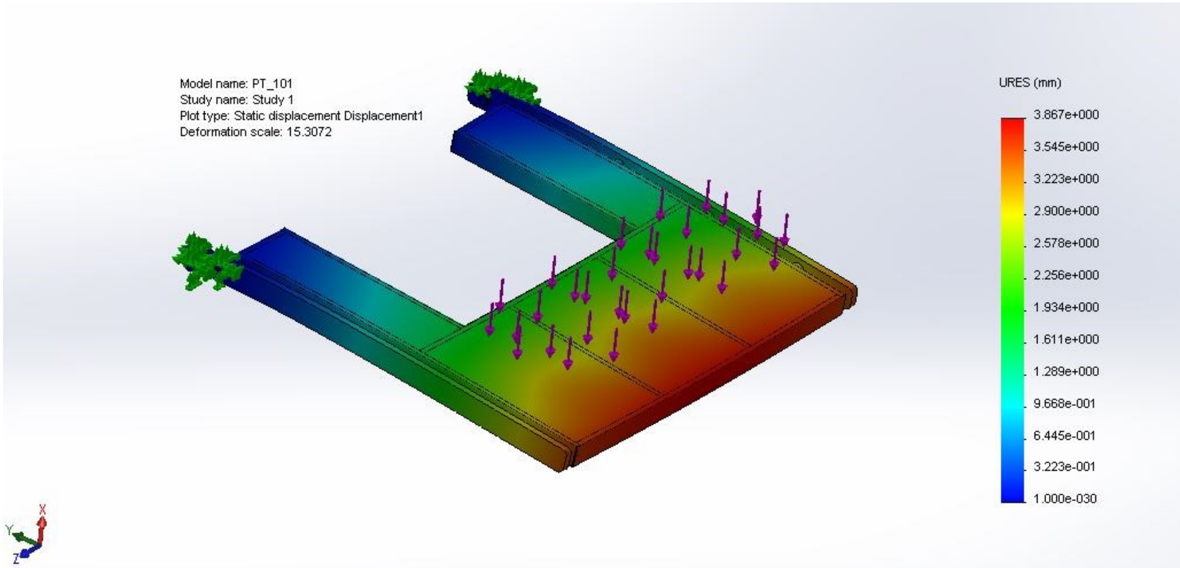


Figure 31: Deflection in the footrest due to an applied weight of 137 kg in the center of the footrest with a deformation scale of 15.5

As a patient sitting in the middle of the footrest is not the worst case scenario, our team also used FEA to determine whether the footrest would fail if someone sat on the corner of the footrest. Using FEA it was found that with a 137 kg person sitting on a corner of the footrest, yielding would occur at the location of the engagement pin on the top and bottom of the footrest railing. The stress distribution in the footrest railing with an applied load of 300 lbs is shown in Figure 32.

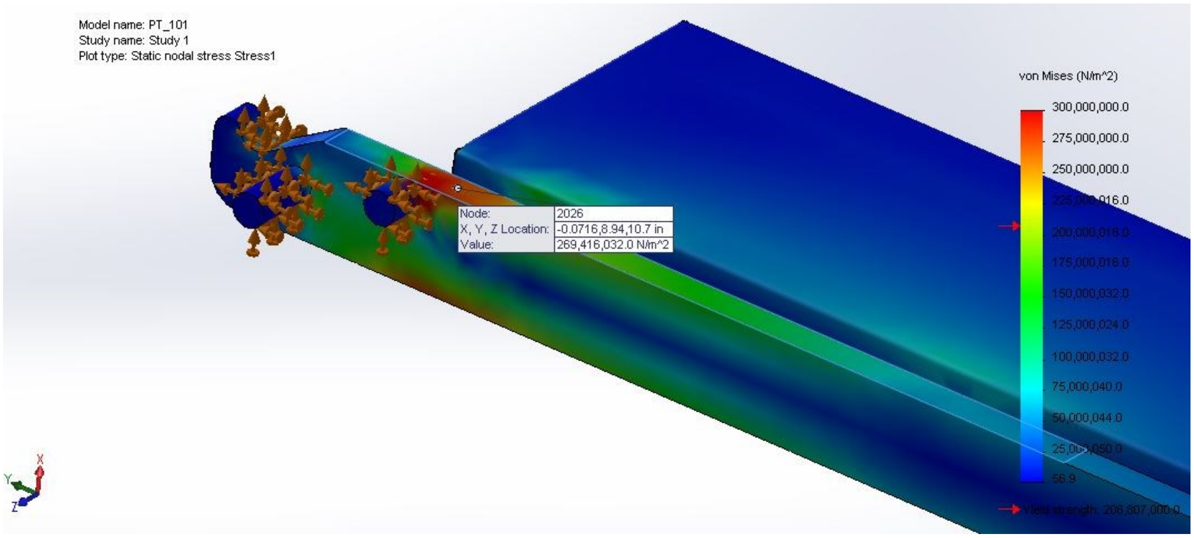


Figure 32: Stress distribution in the footrest due to an applied weight of 137 kg on the corner of the footrest

Although, a single loading of this type would not cause the footrest to break, yielding has begun. As such, our team does not recommend a 137 kg person sit on a corner of the footrest. As shown in Section 4.1, our team determined that the railings could support 68.5 kg. As such, a 68.5 kg person could sit on the edge of the footrest and no yielding would occur. However, we do not recommend that even a person as small as 68.5 kg sit on the edge of the footrest, as the integrity of the table would be compromised.

To verify that the results for the footrest analysis were accurate, a convergence study was performed. The stress of an arbitrary node was recorded over multiple iterations of FEA as the mesh size was decreased. Figure 33 displays the results of the convergence study for the footrest.

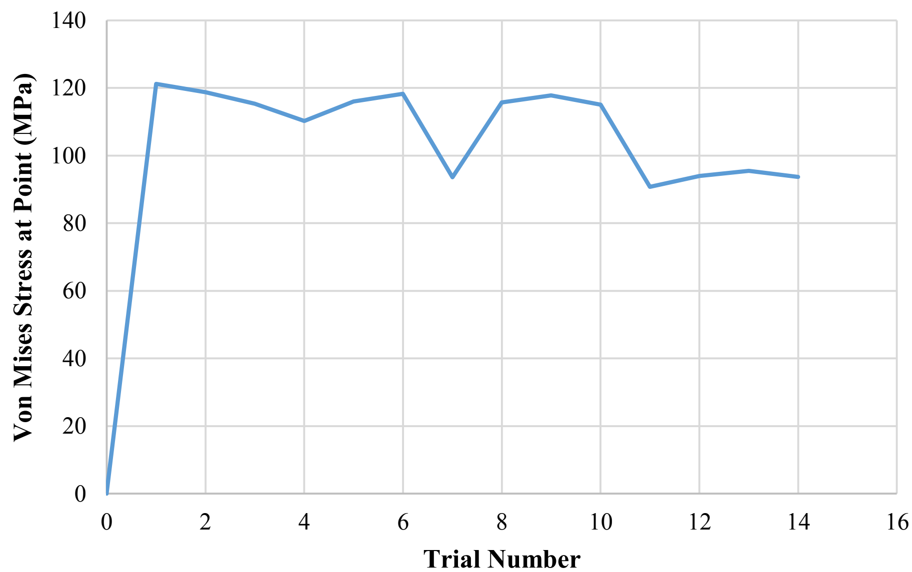


Figure 33: Von Mises stress convergence graph for the footrest

Based on the fact that after 14 iterations of FEA the results began to converge, the preliminary FEA shows that the footrest design is suitable to safely support a 137 kg patient if they were to sit in the center of the footrest, and a 68.5 kg patient if they were to sit on the corner of the footrest.

4.3 Fluid Collection System Analysis

An analysis was performed on the fluid collection system to validate that the pan sitting within the C-channels would be able to withstand the applied load. It was assumed the total applied load was due to the weight the fluid collection system would need to support approximately 4 kg. This total weight includes fluid from the patient's uterus (2000 g), a bowl to collect the fluid from the patient (174 g), a weighted speculum to keep the vaginal cavity open (940 g), and other miscellaneous tools used for the dilation and curettage procedure (750 g).

Assuming a safety factor of 1.5, the fluid collection system was analyzed to see if it could support a weight of 6 kg. The safety factor of 1.5 was used to account for the possibility that extra tools could be placed on the pan during a procedure and the amount of fluid could exceed 2000 g. The safety factor is also used to account for the chance that the weighted speculum is dropped into the pan of the fluid collection system during the procedure.

The pan and the mounting mechanism were modelled as parts and an FEA was performed on the assembly of these parts. The following assumptions were made while completing the FEA analysis for the fluid collection system:

1. The pan and C-channels are made of 304 stainless steel with a yield strength of 240 MPa.
2. The material is isotropic and homogeneous.
3. The top of the C-channel fastened to the underside of the table is considered fixed.
4. The load is applied on a 152 mm (6 inches) circle centered along the width of the pan.
5. The minimum engagement of the pan will be 76 mm (3 inches).
6. The pan and C-channels were assumed to have solid contact.
7. The pan modelled has 9 degree corners.

Since the most commercially available stainless steel is the 304 grade, the material used for the pan and C-channels in FEA was assumed to be AISI 304. It should be noted that the pan was modelled out of 0.76 mm (0.0299 inches) stainless steel, as per manufacturer specifications. It should also be noted that the C-channel was designed out of 14 Ga. stainless steel, as requested after consultation with machinist Nhien Tu. To simplify our design calculations, the 304 stainless steel used to make the pan and C-channels was assumed to be an isotropic and homogenous material.

The top of the C-channel fastened to the underside of the table is considered fixed because theoretically the channels are fastened to the table with flat head screws and should not move. The load of 58.86 N (6 kg) is applied on a 152 mm (6 inches) circle centered along the width of the pan. The load was assumed to be applied in such a way due to the associated footprint of the bowl to collect the fluid from the patient. In Figure 34, the fixed C-channels are shown, along with the load application in the FEA environment.

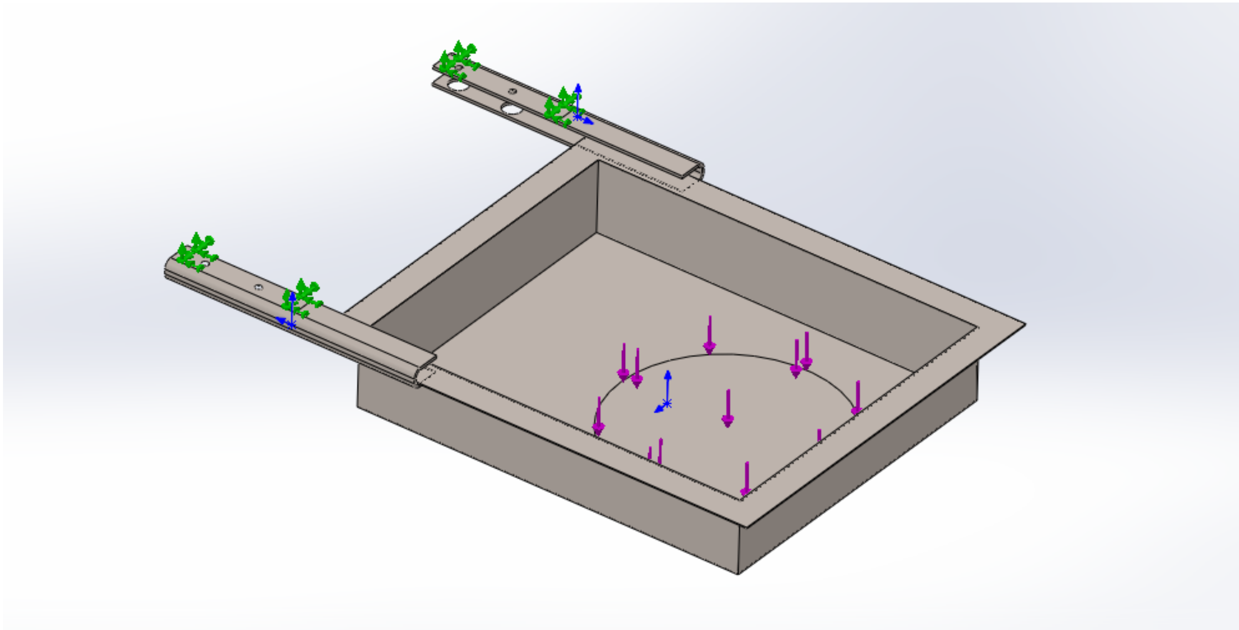


Figure 34: Fixture and applied load on fluid collection system for FEA

For FEA of the fluid collection system, the C-channels were assumed to have a minimum engagement with the pan of 76 mm (3 inches) because during any given procedure, this would be the maximum distance the pan would be deployed (i.e. the worst-case scenario).

We also assumed that solid contact was established between the pan and the C-channels during FEA because in reality when the force is applied, the pan is not deflecting a significant amount.

Although the actual purchased pan will have rounded corners, the pan modelled in SolidWorks for FEA was assumed to have 90 degree corners for simplicity.

The FEA analysis was performed and it was determined that a maximum stress of 56 MPa exists where the C-channels and the pan meet. It should be noted that this stress is below the yield strength of 304 stainless steel. The stress distribution in the C-channels and the pan is shown in Figure 35.

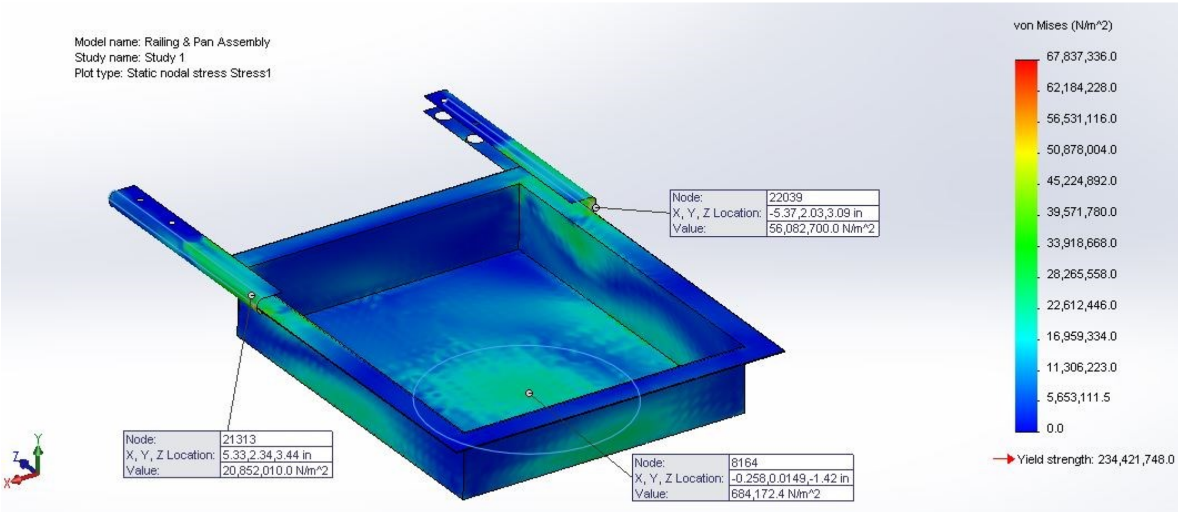


Figure 35: Stress distribution in the fluid collection pan and the C-channel subjected to 6 kg weight

It should be noted that the maximum stress in the C-channels is the red area probed at the end of the C-channels in Figure 35. As shown in Figure 35, the stresses within the fluid collection pan and C-channels are low and generally do not exceed 22 MPa. The mesh details for the FEA on the fluid collection system are summarized in Table XXV.

TABLE XXV: MESH DETAILS FOR FEA ON FLUID COLLECTION SYSTEM

Study name	Study 1 (Default)
Mesher type	Mixed mesh
Mesh used	Standard mesh
Automatic transition	Off
Include mesh auto loops	Off
Jacobian points	At nodes
Jacobian check for shell	On
Element size	0.355465 inches
Tolerance	0.0177733 inches
Mesh quality	High
Total nodes	22389
Total elements	10975
Remesh failed parts with incompatible mesh	Off
Time to complete mesh (hh;mm;ss)	00:00:05

A convergence study was performed to confirm that the results shown in Figure 36 are accurate. The convergence graphs for the von Mises stresses and the percent difference between the consecutive runs are shown in Figure 36 and 37, respectively.

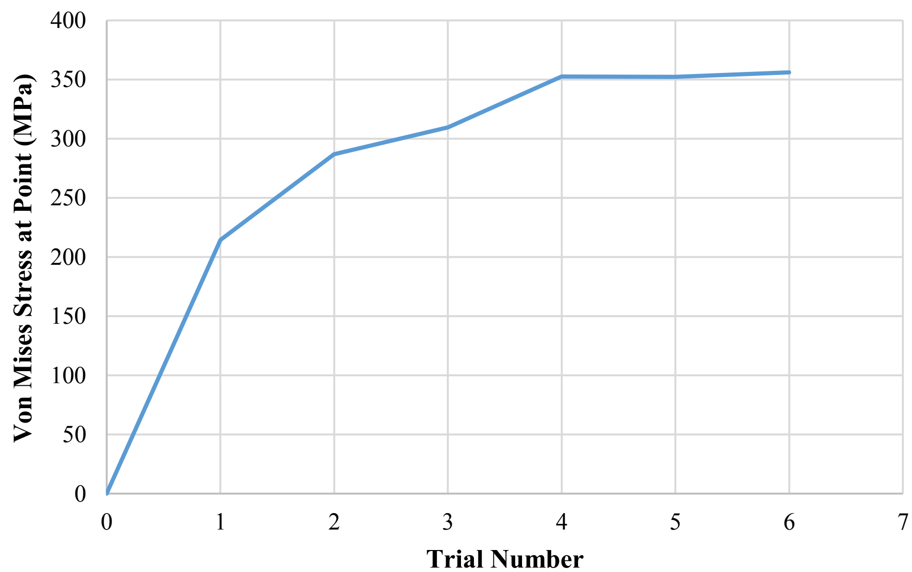


Figure 36: Von Mises stress convergence graph for fluid collection system

Based on the convergence results shown in Figure 36 and 37, it was determined that the analysis was valid and the C-channel and pan combination proposed above would be able to withstand the applied loading.

In order to validate the FEA on the fluid collection system, manual calculations must be performed. For our calculations the C-channel can be considered a beam in bending. Figure 38 shows the basic loading scenario for the C-channels. It should be noted that Figure 37 is not to scale and the dotted line and rectangle in Figure 37 represents the pan and C-channel, respectively.

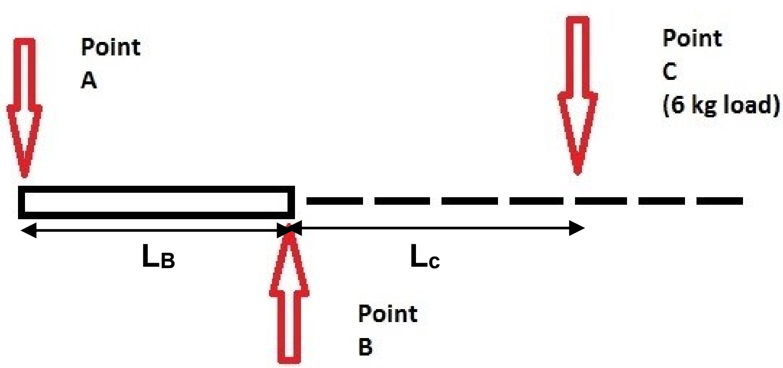


Figure 37: Free body diagram for C-channel for fluid collection system

Point A and B in Figure 37 represent where the pan is contact with the C-channel, and reaction forces are created. Point C in Figure 37 represents where the point load from a distributed load due to the weight of the fluid, bowl, weighted speculum, and weight of the tools would act. A summary of specifications regarding the dimensional parameters of the C-channels is shown in Table XXVI.

Table XXVI: DIMENSIONAL PARAMETERS SUMMARY FOR C-CHANNELS

Description	Symbol	Value (m)
Distance of the gap in the C-Channel	h	0.00925
Thickness of the sheet metal	t	0.0019
Width of the C-channel	b	0.0191
Height of the C-channel	d	0.0133
Distance from Point A to C	L_A	0.24
Distance from Point A to B	L_B	0.1
Distance from Point B to C	L_c	0.14

Using Figure 37 and equations 1, 2, and 3, the following equations are determined.

$$F_B = F_A + F_C \tag{13}$$

$$M_B = F_A \times L_B = F_C \times L_C \tag{14}$$

By knowing the applied load F_C and the lengths L_B and L_C, equations 13 and 14 can be used to determine that F_A, F_B, and M_B are 82 N, 140 N, and 14 Nm, respectively.

Intuitively, it can be seen that the beam is in bending. To validate our FEA results, we must choose a point in our analysis for comparison purposes. We have chosen to analyze point B, as it is subjected to the highest stress along the C-channels. Equation 6 can be used to determine the stress at point B. For a beam in bending with a square channel cross section, I and c are defined as per equation 15 and 16, respectively.

$$I = \frac{bd^3 - h^3(b-t)}{12} \tag{15}$$

$$c = \frac{d}{2} \tag{16}$$

The variables in equation 15 and 16 correspond to those shown in Figure 38.

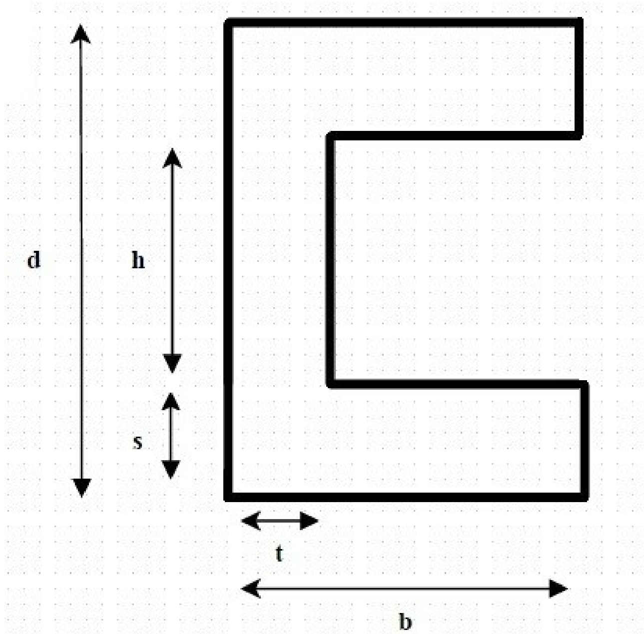


Figure 38: Square C-channel cross section

Using the values in Table XXVI, equation 15 and 16 were used to determine that *I* and *c* are $2.5X10^{-9}$ m^4 and 0.013 m, respectively. Now that we know the moment of inertia, the location of the centroid, and the moment at B, we are able to determine that the stress at B is 75 MPa using equation 6. As the stress we have determined analytically is within the same magnitude as that using FEA, our FEA results for the fluid collection system have been validated. A summary of the values from the calculations of this analysis can be found in Table XXVII.

TABLE XXVII: SUMMARY OF ANALYTICAL RESULTS FOR FLUID COLLECTION SYSTEM

Description	Symbol	Value	Unit
Stress at point B	σ_B	75	MPa
Moment at B	M_B	14	N-m
Force at A	F_A	82	N
Force at B	F_B	140	N
Force at C	F_c	58	N
Centroid	c	0.013	m
Moment of Inertia	I	$2.5X10^{-9}$	m^4

It should be noted that although loading on the fluid collection system is cyclic, a fatigue analysis was not performed on the fluid collection system as the stresses found in the pan and channels were low. Additionally, if failure were to occur over any number of cycles, harm to the patient and user would be minimal, if not non-existent.

In summary, the retrofit design including Pin Design 3 can safely support a patient of 137 kg sitting on the footrest, can safely withstand 300 000 cycles when subjected to 18.5% of a 137 kg person's body weight, and can safely support 6 kg of weight (fluid and tools) on the pan.

5.0 DETAILS OF FINAL DESIGN

Once our footrest retrofit was analyzed and optimized, we were able to compile the details of our design. Within this section of the report, an explanation of how the design operates, and a description of the special features and the main components of the design will be presented. To illustrate the main components of the design, preliminary engineering drawings have been included within this section of the report. A series of steps outlining how to manufacture the table retrofit, as well as a cost estimate to implement the retrofit for one mobile procedural table, will conclude this section of the report.

5.1 OPERATION

The dilation and curettage procedure performed at the Women's Hospital at the HSC involves removing tissue from the uterus. When a patient enters the room prior to surgery, the footrest is up (the angle between the backrest and footrest is 0 degrees), so as to support the patient's legs when they lie down on the table. Once the patient is on the table and her feet are placed in the stirrups, the footrest is lowered to its down position (the angle between the backrest and footrest is 90 degrees) so the procedure can begin. To move the footrest from the up to down position, the footrest must first be lifted past center to disengage the support pins of the actuating locking pin mechanism. Next, the footrest must be pulled towards the user and then lowered. As the footrest is pulled towards the user, the motion is governed by a shoulder bolt moving within the milled slots located on the rails. Figure 39 illustrates the three steps required by the user to move the footrest from the up to down position. Figure 40 illustrates how the locking mechanism specifically works for the three step process outlined in Figure 39.

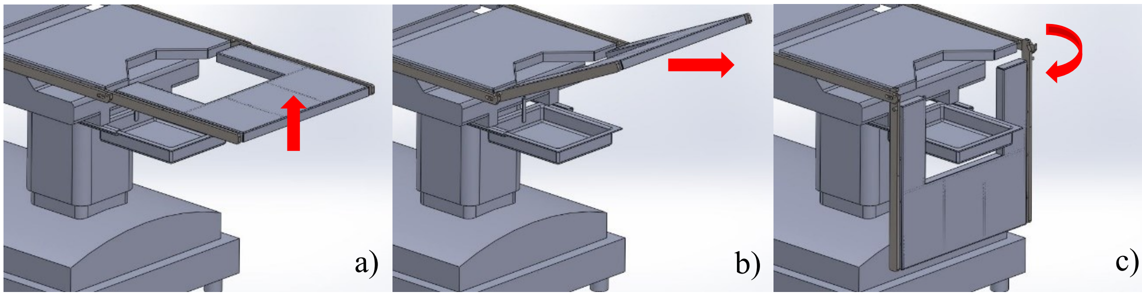


Figure 39: To move the footrest from the up to down position, the footrest is (a) unlocked by lifting the footrest past center, (b) pulled towards the user, and (c) lowered

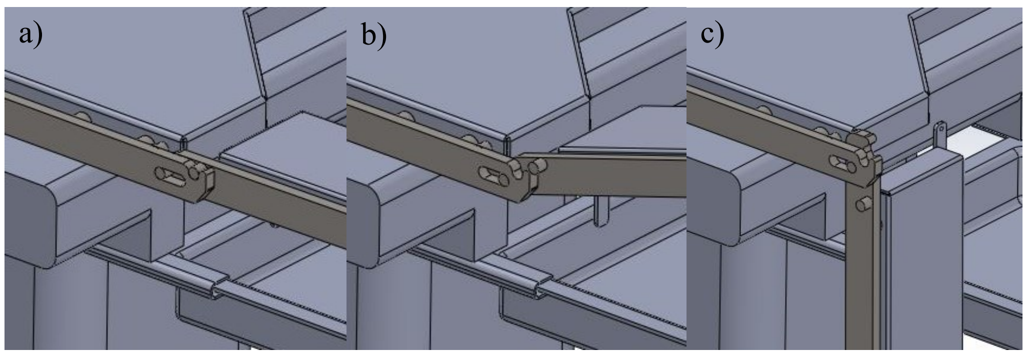


Figure 40: The footrest locking mechanism during the three step process required to move the footrest from the up to down position: the footrest is (a) unlocked by lifting the footrest past center, (b) pulled towards the user, and (c) lowered

Once the footrest has been lowered, the fluid collection system is deployed. The fluid collection system is composed of a pan that runs on C-channels. In order to have the pan in its desired location, the pan must slide along the channels. The pan is not only used to collect fluids from the patient's uterus, but it is also used to provide a working surface for the doctor's surgical tools. Engagement of the pan with the C-channels is illustrated in Figure 41.

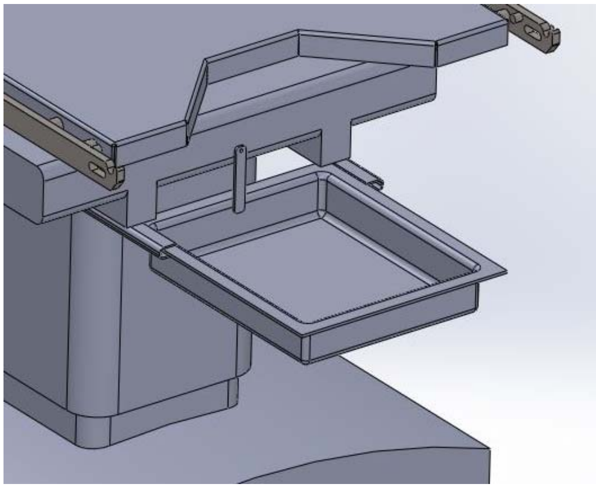


Figure 41: Maximum deployed position of the pan that ensures adequate support from the C-channels and no spillage of fluids

As shown in Figure 41, a rectangular bar is used to prevent the pan from going past a safe point of engagement during the procedure. It should be noted that the back of the pan at this point is in line with the cut-out section in the backrest, to ensure all fluid is collected within the pan. Once the procedure is over, the pan can be removed for disinfection and sterilization purposes by simply rotating the rectangular bar 90 degrees and pulling the pan out of the C-channels. To return the pan to its original position, the pan must be placed on the C-channels and pushed in. The rectangular bar is then rotated 90 degrees to secure the pan for the next procedure.

Once the pan has been returned to its original position, the footrest is moved from it’s down to up position, so that the patient has somewhere to rest her feet. To move the footrest from the down to up position, the footrest must be lifted past center, pushed away from the user, and then lowered onto the engaging support pins. Once again, the sliding motion is governed by the pin moving within the milled slots located on the rails. Figure 42 illustrates the three step process required to move the footrest from the down to up position. Figure 43 illustrates how the locking mechanism specifically works for the three step process outlined in Figure 42.

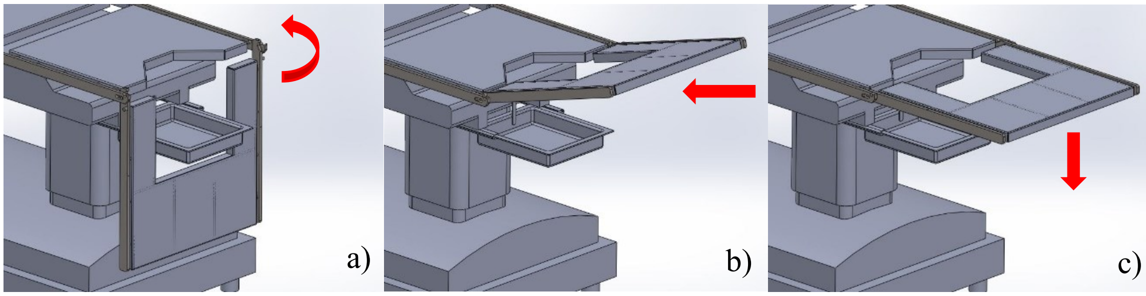


Figure 42: To move the footrest from the down to up position, the footrest is (a) lifted, (b) slid away from the user, and (c) locked into place

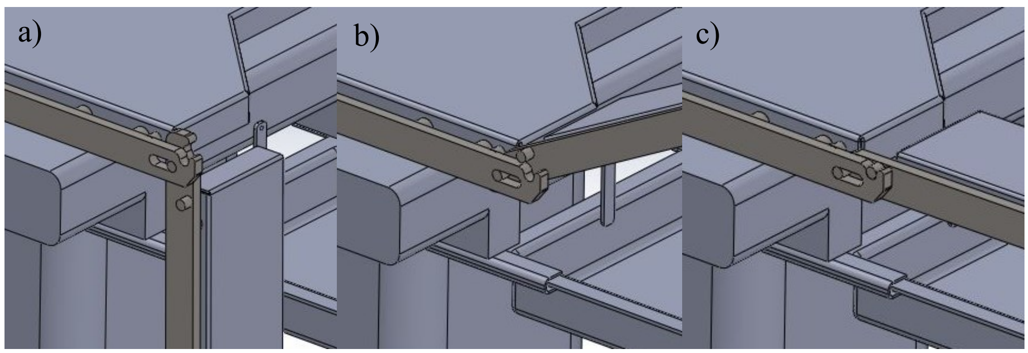


Figure 43: The footrest locking mechanism during the three step process required to move the footrest from the down to up position: the footrest is (a) lifted, (b) slid away from the user, and (c) locked into place

5.2 SPECIAL FEATURES

The following special features have been incorporated into the design:

1. Operation of the footrest is located at the foot end of the bed.
2. Deployment of the footrest can be performed with one hand.
3. Deployment of the footrest can be performed within 3 seconds.
4. Deployment of the footrest does not interfere with the pan when at its maximum position.
5. The retrofit design incorporates rubber stoppers on the back of the footrest.
6. The retrofit design is easy to manufacture.
7. The retrofit design is easy to assemble/disassemble.
8. The retrofit design is easy to clean.

One feature we added to our design is the ability for the operator to deploy the footrest while being positioned at the end of the table. Currently, the footrest on the mobile table is operated with a crank mechanism that is located by the patient's head, not the patient's feet. For the operator, it is valuable to be able to adjust the position of the footrest at the end of the table because the footrest is typically adjusted immediately before or after the patient's feet are placed in the stirrups.

The second feature we have added is the ability to deploy the footrest with one hand. Currently, the non-mobile procedural table that the Women's Hospital use for dilation and curettage requires two hands to operate. The team was able to create a one-handed operating footrest by making the footrest lighter, and the mechanism for locking easy to engage and disengage.

The third feature we have incorporated into the design is the speed at which the footrest can be deployed. Currently, the crank mechanism that is used for the deployment of the footrest on the mobile procedural table takes 10 seconds to deploy. We have determined that with the design proposed within this report, the average time to find the mechanism for deployment will take 1 second, and the time to raise or lower the footrest is 2 seconds. Thus, a total of three seconds is required to change the position of the footrest.

The fourth feature we have added is that the new footrest can be deployed without interfering with the fluid collection system when the pan is at its maximum usable distance. Figure 44 illustrates this feature.

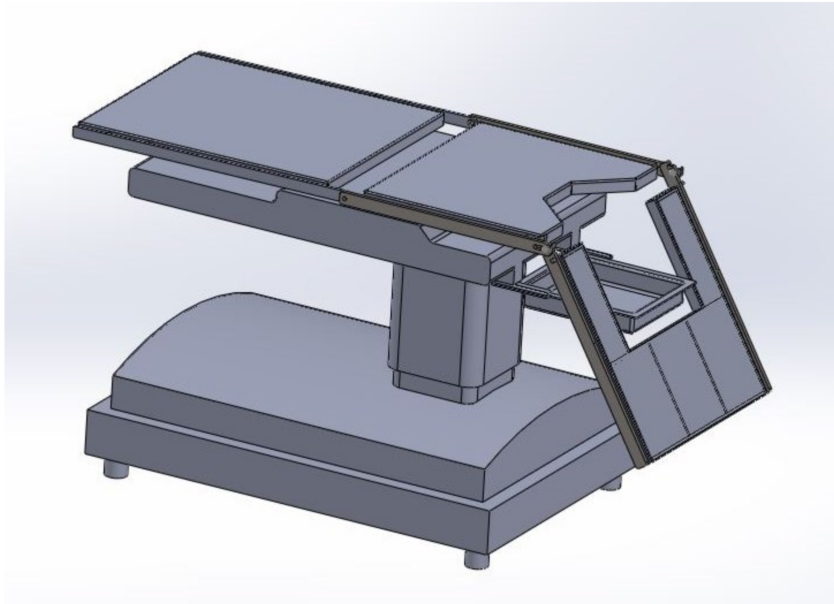


Figure 44: Mobile procedural table displaying that the footrest does not interfere with the fluid collection system during deployment

It should be noted that a pan up to 102 mm (4 inches) longer in length, than that specified in the report, can be used with the current table design. A larger sized pan may be necessary depending on how much fluid is estimated to be collected in the pan from a patient. This larger sized pan must be fully pushed in when the footrest is being deployed to avoid interaction between the footrest and the fluid collection system.

The fifth feature of our design involves the implementation of four rubber stoppers, which are used to absorb the load presented by a swinging footrest if it is dropped. There are four potential points of contact that exist between the footrest and the table. Two potential points of contact are between the base of the table and the bottom of the footrest, and the remaining points of contact are between the gear box and the footrest located 267 mm (10.5 inches) from the pivot point of the footrest. The location of the black rubber stoppers are pictured in Figure 45.

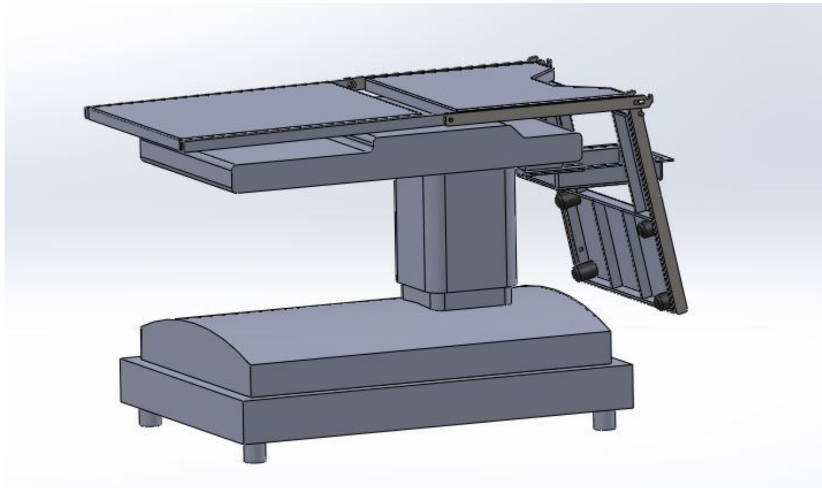


Figure 45: Mobile procedural table with stoppers to absorb the contact load if the footrest hits the base of the table or the gearbox

It should be noted that the gearbox is not pictured in Figure 45, as it would interfere with showing the features we have added to the table.

The sixth and seventh feature of our design is the ease of manufacturability and ease of assembly/disassembly, respectively. Ease of manufacturability has been achieved by keeping the number of components at a minimum. Ease of assembly/disassembly has been achieved by making components quick to attach and detach. The use of shoulder bolts for the sliding pin design is a particular element that helps make assembly/disassembly quick. By creating a design that is easier to assemble/disassemble, the retrofit is also easier to thoroughly clean if desired.

The eighth and final feature of our design involves the ease of cleaning the designed components. Currently, the non-mobile table used for dilation and curettage involves two rods mating with one another for locking. Thus, the mechanism for locking the footrest on the non-mobile table is not entirely visible and creates a tight space where bodily fluid can accumulate. A special feature of our design is that our mechanism for locking and deploying the footrest is entirely visible and contains fewer tight spaces, so cleaning the mechanism is easier.

5.3 MAIN COMPONENTS

The mobile procedural table retrofit consists of two main components: the footrest and the fluid collection system. A description of these components are presented within this section.

5.3.1 FOOTREST

The footrest is made out of 14 Ga. thick piece of 304 stainless steel that is laser cut to the desired shape of the footrest: 513.3 mm wide (20 3/16 inches), 487.9 mm (19 3/16 inches) in height, and 27.3 mm (1 1/16 inches) in depth. A picture of the 2-D sheet of metal that represents the footrest is shown in Figure 46.

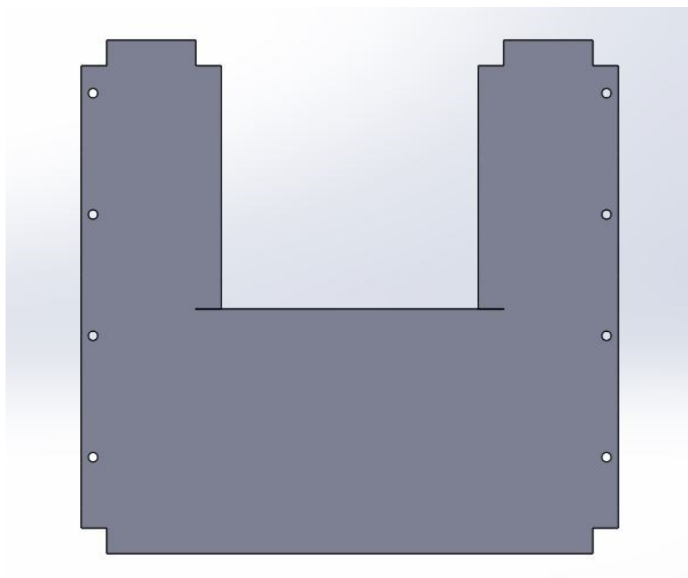


Figure 46: 2-D sheet of metal that represents the footrest before it is bent into shape

To obtain a 3-D footrest, the flat piece of steel must be bent around a support frame using a break. The support structure is made of 304 stainless steel rectangular bar stock and has the shape shown in Figure 47.

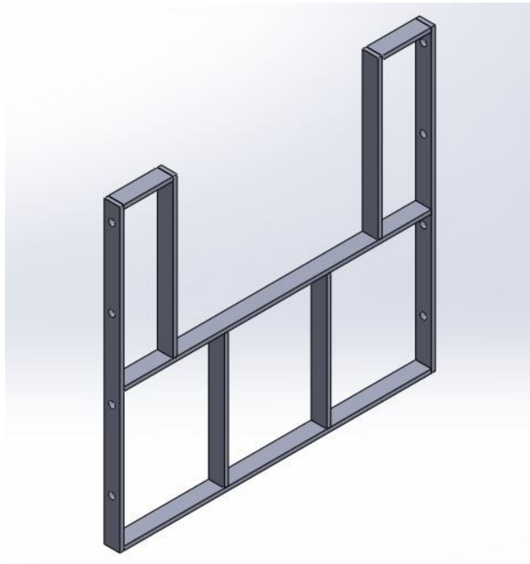


Figure 47: Footrest support structure design

It should be noted that based on consultation with one of our stakeholders, Nhien Tu, the shape of the support structure was chosen based on what would provide the best structural stability with the fewest number of components.

As our client would like to use the same stirrup attachment that they currently use, rails must be attached to the sides of the footrest, as seen in Figure 48.

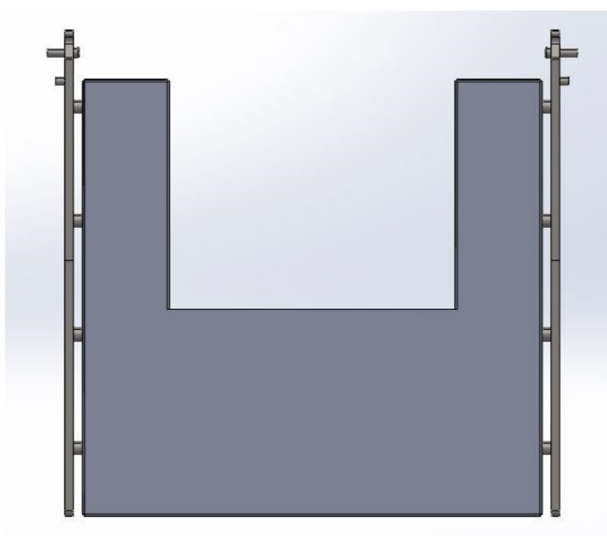


Figure 48: Rails are attached to the footrest using spacers that are welded to the components

The rails in Figure 48 are 9.5 mm (3/8 inches) thick and have a height of 28.6 mm (1 1/8 inches). They attach to the footrest with a series of 15.9 mm (5/8 inches) diameter spacers between the footrest and rail.

For our locking mechanism, two engaging pins and one shoulder bolt are used. The two pins and shoulder bolt are pictured in Figure 49.

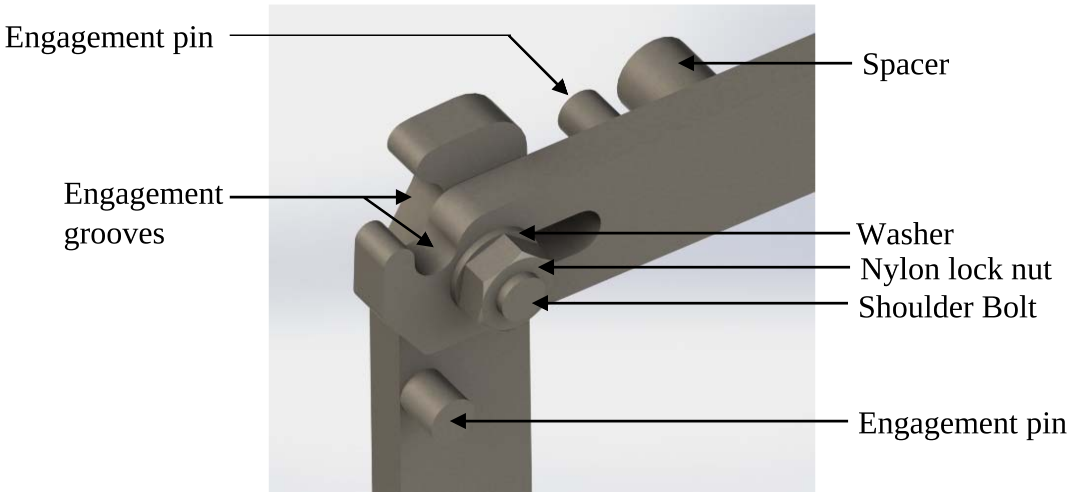


Figure 49: Footrest locking mechanism

As shown in Figure 49, the shoulder bolt is secured with a washer and a lock nut and slides within a slot milled into the rail. The slot is 19.1 mm (0.75 inches) in length, and 9.9 mm (0.3906 inches) wide. This sliding pin mechanism behaves as a hinge point to allow for the footrest to be lifted and locked into position.

5.3.2 FLUID COLLECTION SYSTEM

The fluid collection system consists of a pan with a lip that is supported and deployed on C-channels. The pre-purchased pan is made out of 304 stainless steel and is 265 mm (10 7/16 inches) wide, 309.6 mm (12 3/16 inches) in length, 50.8 mm (2 inches) deep, and 1.5 mm (0.06 inches) thick. The pan has a lip of 19.1 mm (3/4 inches) that runs along the top edge of the pan, as shown in Figure 50.

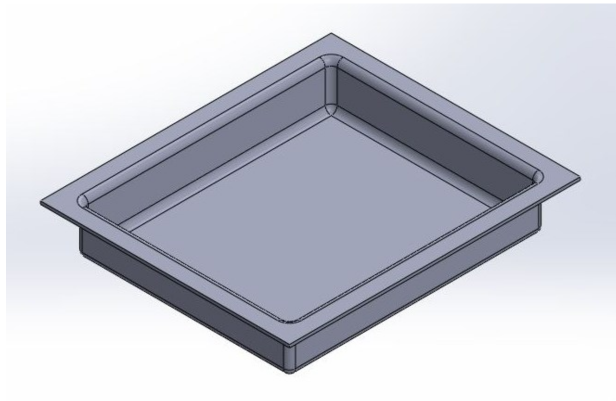


Figure 50: Pan used to collect fluid from a patient, and hold tools for dilation and curettage procedure

The lip of the pan engages with C-channels that have a depth of 21 mm (13/16 inches), as shown in Figure 51. A minimum of 12.7 mm (1/2 inch) engagement must be created between the pan and the C-channel.

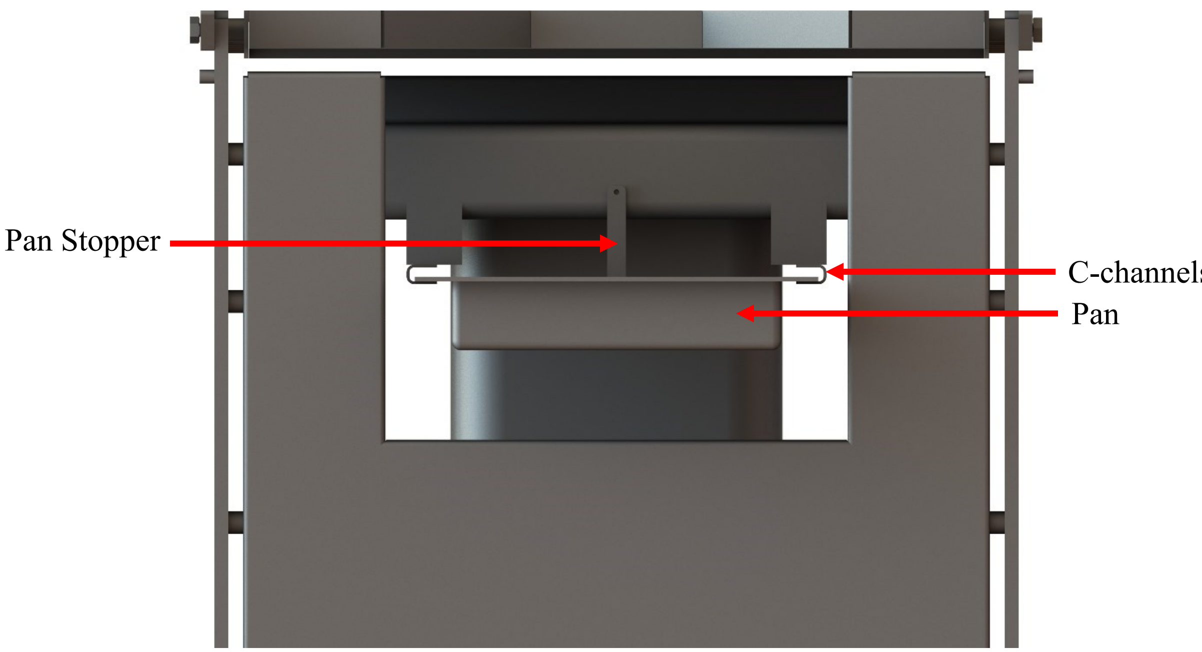


Figure 51: End view of the pan engaging with the C-channels

The channels are 152.4 mm (6 inches) in length and one is located on either side of the table, as shown in Figure 51. The C-channels contain holes on the flanges, so that screws can be used to attach the channels to the footrest, as seen in Figure 52.

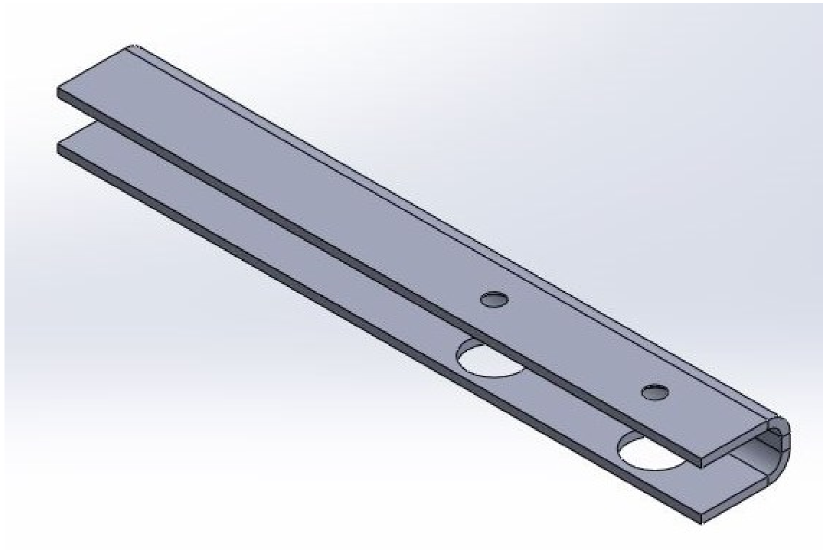


Figure 52: C-channels used to support the fluid collection pan

It should be noted that the holes on the bottom of the C-channels are larger than the holes on the top to accommodate space for the screwdriver to access the predrilled screw holes that will attach the C-channels to the underside of the table. For our design, we have specified a #8 stainless steel flat head bolt; a total of two screws per flange are specified to be used.

5.4 Engineering Drawings

This section presents all preliminary engineering drawings needed to manufacture the footrest and fluid collection system.

5.4.1 Bill of Materials

The Bill of Materials (BOM) for the procedural table retrofit is presented in Table XXVIII. A list of vendors have been included in Table XXVIII for reference.

TABLE XXVIII: BILL OF MATERIALS FOR PROCEDURAL TABLE RETROFIT

Item	Unit	Quantity	Vendors
3/8" Stainless steel shoulder bolt	each	2	McMaster-Carr
Custom C-channel	each	2	McMaster-Carr
1/4" self tapping screw	each	5	Bolt Depot
Purchase pan	each	1	Russel Foods
Pan stopper	each	1	McMaster-Carr
14 Ga. stainless steel sheet 12" x 18"	each	1	McMaster-Carr
Stainless steel bar 1" x 0.25"	ft	12	McMaster-Carr
Footrest railing	each	2	N/A
Stainless steel rod 3/8"	ft	2	Metal Depot
1/4" Locking nut	each	2	Bolt Depot
1/4" Washer	each	2	Bolt Depot
Backrest railing	each	2	N/A
Rubber Stopper 3/8"	each	4	McMaster-Carr

5.4.2 FOOTREST ENGINEERING DRAWINGS

Included within this section are five engineering drawings to make the aforementioned design changes to the mobile AMSCO 2080 procedural table. Figure 53, 54, 55, 56, and 57 presents a preliminary engineering drawing of the footrest, support frame for the footrest, modifications for the backrest railings, modifications for the footrest railings, and pin assembly of the footrest, respectively. It should be noted that all dimensions in square brackets in the engineering drawings are in millimetres.

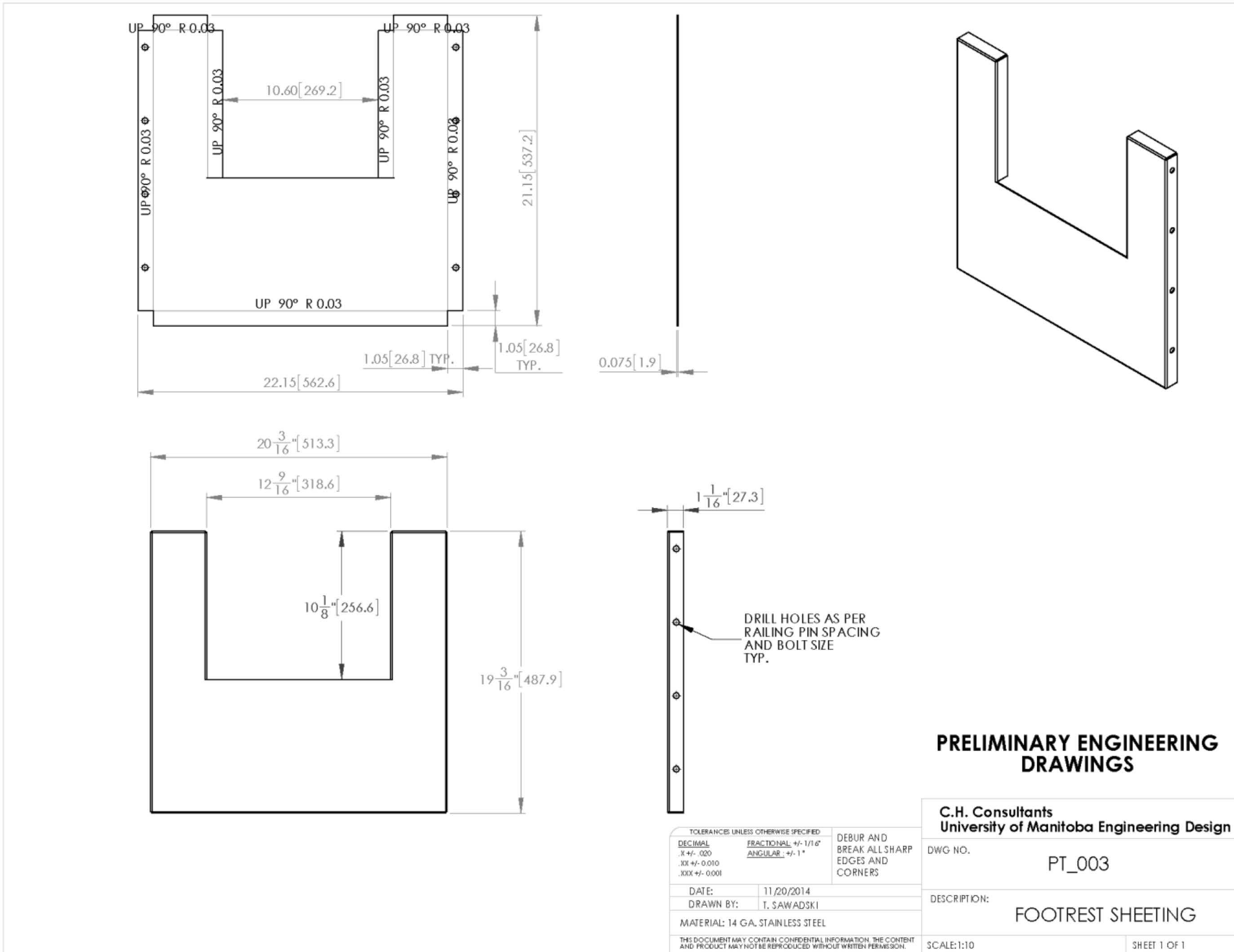


Figure 53: Preliminary engineering drawing of footrest sheeting

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PT_018	1" x 0.25" x 19" 304S/S	2
2	PT_019	1" x 0.25" x 19-1/2" 304 S/S	2
3	PT_020	1" X 0.25" X 10" 304 S/S	2
4	PT_021	1" X 0.25" X 8-1/2" 304 S/S	2
5	PT_022	1" X 0.25" X 3-1/8" 304 S/S	2

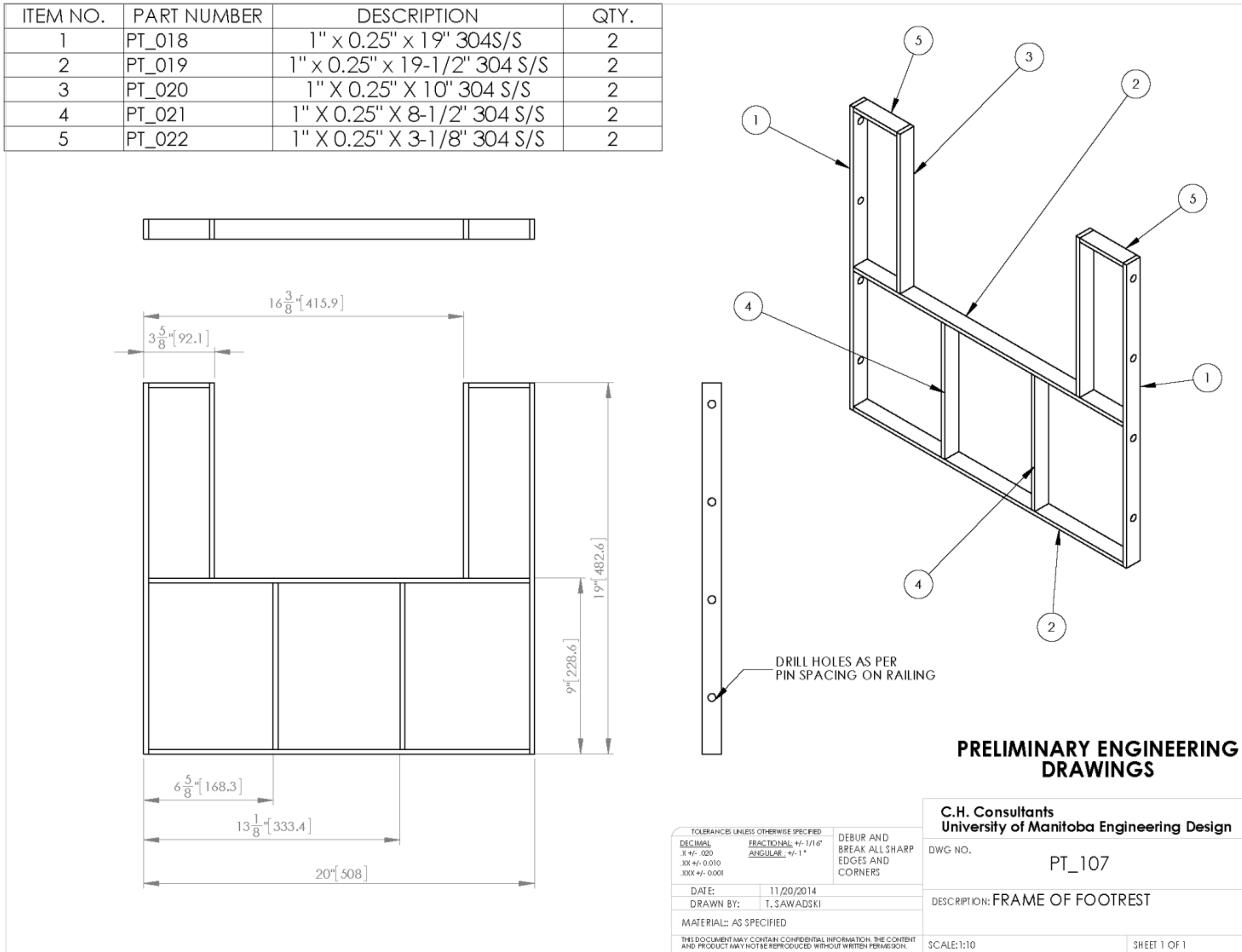


Figure 54: Preliminary engineering drawing of support structure

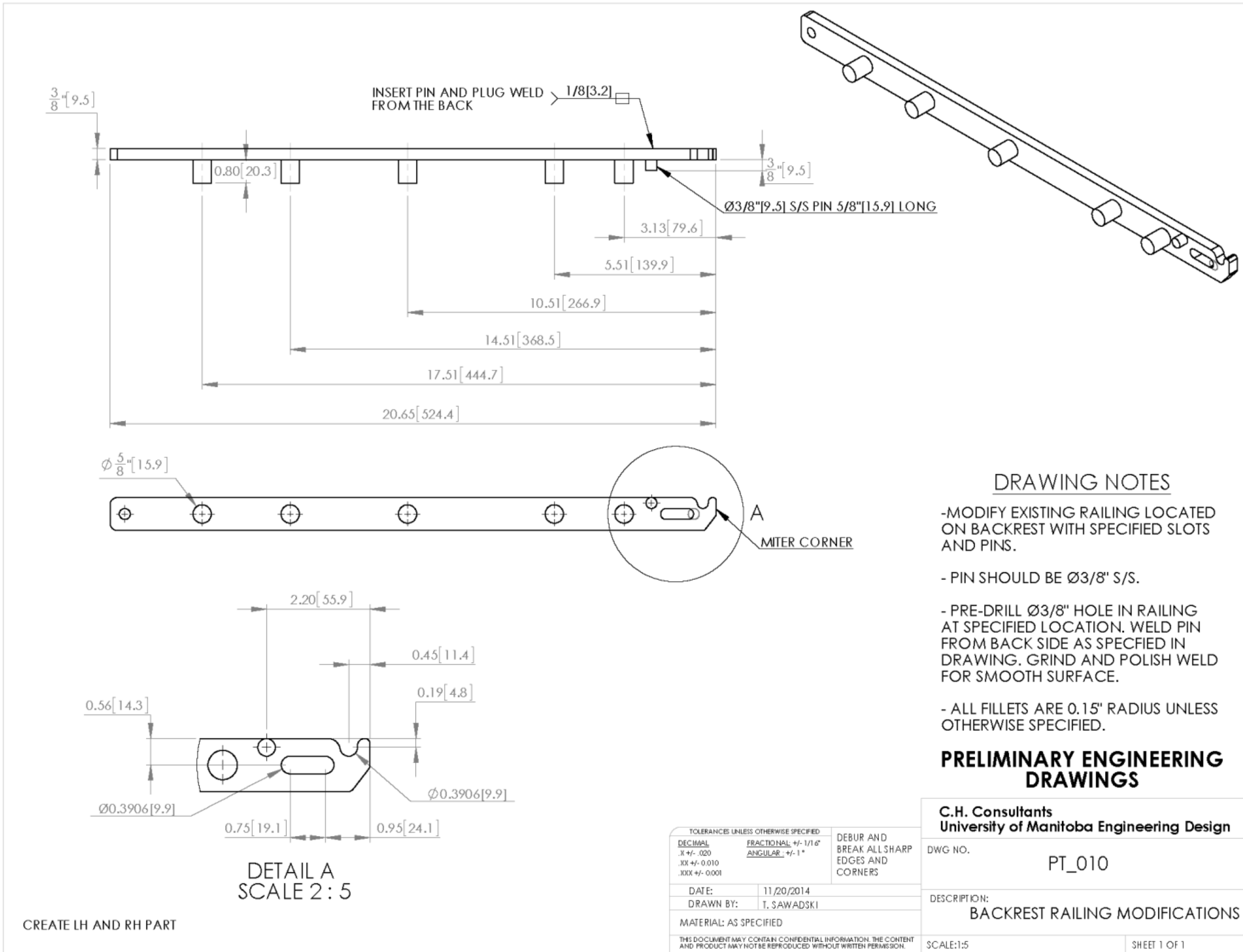


Figure 55: Preliminary engineering drawing for modifications to the backrest railings

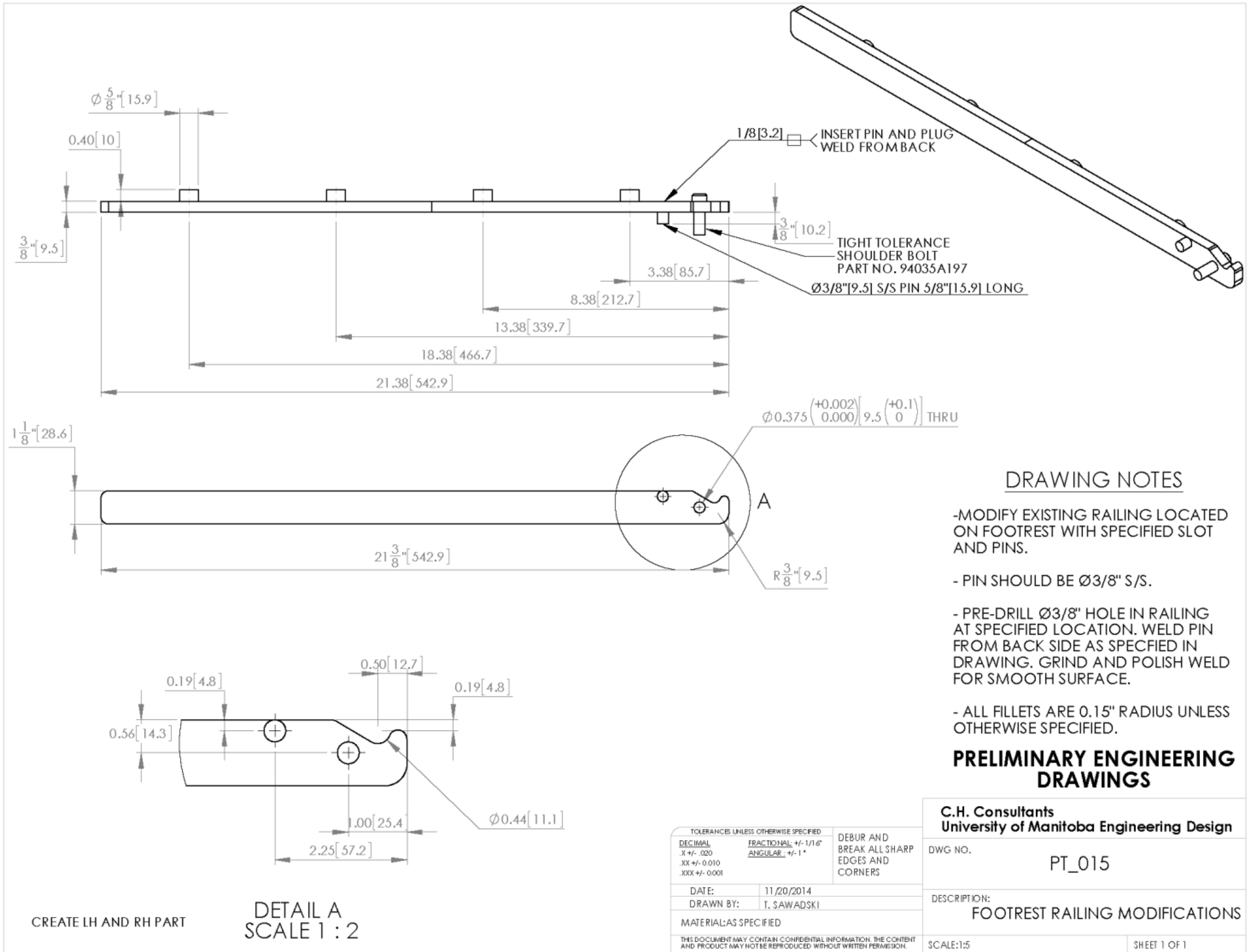


Figure 56: Preliminary engineering drawing for modifications to the footrest railings

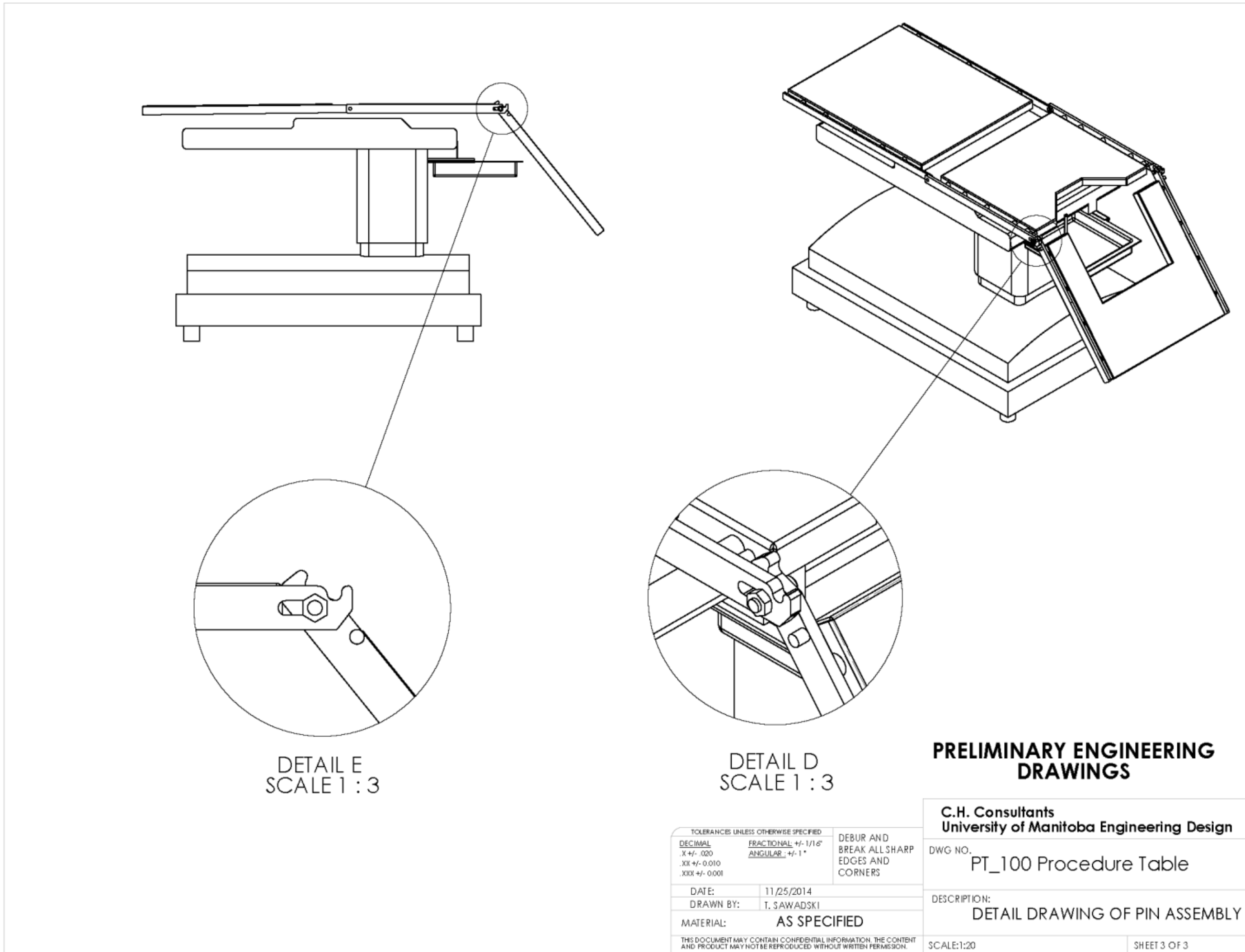


Figure 57: Preliminary engineering drawing for pin assembly of footrest

5.4.3 FLUID COLLECTION SYSTEM ENGINEERING DRAWINGS

Included within this section are two engineering drawings to make the aforementioned design changes to the mobile AMSCO 2080 procedural table. Figure 58 presents a preliminary engineering drawing for the C-channels and Figure 59 presents a preliminary engineering drawing for the mounting of the C-channels. It should be noted that all dimensions in square brackets in the engineering drawings are in millimetres.

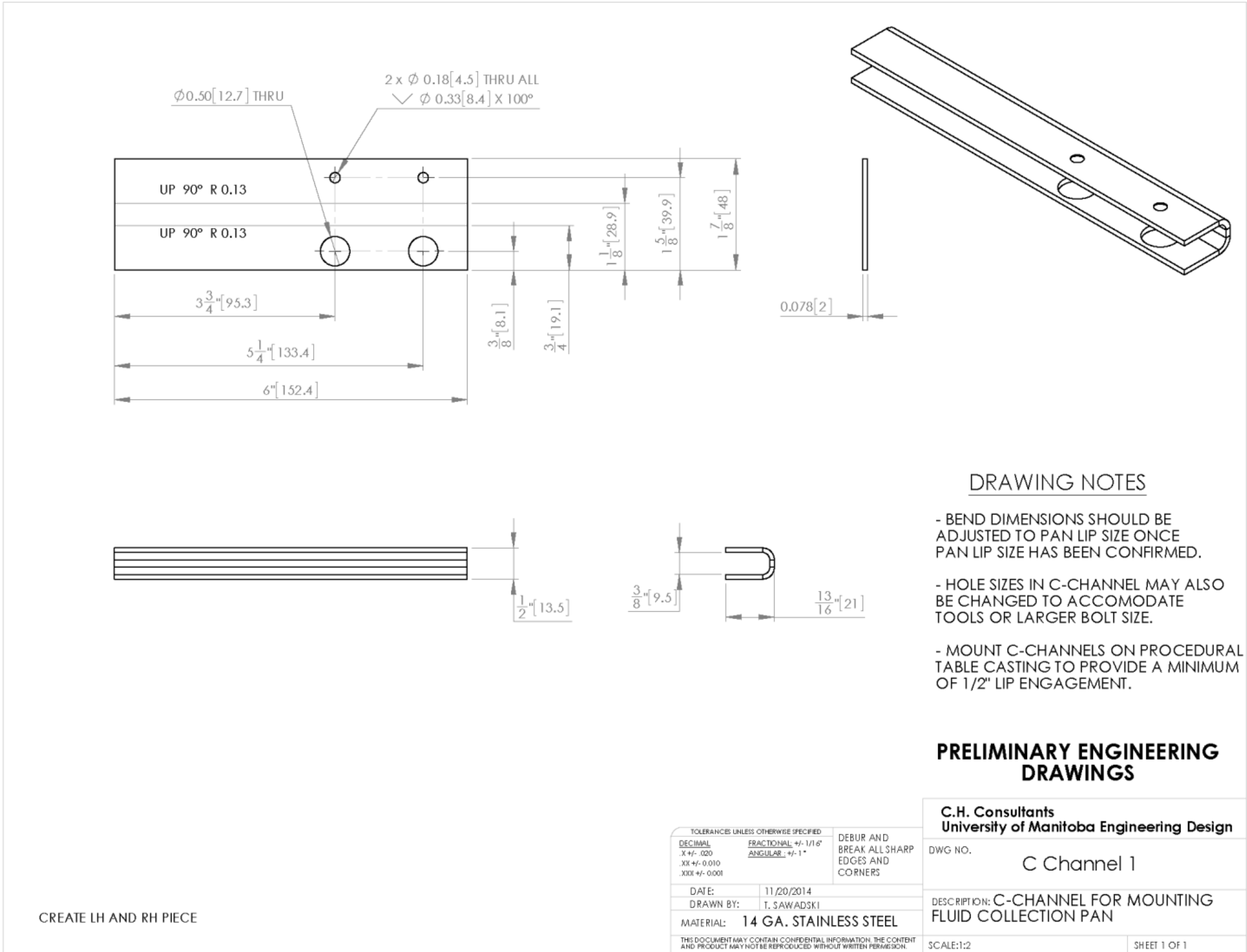


Figure 58: Preliminary engineering drawing for C-channels

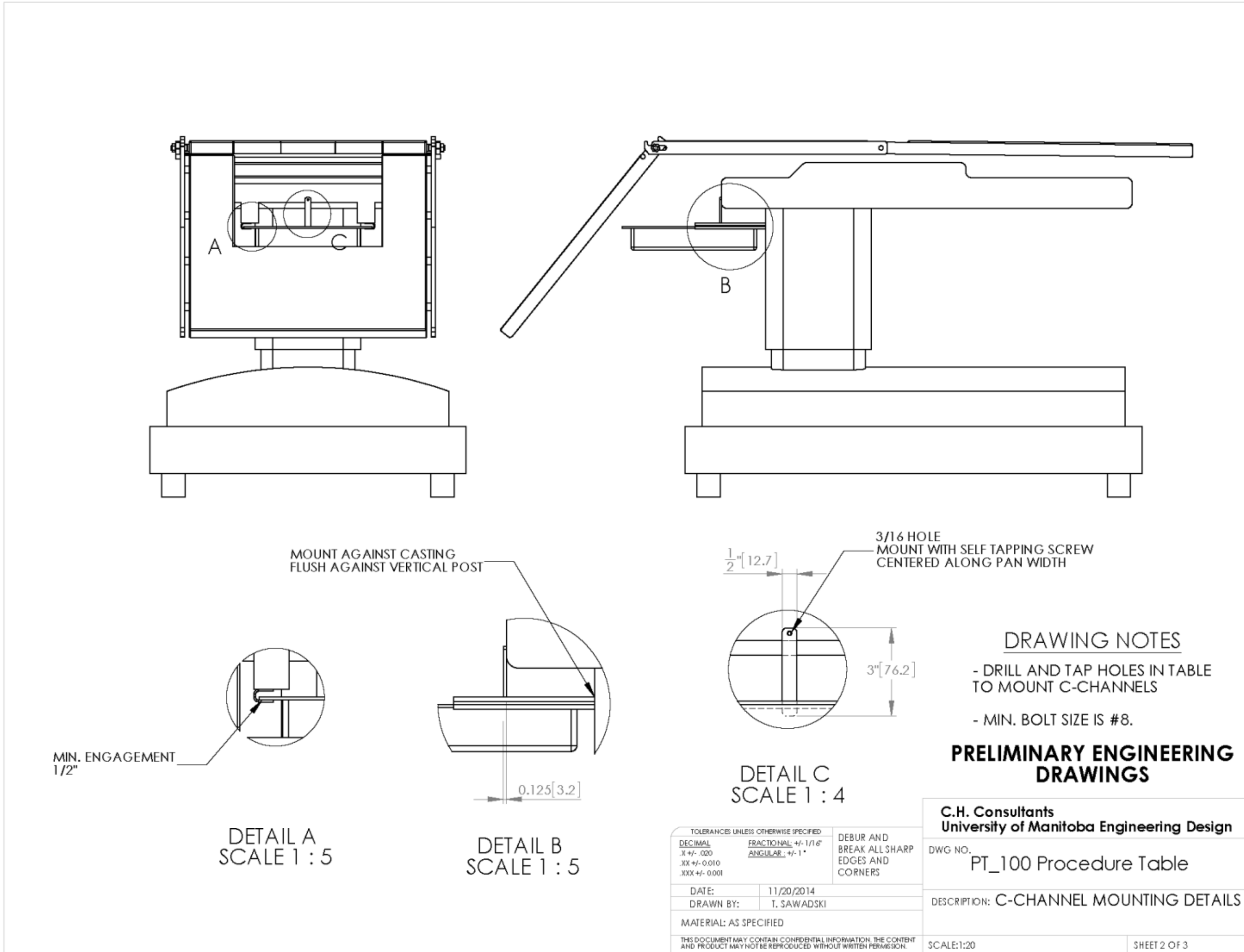


Figure 59: Preliminary engineering drawing of C-channel mounting details

5.5 STEPS TO MANUFACTURE

To execute the procedural table retrofit, the following steps must be performed to produce the retrofit our team has designed for the footrest. It should be noted that the means for accomplishing these steps are not included.

1. Detach footrest from backrest.
    a. Note: The attachment with the lever arm must be disengaged, along with the pivot point with the rail of the backrest.
2. Remove the two lever arms and one rotating shaft from the existing crank assembly.
    a. Ensure removal of the existing gear from the crank assembly does not affect other functions of the table.
3. Remove railings from the footrest and backrest. (Keep existing spacers and associated screws. To be re-used when attaching the railings to the table)
4. Weld shut existing hinge holes on footrest and backrest railings. Grind and polish surface.
5. Mill slot into each railing of the backrest, as specified in Figure 55.
6. Mill engagement grooves into each railing of the backrest and footrest, as specified in Figures 55 and 56.
7. Mill specified hole for the shoulder bolt into each railing of the footrest, as shown in Figure 56.
8. Weld an engagement pin to each footrest and backrest railing at the specified locations shown in Figures 55 and 56.
9. Laser-cut sheet of stainless steel to the specified dimensions shown in Figure 53.
10. Cut bar stock to specified dimensions shown in Figure 54.
11. Drill holes into bar stock as per spacing of spacers on railings, as shown in Figure 56.
12. Weld bar stock as per specified design shown in Figure 54.
13. Bend sheet of laser cut metal around assembled support structure made in step 10.
14. Attach footrest railings to newly assembled footrest using existing bolts.
15. Attach backrest railings to backrest using existing bolts.

16. Align milled slot in the backrest railings to the milled hole in the footrest railings on each side of the table, and fasten with shoulder bolt and washer assembly, as shown in Figure 57.
17. Determine the contact points between the footrest and table to install rubber stoppers.
18. Weld appropriate nuts to the underside of the footrest, and mount rubber stoppers with locking washer.

To execute the procedural table retrofit, the following steps must be performed to produce the fluid collection system.

1. Drill four holes into each C-channel as per specified dimensions shown in Figure 58.
2. Bend sheet of metal to required C-channel dimensions shown in Figure 58.
3. Fasten C-channels to table as per specifications listed in Figure 59.
4. Laser-cut sheet metal for rectangular bar pan stopper as per specifications shown in Figure 59.
5. Drill hole into the table for self-tapping screw to fasten pan stopper in place, as shown in Figure 59.
6. Insert stainless steel pan.

5.6 COST

The budget for the retrofit of the procedural table is $3000 dollars. The following sections will provide a cost estimate to retrofit the design to the current mobile AMSCO 2080 procedural table. The cost analysis will incorporate the associated material costs and the labour costs to create, modify, and install the new features of the design.

5.5.1 FOOTREST COST ANALYSIS

The footrest design consists of two main components: 1) the deployment mechanism and 2) the new footrest. The deployment mechanism consists of adding four engagement pins to the side rails (2 on each side of the table), plus two shoulder bolts complete with washers and locking nuts (1 on each side of the table). The new footrest will include a 14 Ga. 304 stainless steel sheet with braces made from 304 stainless steel bar. The cost to create, modify, and install the footrest design is summarized in Table XXVIII.

TABLE XXVIII: FOOTREST COST ANALYSIS SUMMARY [23] [24] [25] [26] [27]

Aspect of Manufacturing	Number of units (unit)	Cost per unit ($CDN/unit)	Total cost ($CDN)
Stainless steel rod 3/8" for engagement pins	2 ft	2.70	5.40
Stainless steel shoulder bolts	2	19.02	38.02
Stainless steel bar 1" x 0.25"	12 ft	2.86 per ft	41.04
14 Ga. stainless steel sheet 2' x 2'	1	61.02	61.02
Rubber Stopper 3/8" diameter, length 1/2"	4	16.00	64.00
Labour to modify side rails	3	100.00 per hr	300.00
Labour to create new footrest	4	100.00 per hr	400.00
Labour to install	1	100.00 per hr	100.00
Total			1009.48

5.5.2 FLUID COLLECTION SYSTEM COST ANALYSIS

The fluid collection system requires a new pre-purchased stainless steel pan that can be acquired from the distributor Russel Foods. The supporting C-channels will have to be manufactured separately at the machine shop at the HSC. The labour will incorporate the hardware for mounting and the man hours to manufacture and assemble the design. The cost analysis for the fluid collection system is summarized in Table XXIX.

TABLE XXIX: FLUID COLLECTION SYSTEM COST ANALYSIS [27] [28] [29]

Aspect of Manufacturing	Number of units (unit)	Cost per unit ($CDN/unit)	Total cost ($CDN)
Fluid collection pan	1	14.98 per pan	14.98
14 Ga. stainless steel sheet 12” x 18”	1	29.34	29.34
#8 Stainless steel flat head bolt ½”	4	0.07	0.28
Screw	1	0.07	0.07
Labour to create C-channels	1	100.00 per hr	100.00
Labour to install	6	100.00 per hr	600.00
Total			744.67

It should be noted that the cost of the pan stopper was not included in the fluid collection system cost analysis, as it will be manufactured from the left over stainless steel 1”x 0.25” bar stock used to create the footrest support structure. Through conducting a cost analysis, we determined that the cost of the procedural table retrofit is $1754.15. As the budget provided by the Clinical Engineering Department for the retrofit of the procedural table is $3000 dollars, we are under budget by $1245.85.

In summary, the mobile procedural table retrofit consists of two main components: the footrest and the fluid collection system. The footrest is made from a 14 Ga. 304 stainless steel wrapped around a support structure made out of 304 stainless. The footrest is deployed with a 3 pin sliding actuating mechanism. To move the footrest from the up to down position, the footrest must first be lifted past center to disengage the support pins of the actuating locking pin mechanism. Next, the footrest must be pulled towards the user and then lowered. Similarly, to move the footrest from its down to up position, the footrest must be lifted past center, pushed away from the user, and then lowered onto the engaging support pins.

The fluid collection system consists of a pan that is supported and deployed on C-channels. Both the pan and C-channels are made out of 304 stainless. The pan is not only used to collect fluids from the patient’s uterus, but it is also used to provide a working surface for the doctor’s surgical tools.

The following special features have been incorporated into our design: operation of the footrest is located at the foot end of the bed, deployment of the footrest can be performed with one hand, deployment of the footrest can be performed within 3 seconds, deployment of the footrest does not interfere with the pan when at its maximum position, the retrofit design incorporates rubber stoppers on the back of the footrest, the retrofit design is easy to manufacture, the retrofit design is easy to assemble/disassemble, and the retrofit design is easy to clean.

The retrofit can be made and installed by the technicians at the machine shop at the HSC. The cost of the procedural table retrofit is $1754.15, which puts our design at $1245.85 under budget.

6.0 CONCLUSION

Our group has designed a fast deploying footrest and a fluid collection system for the mobile padded procedural tables used for dilation and curettage at the Women's Hospital at the HSC. Our client has specified that the procedural table retrofit should be easy to manufacture, easy to assemble/disassemble, and be able to be disinfected with Oxivir and/or sterilized in an autoclave. Additionally, our client has specified that our design meet the codes and standards of a class 1 medical device in Canada, and cost a total of $3000 to implement. Furthermore, our client would like a fluid collection system that contains and supports 2L of fluid, and a footrest that is quick and easy to deploy, and can support a patient's weight of 137 kg.

The retrofit has been designed with a minimum number of components that can either be purchased or are simple to manufacture. Additionally, the retrofit has been designed to assemble and disassemble easily with the use of components like shoulder bolts. All components specified in the design are made out of 304 stainless steel, except the shoulder bolts, which are made of 316 stainless. 304 and 316 stainless steel can both be disinfected with Oxivir and sterilized in an autoclave. Furthermore, the stainless steel is polished and will have no scratches or indelible markings. Small spaces have also been kept at a minimum, and can be cleaned through disassembly if necessary. As the retrofit imposes very low risk to the patient and does not require power, our design meets the codes and standards of a class 1 device in Canada. The retrofit costs a total of $1754.15, which is $1245.85 under budget.

The footrest the team has designed is made out of 14 Ga. stainless steel wrapped around a support structure composed of welded bar stock. The footrest is attached to the table at the rails of the backrest where a sliding pin mechanism is located to lock the footrest in place when in use. The footrest is light weight (10kg ~ 25% lighter than the original) and takes three seconds to deploy the footrest in three simple steps: lift, pull, lower. The sliding pin mechanism consists of two engagement pins and one sliding pin (shoulder bolt) where all three pins are 9.5 mm in diameter. Using FEA and analytical tools, we confirmed that the footrest can safely support the maximum weight of a patient (137 kg) sitting on the footrest with a safety factor of 1, and can withstand 25 years of service when subjected to 18.5% of a

137 kg person's body weight with a safety factor of 2. The footrest costs $1009.48 to implement.

The fluid collection system the team has designed is composed of a purchased pan with a lip that is supported and deployed by C-channels. The fluid collection system is located relative to the patient's pertinent anatomy (uterus) and provides a working surface for the doctor to place his/her tools during surgery. Using FEA and analytical tools, we confirmed that the pan can safely support the maximum weight of 6 kg which includes 2L of fluid and the weight of the surgical tools with a safety factor of 1.5. The fluid collection system weighs a total of 1.0 kg and costs $744.67.

With the aforementioned features made and installed by the technicians at the machine shop at HSC, the staff at the Women's Hospital will gain access to a mobile procedural table capable of being used for dilation and curettage. Having access to said equipment will increase the overall efficiency of operations within the hospital. The design proposed within this report has been approved by our client, Michael Hamilton, Clinical EIT at the HSC. The document of approval our client has signed is included in Appendix C.

7.0 REFERENCES

[1] The Winnipeg Regional Health Authority. (n.d.). *About Us: WRHA* [Online]. Available: http://www.wrha.mb.ca/about/aboutus.php [September 20, 2014].

[2] Health Sciences Centre. (n.d.). *HSC White Pages* [Online]. Available: http://www.hsc.mb.ca/files/hscWhitePages.pdf [September 20, 2014].

[3] The Winnipeg Regional Health Authority. (n.d.). *Mission* [Online]. Available: http://www.wrha.mb.ca/about/mission.php [September 20, 2014].

[4] E. Sosnowski. "Overview of Stationary Table." Winnipeg: Design Eng., University of Manitoba, Winnipeg, MB, 2014, July 28.

[5] C. Bjornsson. "Envelope Support for Pan Attached to Stationary Table." Winnipeg: Design Eng., University of Manitoba, Winnipeg, MB, 2014, September 15.

[6] "30411.jpg," (n.d.) in *Quick Medical* [Online]. Available: http://www.quickmedical.com/images/sku/tnails_250/30411.jpg [October 22, 2014].

[7] E. Sosnowski. "Overview of Mobile Table." Winnipeg: Design Eng., University of Manitoba, Winnipeg, MB, 2014, July 28.

[8] World Medical Equipment. (n.d.). *AMSCO 2080 Manual Control Surgical Table* [Online]. Available: http://www.worldmedicalequip.com/ProductSheetPDFs/AMSCO_2080M.pdf [September 27, 2014].

[9] Autoclave, by A. Lussi. (1996, September 7). Patent US 5535141 A [Online]. Available: http://www.google.com/patents/US5535141 [October 22, 2014].

[10] American Process Systems. (n.d.). *Surface Textures of Stainless Steels* [Online]. Available: http://airprocesssystems.com/pdf/eirich/surfacetextures.pdf [October 22, 2014]

[11] "Concept Generation," class notes for MECH 4860, Department of Mechanical Engineering, University of Manitoba, 2014.

[12] Medical EXPO. *Universal operating table OPT30/1 Specifications* [Online]. Available: http://www.medicalexpo.com/prod/officina-di-protesi-trento-spa-opt/universal-operating-tables-hydraulic-electric-x-ray-transparent-mobile-77860-474536.html [October 20, 2014].

[13] Draft Guidance Document Risk-based Classification System [Online]. May 4, 1998. Available: http://www.hc-sc.gc.ca/dhp-mps/alt_formats/hpfb-dgpsa/pdf/md-im/risk5_risque5-eng.pdf [October 21, 2014].

[14] Medical Devices Regulations [Online]. SOR/98-282, 2011. Available: http://laws-lois.justice.gc.ca/eng/regulations/sor-98-282/ [September 16, 2014].

[15] Folding Footrest, by J.M. Knight. (1937, September 21). Patent US 2 093 455 [Online]. Available: http://www.freepatentsonline.com/2093455.html [October 16, 2014].

[16] Foot Section for Birthing Bed, by Richard L. Borders. (1992, October 27). Patent US 5 157 800 [Online]. Available: http://www.google.com/patents/US5157800 [October 16, 2014].

[17] Operating Table, by R.W. Lanigan. (1968, November 19). Patent US 3 411 766 [Online]. Available: http://www.google.com/patents/US3411766 [October 9, 2014].

[18] "Concept Development and QFD," class notes for MECH 4860, Department of Mechanical Engineering, University of Manitoba, 2014.

[19] Lynn Kurylko. OR Manager, Women's Hospital at the Health Sciences Centre. Phone call. Winnipeg, MB. September 24, 2014.

[20] Robert L. Mott, *Machine Elements in Mechanical Design,* 4th ed. New Jersey: Pearson, 2004.

[21] S. Plagenhoef, F. G. Evans, and T. Abdelnour. (1982). "Anatomical data for analyzing human motion," *Exercise and Sport* [Online], vol. 54 pp. 169-178. Available: Taylor & Francis Online [November 23, 2014].

[22] North American Stainless. (n.d.) *North American Stainless* [Online]. Available: http://www.northamericanstainless.com/wp-content/uploads/2010/10/Grade-304-304L-304H.pdf [November 20, 2014].

[23] Metals Depot International. (2012). *Metals Depot* [Online]. Available: http://www.metalsdepot.com/products/stainless2.phtml?page=round&LimAcc=%20&aident= [November 20, 2014].

[24] Type 316 Stainless Steel Shoulder Screw. (n.d). *McMaster-Carr* [Online]. Available: http://www.metalsdepot.com/products/stainless2.phtml?page=round&LimAcc=%20&aident= [November 20, 2014].

[25] McMaster-Carr. (n.d.). *McMaster-Carr* [Online]. Available: http://www.mcmaster.com/#standard-stainless-steel-sheets/=usr2dy [November 15, 2014].

[26] McMaster-Carr. (n.d.). *McMaster-Carr* [Online]. Available: http://www.mcmaster.com/#standard-bumpers/=usr6ft [November 15, 2014].

[27] N.Tu. (2014, November 26). “Labour Cost.” Personal e-mail.

[28] Bolt Depot (2014). *Bolt Depot, Inc.* [Online]. Available: https://www.boltdepot.com/Machine_screws_Phillips_flat_head_Stainless_steel_18-8_8-32.aspx?nv=l [November 26, 2014].

[29] R.Thieme. (2014, October 23). “Pan.” Personal e-mail.

Procedural Table Equipment Retrofit Appendix A: Monitoring and Controlling

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX A: MONITORING AND CONTROLLING

In order to meet the deliverables and deadlines of this course and for our client, the team needed to be constantly monitoring and controlling the progression of the project. By doing so, work was completed on time and met the quality standards set by the team. Time and risk management both involve monitoring and controlling, and will be discussed in detail within this section.

A.1 TIME MANAGEMENT

To help visualize what tasks needed to be completed in order to complete our project, a Work Breakdown Structure (WBS) was created. A WBS helps organize the tasks that are required to complete the project into manageable work packages. Once the WBS for our project was created, a gantt chart and resource requirements list were made. The gantt chart adds a timeline to the tasks broken down in the Work Breakdown Structure and helps make scheduling and project planning easier and more efficient. In this sub-section of the report, our Work Breakdown Structure and schedule in gantt chart format are presented, and the resource requirements to achieve our objectives are listed.

A.1.1 WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure, shown in Figure 2, was created by breaking the project down into smaller components and sub-components that could be treated as individual tasks. The WBS shows a visual hierarchical representation of tasks that need to be completed in order to complete the project. The project is broken down into five sublevels, which represent the five major sections of managing the project. These sections are initiation, planning, execution, monitoring and controlling, and closeout. All the deliverables are shown in the third level of the execution section. All the other tasks shown in the third and fourth decomposition level are additional tasks that need to be completed for the deliverables and for the successful completion of this project.

The execution sublevel pertains to documentation for submittal, but is also a reflection of the actual progression of the project. For example, documentation of 1.3.2.1, Technical Specifications, and 1.3.2.2, Internal and External Search Results, requires reviewing medical device regulations, brainstorming, and hospital visits to meet with the OR Manager and nurses of the Women's Hospital, as well as the engineers and technicians from the Clinical Engineering Department. Another documented task that reflects the progression of the project is 1.3.2.3, Concept Analysis and Selection, which requires screening and scoring our ideas by analyzing them from a technical and cost perspective.

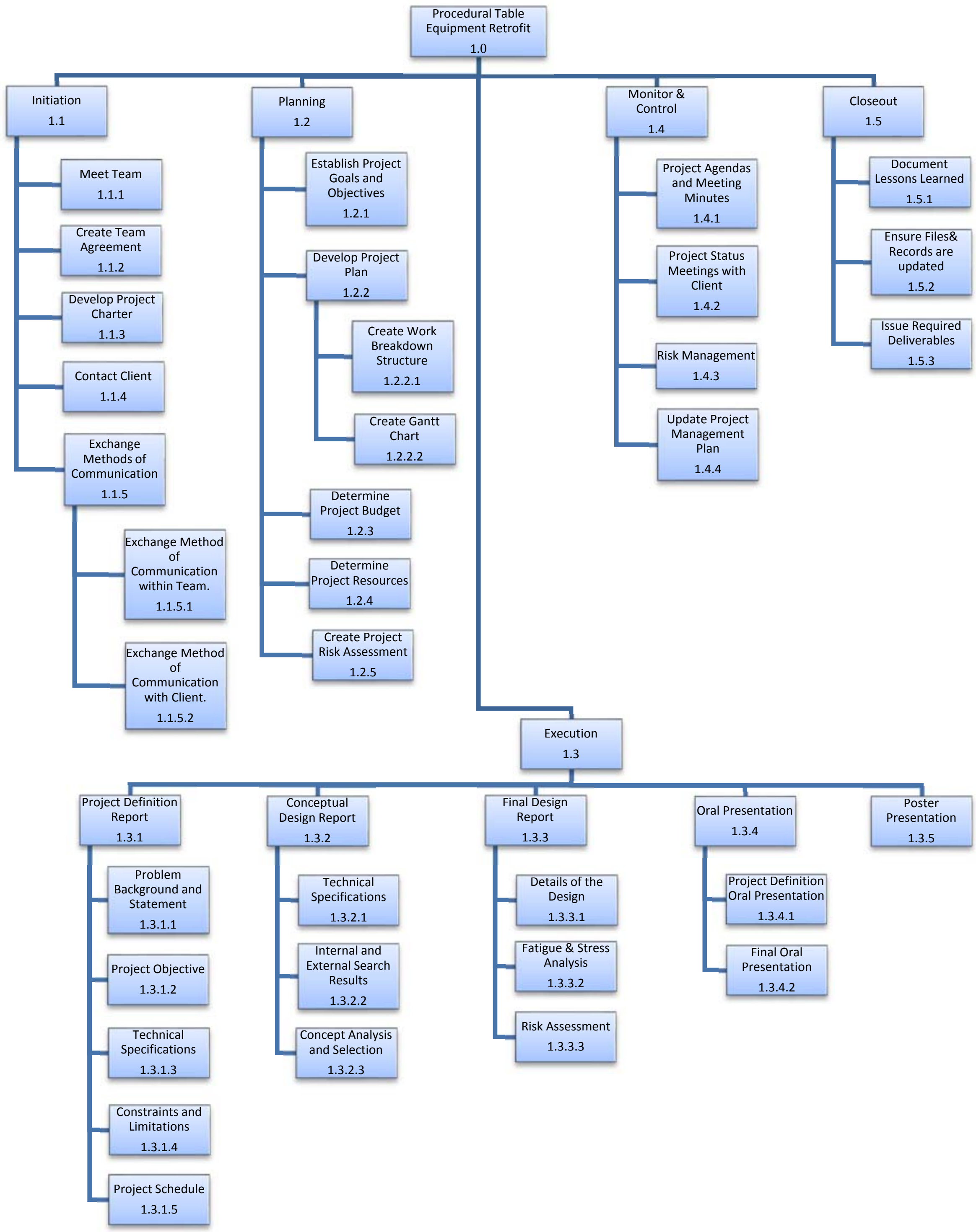


Figure 1: Work Breakdown Structure for the Procedural Table Retrofit

A.1.2 GANTT CHART

The gantt chart presented in Figure 3 shows the WBS tasks and the completion time frame associated with each task. Additionally, the gantt chart tracks the progress and completion of individual tasks. In our gantt chart, the thick red vertical line indicates the current date and the percentage of each task completed is listed. Some tasks are shown to start on the same date as the tasks predecessors are being completed; this is based on the assumption that when a task is completed, the following task can be started immediately. Also, the subtasks for some of the major deliverables have due dates set before the major deliverable is due; this is to allow some time for report compilation and editing, as well as to provide a safety buffer in case anything goes wrong.

When reviewing our gantt chart, it should be noted that preliminary task leads have been assigned to most tasks; however, some tasks have been left blank as they have been completed by the entire team and did not have a task lead. It should also be noted that task 1.5.3 is considered the final closeout and consists of presenting all the deliverables to the client. Furthermore, all tasks from the WBS are shown in the gantt chart except the tasks from section 1.4, Monitoring and Controlling. This section was excluded because all the subsections in 1.4 are associated with tasks that are perpetual, and often don’t have a set delivery date or deadline.

WBS	Task	Task Lead	Task #	Task Duration	Predecessors	% Complet
1.1	Initiation					100
1.1.1	Meet Team		1	1		100
1.1.2	Create Team Agreement		2	2	1	100
1.1.3	Develop Project Charter	Devin	3	4	1,4	100
1.1.4	Contact & Meet Client	Olivia	4	6	1	100
1.1.5	Exchange Methods of Communication	Olivia	5	6	1,4	100
1.2	Planning					100
1.2.1	Establish Project Goals and Objectives	Olivia	6	1	4	100
1.2.2	Develop Project Plan	Thomas	7	3	3,4,6	100
1.2.2.1	Create Work Breakdown Structure	Thomas	8	3	3,4,6	100
1.2.2.2	Create Gantt Chart	Thomas	9	3	3,4,6	100
1.2.3	Determine Project Budget		10	6	4	100
1.2.4	Determine Project Resources	Devin	11	6	4	100
1.2.5	Create Project Risk Assessment	Cody	12	4	4	100
1.3	Execution					
1.3.1	Project Definition Report	Olivia	13	13	4,6,8,9	100
1.3.1.1	Problem Background and Statement	Olivia	14	9	4	100
1.3.1.2	Project Objective	Devin	15	9	6	100
1.3.1.3	Target Specifications	Olivia	16	9	4	100
1.3.1.4	Constraints and Limitations	Olivia	17	9	4	100
1.3.1.5	Project Schedule	Thomas	18	5	8,9	100
1.3.2	Conceptual Design Report	Olivia	19	25	14,15,16,17,20, 21	100
1.3.2.1	Technical Specifications	Thomas	20	12	14,15,16,17	100
1.3.2.2	Internal and External Search Results	Cody	21	21	14,15,16,17	100
1.3.2.3	Concept Analysis and Selection	Devin	22	4	20,21	100
1.3.3	Final Design Report	Olivia	23	39	19, 22, 24	100
1.3.3.1	Details of the Design	Cody	24	17	22	100
1.3.3.2	Fatigue and Stress Analysis	Thomas	25	7	24	100
1.3.3.3	Risk Assessment	Cody	26	3	22	100
1.3.4	Oral Presentation	Devin	27	69	13,14,15,16,17, 18,19,24,25,26	100
1.3.4.1	Project Definition Oral Presentation	Devin	28	9	14,15,16,17,18	100
1.3.4.2	Final Oral Presentation	Olivia	29	9	13,19,24,25,26	100
1.3.5	Poster Presentation	Thomas	30	9	13,19,24,25,27	100
1.5	Closeout					
1.5.1	Document Lessons Learned	Cody	31	1	13,19,24,25,26	100
1.5.2	Ensure Files and Records are Updated	Devin	32	4	13,19,24,25,27	100
1.5.3	Issue Required Deliverables	Olivia	33	1	23,29,30	100

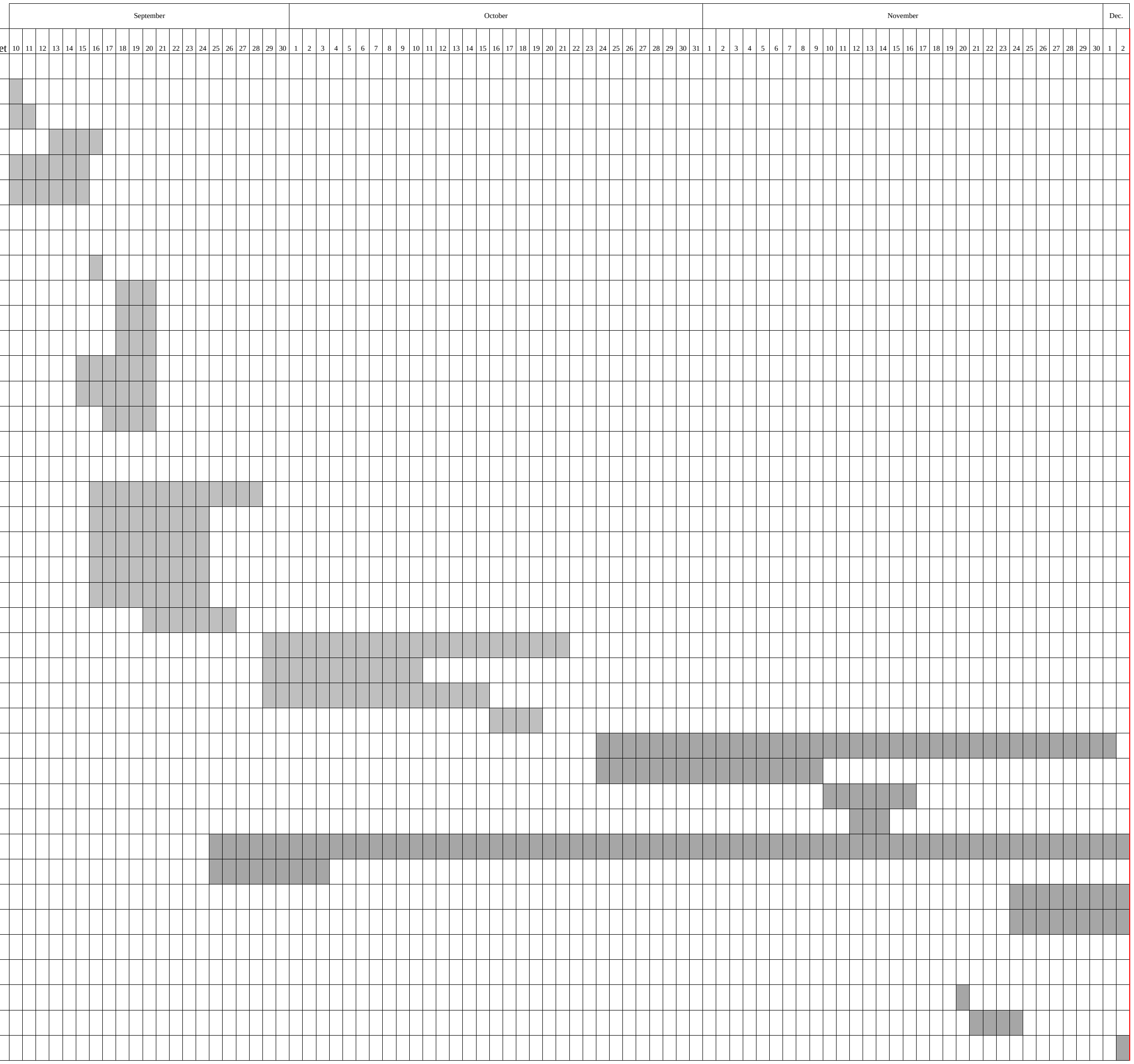


Figure 2: Gantt chart for duration of the project

A.1.3 PROJECT RESOURCE REQUIREMENTS

For scheduling purposes, the team developed a list of resources needed to accomplish the project. The team determined that five main resources were required to complete the project: money, labour, materials, software, and space. The list of resource requirements for the project is presented in Table I.

TABLE I: PROJECT RESOURCE REQUIREMENTS

Resource Requirements	Source	Details	Total	Units
Money				
1. University Money	School Funds	Sponsorship money for project expenses	300	CAD $
2. Project Design Money	Health Sciences Center	Required budget for labour and materials of the final design	<3000	CAD $
Labour				
1. Project Members	University of Manitoba	Cody Bjornsson, Olivia Essex, Thomas Sawadski, Devin Windeatt	4	Undergrad ME
2. Project Advisor	University of Manitoba	Dr. Paul Labossiere P.ENG	1	Professor
3. Regional Clinical Engineers	Health Sciences Center	Kyle Eckhardt, Michael Hamilton	2	Client/Engineer
4. Surgical Instrument Technician	Health Sciences Center	Nhien Tu	1	Client/Technician
5. Operating Room Manager	Health Sciences Center	Lynn Kurylko	1	Client
6. Nurses	Health Sciences Center	Nurses at the woman's hospital who work with the existing and new procedural tables	1	Nurse
7. CAD Printing Expert	University of Manitoba	CAD printing expert for printing Poster (Dept. of Architecture)	1	CAD Printing Expert
8. Suppliers	Office Suppliers	Provide office supplies for meeting notes, recording research and engineering calculations.	N/A	N/A
Materials				
1. Laptops	Team members	Assumed each team member has own laptop to use for research, report writing, meeting minutes etc.	4	Laptop
2. Cell Phones	Team members	Assumed each team member has their own cell phone to stay in contact with the team and client.	4	Cell Phones
3. Log Books	Book Store	Each team member should have a log book for documenting the project	4	Log Books
4. Engineering Report Supplies	Copy Center	11"x8.5" Paper, 1 x Clear cover, 1 x Black backing, 1 x Coil Binding	3	Paper/Plastic
7. Mechanical Pencils	Staples	4 x 0.7mm Lead Mechanical pencils with lead	4	Pencils
8. Graphing Paper	Staples	4 x Pads of Graph Paper	4	Paper
9. Calculators	Staples	4 x Scientific Calculators for Engineering analysis	4	Calculator
10. USB Stick	Staples	1 x 1GB For storage of CAD files and oral presentations	1	GB Stick
11. Projector	University of Manitoba	1 x Projector to be used for oral presentations	1	Projector
12. Poster Paper	University of Manitoba	36" x 48" Poster Board	1	Poster Board
Software				
1. Solidworks	University of Manitoba	3D CAD Design Software	1	Software
2. Ansys	University of Manitoba	Finite Element Analysis Software	1	Software
Space				
1. Meeting Rooms	University of Manitoba or HSC	Space for meeting with team or client	2	Room
2. Table Work Space	HSC	Space for table assembly/disassembly	1	Room

A.2 Risk Management

A risk management plan was created to provide guidance for our group in the event of a risk or risks becoming a reality. In this section, eleven risks of the table retrofit design are identified and reviewed using a risk assessment matrix. In addition, our approach towards these risks and measures that were performed to overcome these risks will be explained.

A.2.1 Risk Identification

The risk management plan for our project was developed by first identifying risks that we may encounter in our design process. The risks associated with our project are presented in Table IV. In Table IV, the biggest risk was given a rank of 1, and the smallest was given a rank of 11. The severity of each risk was determined based on the likeliness of occurrence and the magnitude of the risk. The probability and magnitude of occurrence ranking schematics are shown in Table II and Table III, respectively.

TABLE II: PROBABILITY OF OCCURRENCE OF RISKS

Rank	Probability of Occurrence
1	Rare (0-20%)
2	Unlikely (20-40%)
3	Likely (40-60%)
4	Very likely (60-80%)
5	Almost certain (80-100%)

TABLE III: MAGNITUDE OF RISK CONSEQUENCES

Rank	Magnitude of Consequence
1	No impact
2	Minor issue
3	Moderate issue
4	Major issue
5	Extreme impact

Once a rank was assigned to each risk, a trend and approach was determined for each risk. The trend type represents how the team felt the risk may progress from the approach chosen. It should be also noted that in the approach column in Table IV, M, R, and W stand for mitigate, research, and watch, respectively. The risks identified during the projection definition phase, along with new risks that arose during the duration of the project, are listed in Table IV.

TABLE IV: RISK IDENTIFICATION

Rank	Trend	Risk ID	Approach	Risk Title
1	Improving	A-1	M	Fluid Collection System Space Constraints
2	Improving	A-2	M	Footrest Interference
3	Improving	A-3	R	Codes and Standards
4	Unchanging	A-4	R	Project Durability
5	Unchanging	A-5	R	Long Term Design Flaws
6	Improving	A-6	W	Project Budget
7	Unchanging	A-7	W	Technical Errors
8	Unchanging	A-8	M	No Access to WHRA Staff
9	Improving	A-9	W	Project Scope
10	Unchanging	A-10	M	No Access to Procedural Table
11	Unchanging	A-11	W	Material Availability

Legend	M, Mitigate	R, Research	W, Watch

Once the risks were identified in terms of rank, trend, and approach, a risk assessment matrix was implemented to help us visualize the severity of all our risks as a collective group. The risk assessment matrix is shown in Figure 4, and Table II and III were used in creating this matrix.

Risk Assessment Matrix						
Likelihood	5					A-1
	4			A-3		A-2
	3			A-4	A-5	A-6
	2			A-9	A-7	
	1	A-11			A-10	A-8
		1	2	3	4	5
		Consequences				

Risk	Low	Medium	High

Figure 3: Risk Assessment Matrix

As seen in Figure 4, the risks A-1 through A-4wereour highest risks; this is due to the unknown nature of these risks and could improve as the project moved forward. The red, yellow, and green boxes in Figure 4 determine the high, medium, and low risk problems, respectively. If a high risk problem occurred, immediate action was taken to solve the problem. If a medium risk problem occurred, solution was thought of and the action was taken as soon as possible to prevent any further problems. For the low risk problems, immediate action was not immediately taken but dealt with according to the mitigation plan set forth.

A.2.2 RISK MITIGATION PLAN

Measures taken to overcome the risks associated with each risk ID are presented in Table V. This table presents each risk ID, along with the name and description of each risk, and the measures that were in place to mitigate the risk.

TABLE V: MEASURES TAKEN TO OVERCOME RISKS

Risk ID	Risk Title	Description & Measures Taken
A-1	Fluid Collection System Space Constraints	Due to the mobile table's current design, the fluid collection system can only be mounted in certain areas. Additionally, the space available underneath the table is a lot less than what is currently available on the stationary table. The design team took measurements and came up with a solution to accommodate our client.
A-2	Footrest Interference	Since the fluid collection system cannot be mounted in the same place as it was on the previous table, there will be interference issues between the footrest and fluid collection system when the footrest is being deployed. This will be addressed during the conceptual design phase of the project.
A-3	Codes and Standards	To ensure marketability of the table, Canadian healthcare codes and standards must be met for the design. The design team is aware of these standards and is currently investigating.
A-4	Project Durability	Due to the nature of the use of the table, the design of the retrofit must be durable for repeated use. This will be addressed during the conceptual design phase of the project.
A-5	Long Term Design Flaws	The current non-mobile table has been in operation for 30+ years, so we expect our adjustments on the table to last just as long, if not more. This issue will be addressed when designing the table retrofit.
A-6	Project Budget	Currently, the total budget is known, but there are some factors that are unknown. These factors include the type of material we will be using, and the rate of labour to build. These factors will be investigated further to determine the budget in detail and to ensure the budget is met.
A-7	Technical Errors	Due to the use of CAD software, errors can come about that will be seen during building of the design. The design team will take extra measures to spot these errors and use the expertise and knowledge of the staff at the WHRA.
A-8	No Access to WHRA Staff	The schedules of the staff and the design team are not identical, so meeting times are limited to certain days and times. The design team is currently coordinating that with the WHRA.
A-9	Project Scope	The scope that the design team sees could differ from the scope the WHRA requires, which could mean a different end product than desired. The design team is communicating with the WHRA to ensure this does not happen.
A-10	No Access to Current Procedural Table	If access to the procedural table is lost, the project could be harmed due to lack of physical measurements and little knowledge about the table. Currently the design team has access and this should not be an issue.
A-11	Material Availability	If the material is unavailable to the WHRA, the end product will not proceed as expected.

In summary, a WBS and gantt chart were created in order to complete our project in an organized and timely matter. The project was broken down into five sub levels in the WBS, which represent the five major sections of managing the project. These sections are initiation, planning, execution, monitoring and controlling, and closeout. Also, a risk management plan was created to provide guidance in managing the risks associated with our project. Eleven risks have been identified, where the risks that have the most potential of affecting the final design are the fluid collection system's space constraints and interference with the footrest.

Procedural Table Equipment Retrofit
Appendix B: Concept Generation

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX B: CONCEPT GENERATION

Once our project was thoroughly defined, we were able to proceed to the concept generation phase of the project. During this phase, our team decided to isolate the two problems we are tasked with solving: the presence of a fast deploying footrest and a fluid collection system. Within this appendix, a list of concepts our team generated for the footrest design will be presented, along with the tools used to explore our ideas systematically. A presentation of our fused ideas will conclude this section.

B.1 INTERNAL SEARCH RESULTS

In Table I, the concepts our team generated for the footrest design are presented. Advantages and disadvantages of each design are listed in Table I as well.

TABLE I: FOOTREST CONCEPT GENERATION

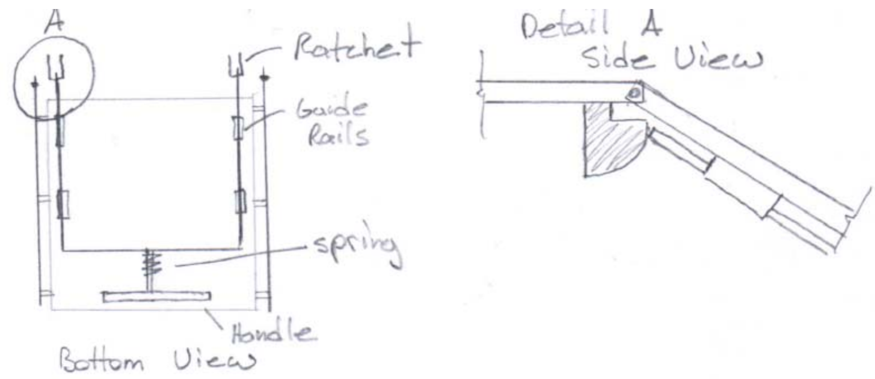
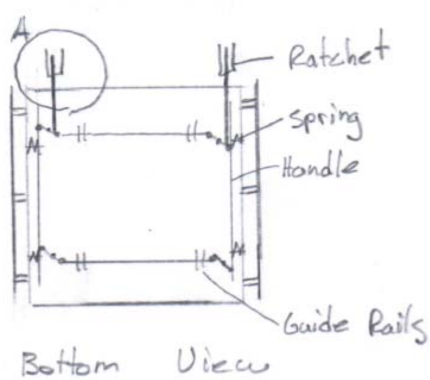
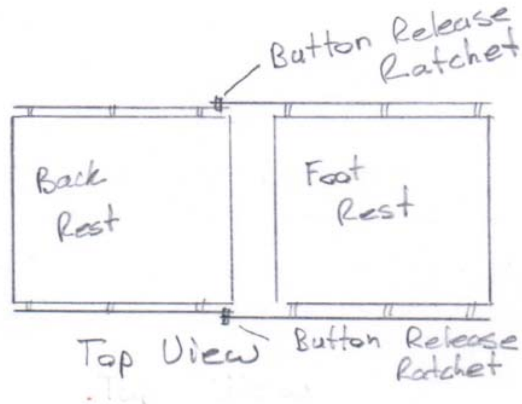
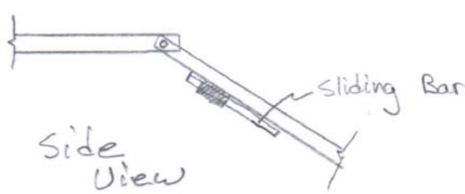
<table>
<tr><td rowspan="3">Concept 1: Lever-Ratchet Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Can be operated with one hand and would be very smooth to operate.
- Fast deployment time.</td><td>- Complex to manufacture.
- Contains a spring.
- Difficult to clean.
- Mechanism could become off centered due to single spring.
- All the patient’s weight relies on two pins in a ratchet.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 2: Double Lever-Ratchet Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Good accessibility from both sides of the table.
- User friendly and easy to operate.</td><td>- Complex to manufacture.
- Contains multiple springs.
- High risk of jamming during operation.
- Operation is from the side of the table, not the end.
- All the patient’s weight relies on two pins in a ratchet.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE I: FOOTREST CONCEPT GENERATION

<table>
<tr><td rowspan="3">Concept 3: Button Release Ratchet Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to manufacture.
- Easy to use.</td><td>- Not very ergonomic for nurses.
- Not very durable.
- Lack of support.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 4: Sliding Bar Support Footrest</td><td colspan="2">

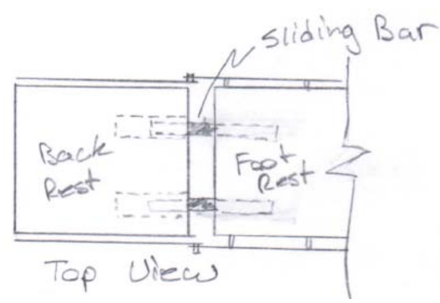

</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to manufacture.
- Provides good support.
- Similar to existing range of motion by nurses to operate.</td><td>- Difficult to use.
- Requires two operations to complete deployment.
- Weight could pose as an issue.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE I: FOOTREST CONCEPT GENERATION

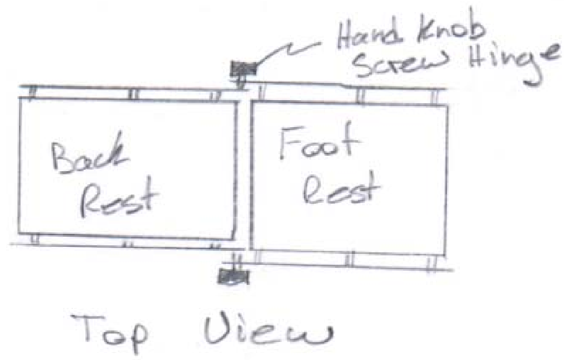
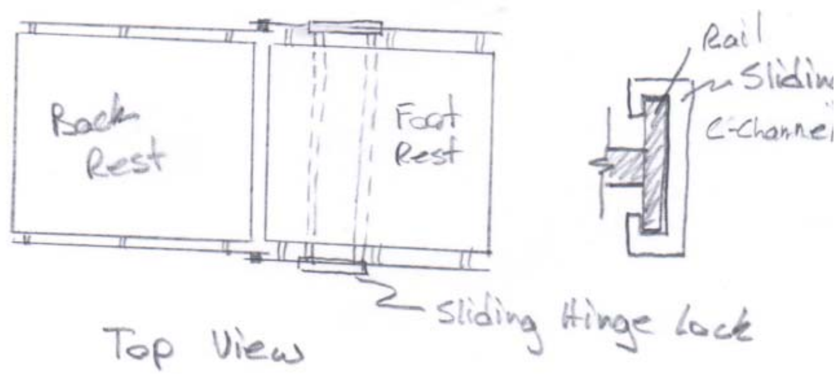
<table>
<tr><td rowspan="3">Concept 5: Screw Hinge Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to manufacture and install.
- Simple to operate.
- Easy to understand.</td><td>- Not ergonomic for nurses.
- Short expected life cycle of screw.
- Lack of support strength.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 6: Sliding Hinge Lock on Railing Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Provides good structural support.
- Easy to manufacture and install.</td><td>- Not ergonomic for nurses.
- Could interfere with stirrups.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE I: FOOTREST CONCEPT GENERATION

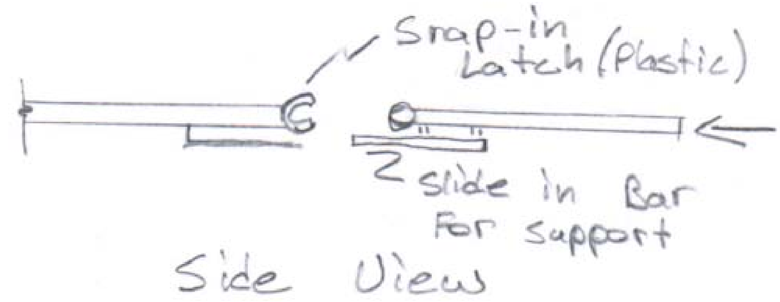
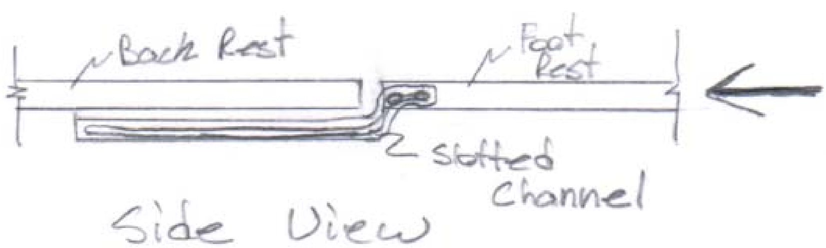
<table>
<tr><td rowspan="3">Concept 7: Removable Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Footrest is out of the way for the procedure.</td><td>- Difficult to design to support required weight specification.
- Footrest needs to be stored when it is removed.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 8: Hidden Slide-in Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to use.
- Aesthetically pleasing.
- Quick to operate.</td><td>- Difficult to manufacture.
- Space restriction under the table.
- Difficult to clean slide tracks.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE I: FOOTREST CONCEPT GENERATION

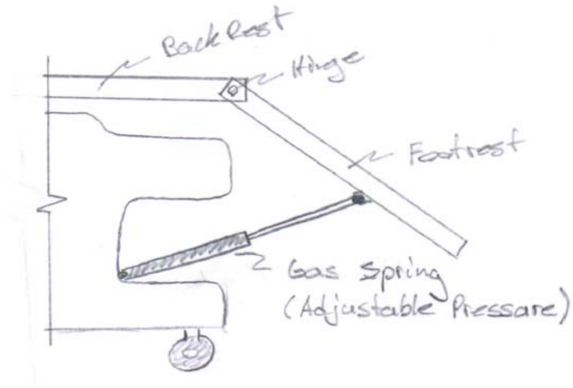
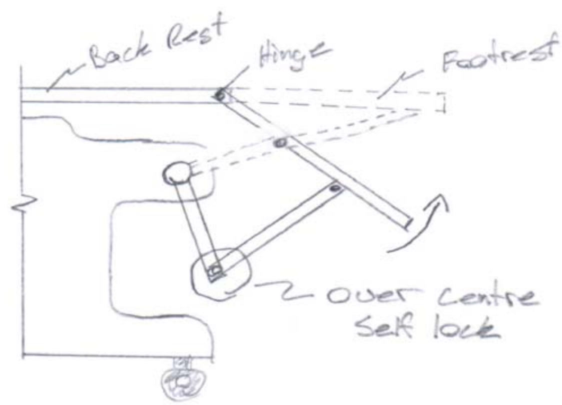
Concept 9: Gas Spring Deployed Footrest		
	Advantages	Disadvantages
	- Automatic deployment. - Simple to use. - Fast deployment.	- Requires large force to compress spring. - Not ergonomic.
Concept 10: Lever Arm Assembly Over Center Footrest		
	Advantages	Disadvantages
	- Uses current support system (low cost). - Provides good support for required weight specification. - Quick to operate.	- Difficult to provide simple locking mechanism for lever arm assembly.

TABLE I: FOOTREST CONCEPT GENERATION

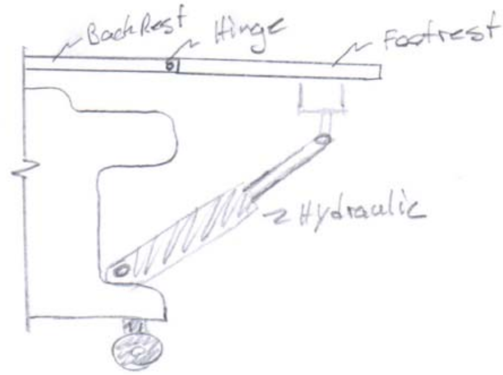
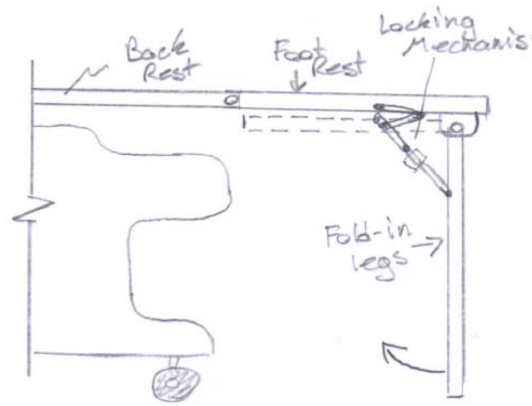
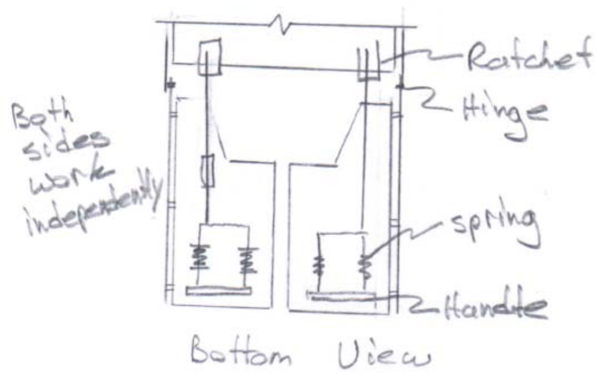
<table>
<tr><td rowspan="3">Concept 11: Hydraulic Powered Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to use.
- Requires no physical effort from nurses.</td><td>- Would take too long to deploy footrest.
- Difficult to implement.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 12: Fold out legs Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Provides solid support for footrest.
- Easy to manufacture.</td><td>- Long deployment time.
- Cumbersome to operate.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

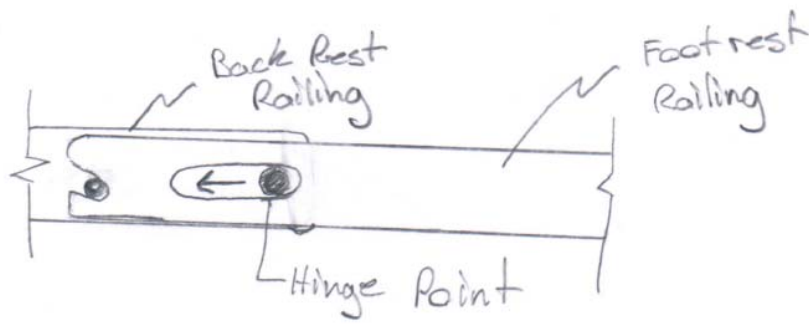
TABLE I: FOOTREST CONCEPT GENERATION

Concept 13: Two-piece Footrest with Ratchets



Advantages	Disadvantages
- Not a lot of effort required for deployment. - Ergonomic. - Easy to understand/operate. - Option to keep one leg supported.	- Deployment is a two-step procedure (longer deployment time). - Contains multiple springs. - Complex to manufacture.

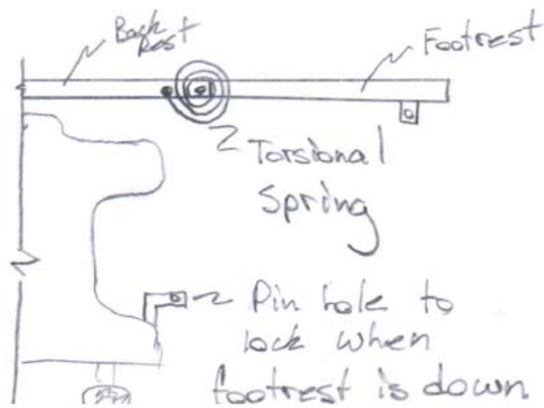
Concept 14: Slide Pin Footrest



Advantages	Disadvantages
- Easy to manufacture. - Simple to operate.	- Difficult to design to support required weight specifications. - Risk of footrest falling if not properly engaged.

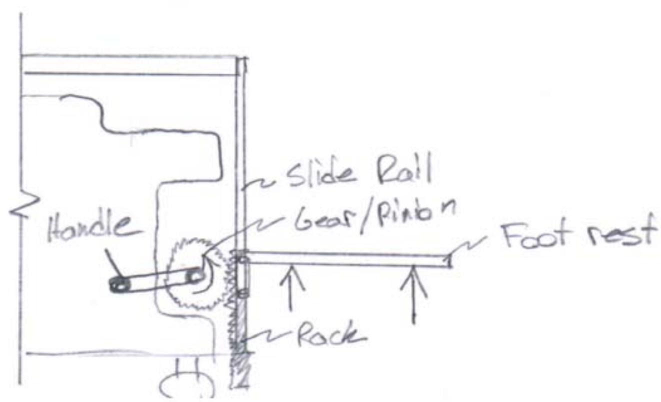
TABLE I: FOOTREST CONCEPT GENERATION

Concept 15: Torsional Spring Loaded Footrest



Advantages	Disadvantages
- Automatic deployment. Requires no physical effort from nurses. - Fast deployment.	- Spring is difficult to clean. - Requires significant force to load spring. - Spring force to support weight would be difficult.

Concept 16: Rack and Pinion Lift Footrest



Advantages	Disadvantages
- Smooth and simple to operate.	- Would take long to deploy the footrest. - Onerous for nurses deploying the footrest. - Difficult to clean rack and pinion. - Complex to manufacture. - Footrest would be in the way during the procedure.

TABLE I: FOOTREST CONCEPT GENERATION

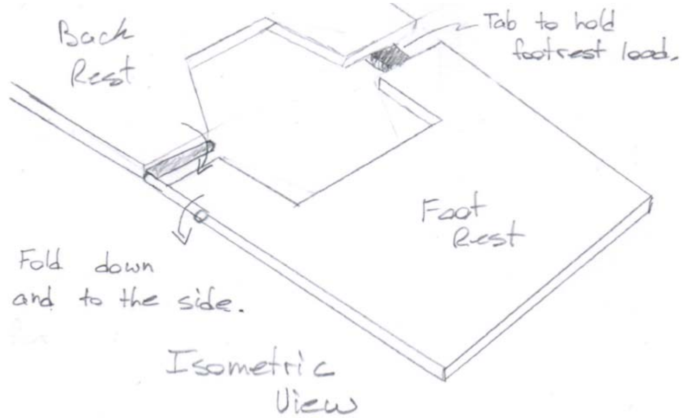
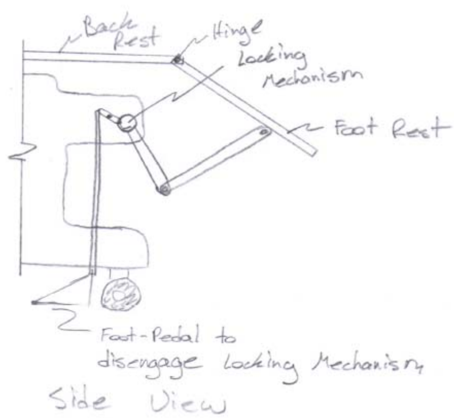
<table>
<tr><td rowspan="3">Concept 17: Side Hinged Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Footrest is out of the immediate vicinity where the procedure will be performed.</td><td>- Big sweeping movements of the footrest is required.
- Difficult to design to support required load.
- Not ergonomic.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 18: Pedal Operated Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Simple and quick to operate.
- Uses current support system (low cost).
- Provides good support for required weight specification.</td><td>- Only accessible from one side.
- Operation is from the side of the table, not the end.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE I: FOOTREST CONCEPT GENERATION

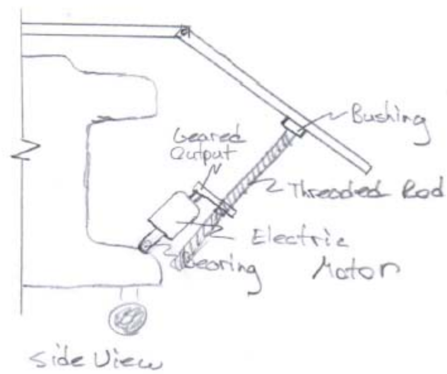
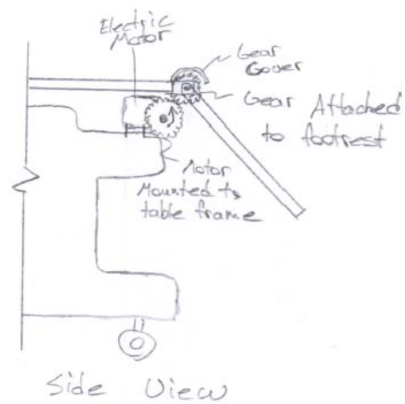
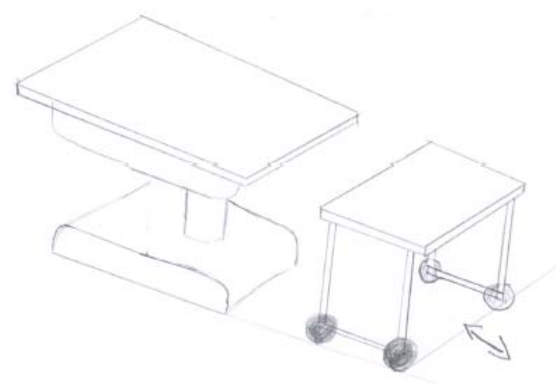
<table>
<tr><td rowspan="3">Concept 19: Electrically Screw Driven Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- No physical effort required for deployment.
- Could easily support required weight.</td><td>- Difficult to clean.
- Deployment time would take too long.
- High cost.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 20: Geared Electrical Motor Actuated Footrest</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- No physical effort required for deployment.
- Fast deployment.</td><td>- Safety concerns for patient during deployment.
- Gearbox would be costly.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE I: FOOTREST CONCEPT GENERATION

<table>
<tr><td rowspan="3">Concept 21: Trolley Cart Footrest</td><td colspan="2"></td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to move.
- Easy to manufacture.
- No interference with fluid collection system.</td><td>- Requires additional storage space when not in use.
- Cumbersome to maneuver.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

The concepts generated for the fluid collection system are shown in Table II. Advantages and disadvantages of each design are listed in Table II as well.

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

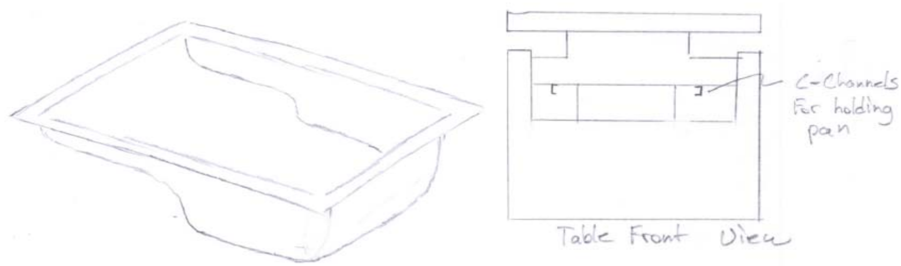
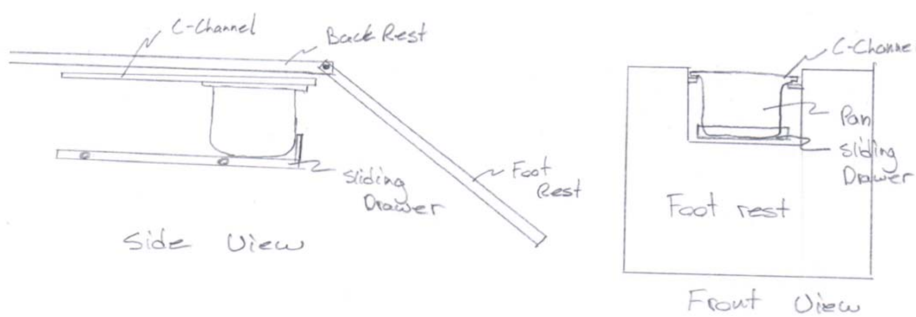
<table>
<tr><td rowspan="3">Concept 1: Custom Fluid Collection Pan on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Keeps the current volume specifications.
- Fits around the gearbox located underneath the table.</td><td>- Difficult to manufacture.
- More costly than a pre-made pan.
- Could have 90 degree corners, which are difficult to clean.
- Cannot store pan under the table.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 2: Small Fluid Collection Pan with Sliding Drawer on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to deploy.
- Simple to manufacture/modify purchased pan.
- Could store pan under the table.</td><td>- Total volume is less than current pan.
- Deployment mechanism may be quite complicated to install.
- Fluid could get inside bearings.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

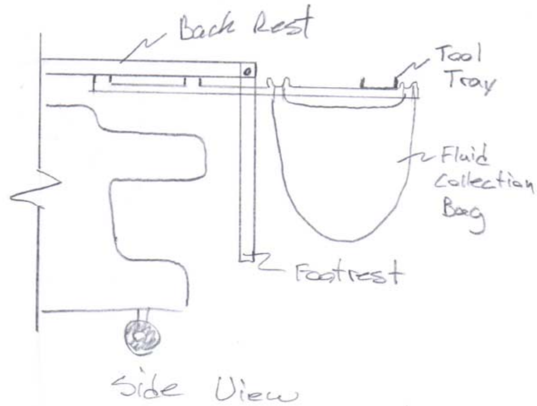
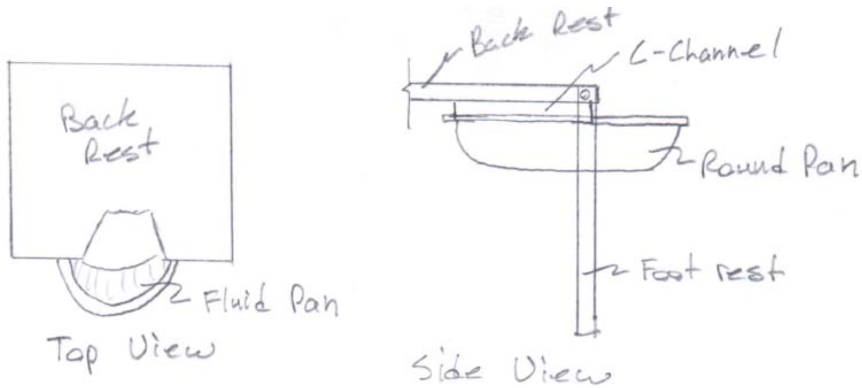
<table>
<tr><td rowspan="3">Concept 3: Fluid Collection Bag on Rails with Hooks</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Eliminates need to clean pan.
- Fast deployment.</td><td>- Fluid bag is unsupported.
- Need to find pre made bags that they can purchase.
- Tools are not in the location where surgeons are used to them.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 4: Round Fluid Collection Pan on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to deploy.
- Easy to manufacture.
- Pan is premade, so cheap to purchase.
- Could store pan under the table.</td><td>- Will not contain volume the same volume as the current pan.
- Could have cleaning issues in deploying railings.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

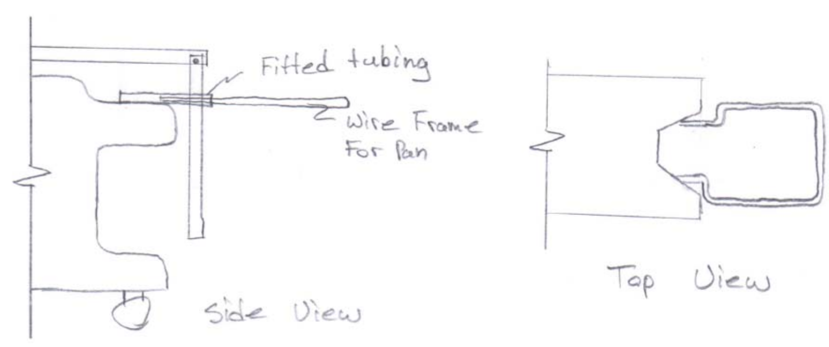
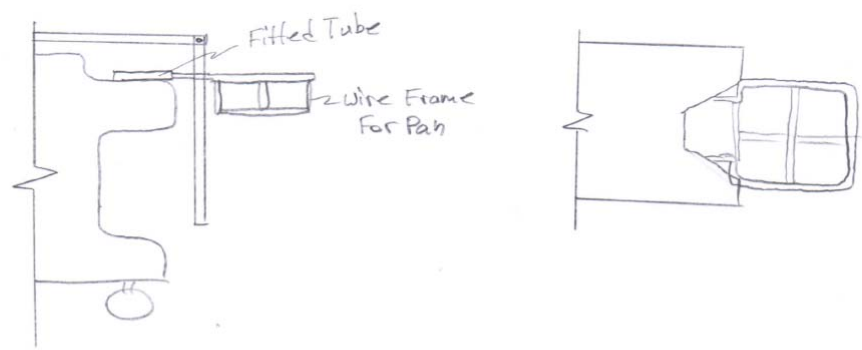
Concept 5: Rod Frame Fluid Collection Pan Holder with Fitted Tubing		
	Advantages	Disadvantages
	- Not restricted to pan size (rod can be bent to fit any pan shape). - Easy to install. - Easy to remove pan after procedure. - Easy and cheap to manufacture.	- Cannot store tray under the procedural table as currently practiced.
Concept 6: Supported Rod Frame Fluid Collection Pan Holder with Fitted Tubing		
	Advantages	Disadvantages
	- Not restricted to pan size (rod can be bent to fit any pan shape). - Easy to install. - Added support for contents of the pan, and the pan itself.	- Cannot store tray under the procedural table as currently practiced.

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

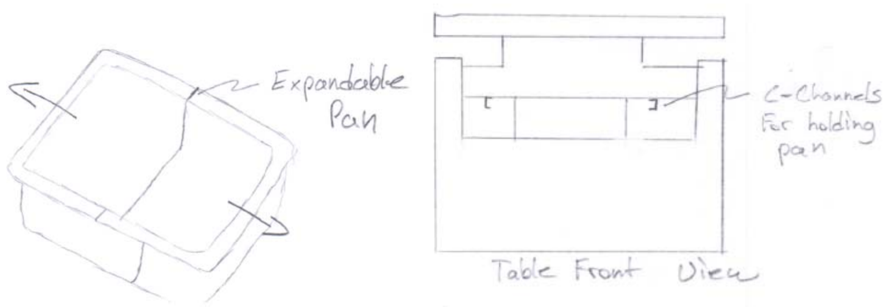
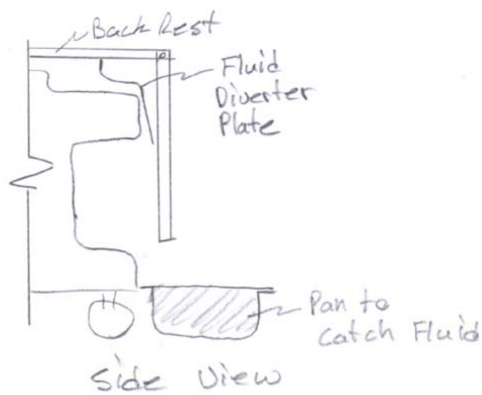
<table>
<tr><td rowspan="3">Concept 7: Expandable Fluid Collection Pan on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Could store pan under the table.
- Expand pan for fluid capacity during procedure.</td><td>- Difficult to have an expandable pan that will seal well.
- Difficult to clean sealed edges.
- Difficult to manufacture</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 8: Fluid Diverter to Fluid Collection Pan on the Ground</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Not limited by size constraints.
- Easy to manufacture.</td><td>- Fluid tray would be inconvenient on the ground.
- Splashing of fluid would be a concern.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

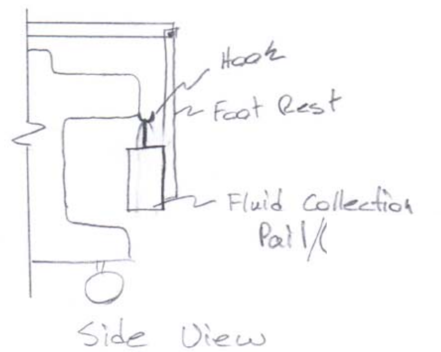
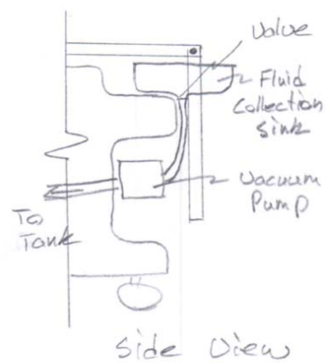
Concept 9: Hanging Fluid Collection Pail		
	Advantages	Disadvantages
	- Easy to remove pail with fluids when procedure is complete. - Pail can contain specified volume.	- Surgeon has no place to put tools. - Difficult to fit bag for fluid waste into pail.
Concept 10: Small Fluid Collection Pan with Vacuum Pump		
	Advantages	Disadvantages
	- Fluid would be pumped into larger waste container immediately. - Not limited to size due to volume requirements.	- Noisy. - Expensive to implement.

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

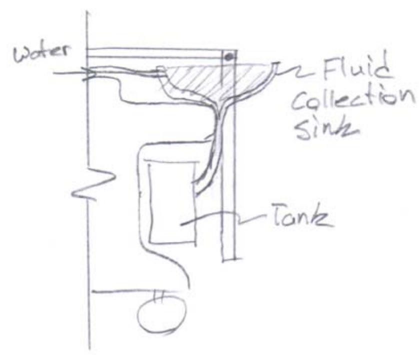
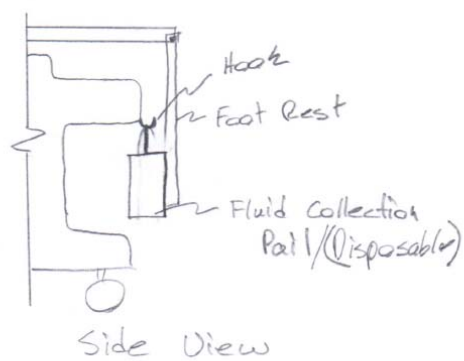
<table>
<tr><td rowspan="3">Concept 11: Fluid Collection Sink with Drain and Flush System</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- No volume requirements as fluid would drain immediately.
- Flush system would do most of the cleaning.</td><td>- Expensive to implement.
- Not comfortable for surgeon to have a flush system under their work area.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 12: Disposable Hanging Fluid Collection Pail</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- No cleaning required of the pan.
- All-in-one system used for collecting and disposing of fluids.</td><td>- No working surface for surgeon.
- Difficult to find supplier.
- Long term costs.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

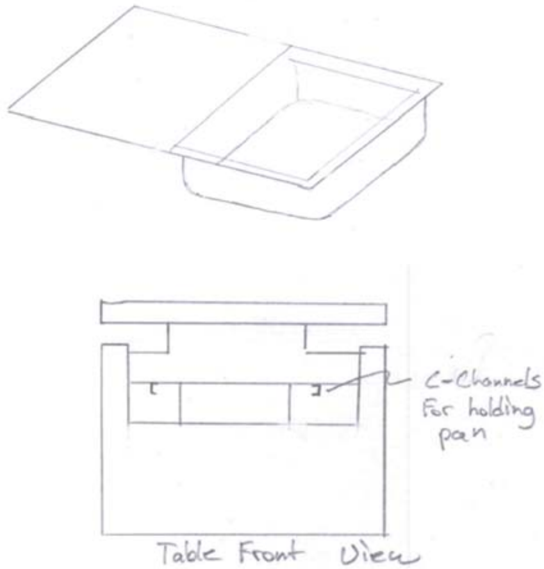
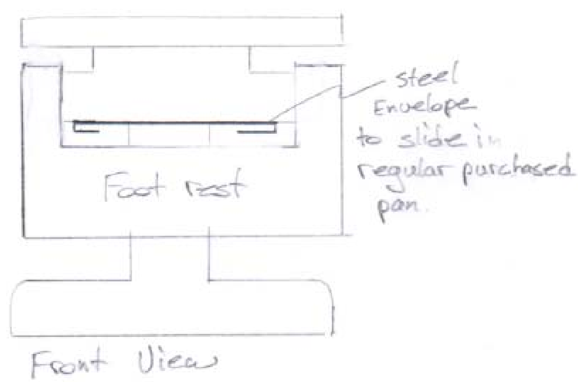
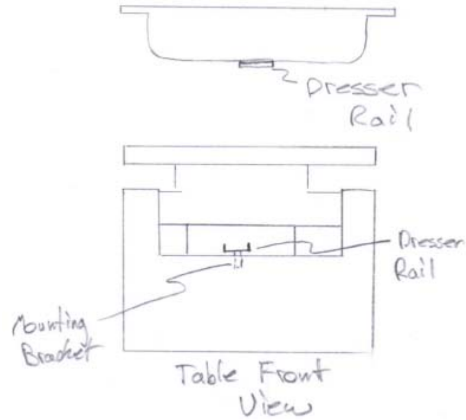
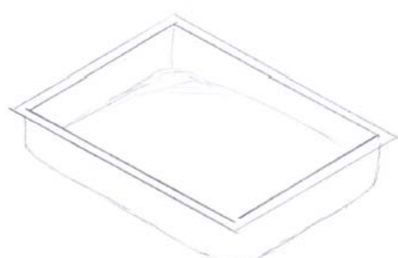
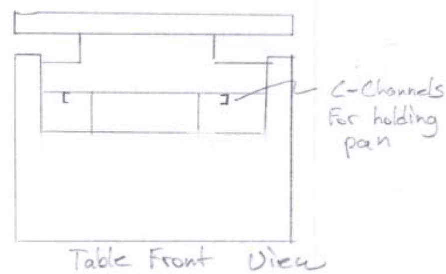
<table>
<tr><td rowspan="3">Concept 13: Extended Flange Fluid Collection Pan on C-channels</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Provides additional deployment distance.
- Easy to manufacture/modify purchased part.</td><td>- Decreased pan volume.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 14: Regular Fluid Collection Pan with Envelope Retaining/ Deployment Method</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Provides rigidity to pan support structure.
- Consistent with current design.</td><td>- Requires more custom manufacturing.
- No improvements in overall function of the pan and deployment.
- Difficult to install.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

TABLE II: FLUID COLLECTION SYSTEM CONCEPT GENERATION

<table>
<tr><td rowspan="3">Concept 15: Regular Fluid Collection Pan with Dresser Rail on the Bottom</td><td colspan="2">
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Smooth movement of pan.
- Easy to install to pan.</td><td>- Difficult to clean.
- Difficult to fully remove the pan for cleaning.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 16: Regular Fluid Collection Pan on C-channels</td><td colspan="2"> 
</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Pan can be purchased/easily modified to meet size constraints.
- Same as current design.</td><td>- Hard to fit purchased pan into designated area.
- May require frame modifications to make pan fit.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

B.2 SYSTEMATIC EXPLORATION OF IDEAS

Once our team performed a wide variety of external search results, and generated the concepts listed in Table I and II, we began to generate ideas using a more systematic approach. Particularly, our team used the following tools: a morphologic box and a contradiction matrix. Through the use of a morphologic box and the contradiction matrix connected to TRIZ, we were able to generate a number of fused concepts for the footrest and fluid collection system.

B.2.1 MORPHOLOGIC BOX

A morphologic box is a tool that categorizes solutions to specific sub-functions of a product. A morphologic box is typically used to generate new and non-obvious combinations of sub-functions to the main function [1]. In order to generate a morphologic box, sub-functions of the main function of a problem have to be determined. For the footrest, we determined the sub-functions to be support the weight of the patient and deployable. For the fluid collection system, we determined the sub-functions to be: deployable, contain fluid, support fluid, and dispose of fluid. Our morphologic box for the footrest and fluid collection system are presented in Table III and IV, respectively.

TABLE III: MORPHOLOGIC BOX FOR FOOTREST

1 Support weight	1.1 Legs	1.2 Drawer	1.3 Posts	1.4 Leg section lever arm assembly	1.5 Spring loaded lever and ratchet system	1.6 Latch at pivot point	1.7 Screw support at pivot point	1.8 Rail	1.9 Fitted tubes	1.10	1.11	1.12
2 Deployment	2.1 Spring loaded lever and ratchet system	2.2 Rails	2.3 C-channels	2.4 Fitted tube	2.5 Latch at pivot point	2.6 Screw support at pivot point	2.7 Pneumatics	2.8 Hydraulics	2.9 Magnetic	2.10 Torsional spring	2.11 Hinge	2.12 Rack and pinion

TABLE IV: MORPHOLOGIC BOX FOR FLUID COLLECTION SYSTEM

1 Contain fluid	1.1 Stainless steel pan	1.2 Polypropylene pan	1.3 Bag	1.4 Sponge	1.5 Bucket	1.6 Can	1.7
2 Support fluid	2.1 Looped wand	2.2 Looped wand with cage	2.3 C-channels	2.4 Envelope	2.5 Rails with hooks	2.6 Rails with slots	2.7
3 Deployment	3.1 C-channels	3.2 Rail on base of pan	3.3 Bearings	3.4 Fitted steel tube	3.5 Gear system	3.6 Rails with hooks	3.7 Rails with slots
4 Disposal of fluids	4.1 Vacuum	4.2 Flush system	4.3 Slide	4.4 Plastic bag	4.5 Pump	4.6 Flame	4.7

Through the creation of the morphologic boxes, we were able to identify a number of solutions to our sub-functions that we did not think of in our brainstorming session. Unfortunately, a number of these ideas are not feasible due to the lack of practicality of their implementation within the Women's Hospital at the HSC. Such ideas include using a sponge for containing fluid from the patient and using a flame to evaporate this fluid.

B.2.2 CONTRADICTION MATRIX

Genrich Saulovich Altshuller developed a contradiction matrix by determining 39 factors which are potentially contradictory to one another. The combination of these factors are plotted in a matrix, and the 40 design principles of TRIZ are provided as tips to find solutions to these contradictions.

Throughout our concept generation process we found that we were presented with two main contradictions: easy to operate vs. easy to manufacture, and durable vs. lightweight. The contradiction matrix suggested taking out, merging, the other way round, and partial or excessive actions for our first contradiction [2]. For the second contradiction, the matrix suggested taking out, cheap short-living objects, periodic action, and universality. The suggestions derived by the contradiction matrix were considered when deriving our fused concepts.

B.2.3 FUSION

Both the morphologic box and the contradiction matrix were used as tools to generate a number of fused concepts for the footrest and fluid collection system. Fused concepts for the footrest are presented in Table V. For the footrest, Concept 14 and Concept 1 were combined to yield Concept 22; Concept 14, Concept 1, and Concept 7 were combined to produce Concept 23; Concept 6 and Concept 4 were combined to yield Concept 24.

TABLE V: CONCEPT FUSION FOR THE FOOTREST

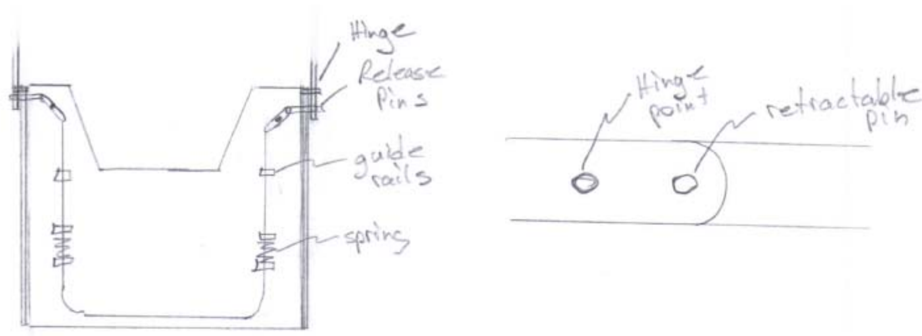
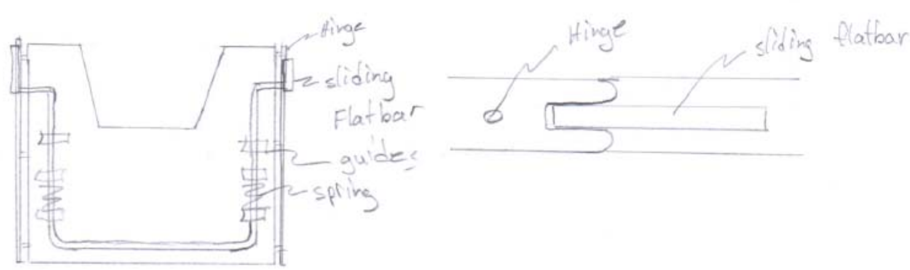
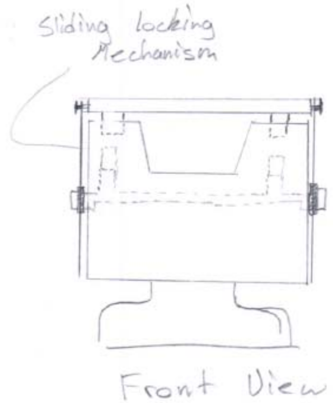
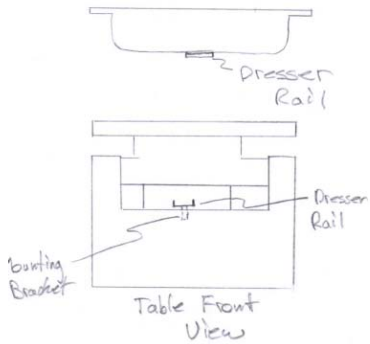
Concept 22: Horizontal Spring Loaded Pin with Handle on Footrest		
	Advantages	Disadvantages
	- Fast deployment. - User friendly and easy to operate. - Requires minimal change to current footrest.	- May result in jamming of rods between handle and pin. - X-motion needs to be converted to Y-motion.
Concept 23: Spring Loaded Flat-bar with Handle on Footrest		
	Advantages	Disadvantages
	- Fast deployment. - User friendly and easy to operate. - Requires minimal change to current footrest.	- May result in jamming of rods between flat-bar and handle.

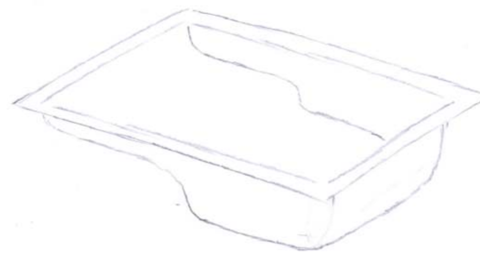
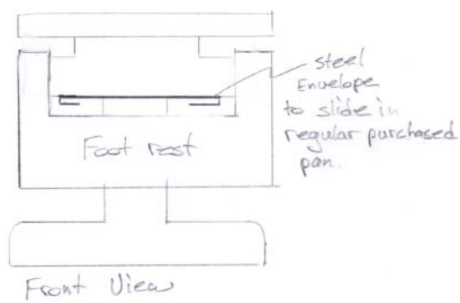
TABLE V: CONCEPT FUSION FOR THE FOOTREST

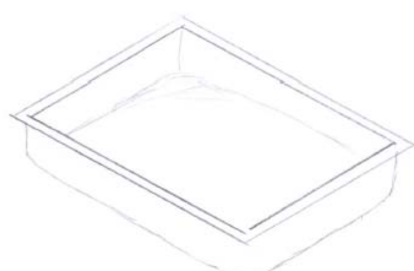
<table>
<tr><td rowspan="3">Concept 24: Sliding Bar Locking Mechanism Footrest</td><td colspan="2"></td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy to manufacture and cheap.
- Easy to install.</td><td>- Could be cumbersome to operate.
- Will add additional weight to footrest.
- Handles would be interfere with side rails.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

Through the use of the morphologic box and the contradiction matrix, we were able to generate two fused concepts for the fluid collection system, which are presented in Table VI. For the fluid collection system, Concept 1 and Concept 15 were combined to generate Concept 17, and Concept 14 and Concept 16 were combined to yield Concept 18.

TABLE VI: CONCEPT FUSION FOR THE FLUID COLLECTION SYSTEM

<table>
<tr><td rowspan="3">Concept 17: Custom Pan with Drawer Hinge Deployment</td><td colspan="2">

</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Easy deployment.
- Contains high volume of fluid.</td><td>- Difficult to manufacture.
- Difficult to clean.
- Difficult to fully disengage.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">Concept 18: Regular Small Fluid Collection Pan with Envelope Deployment Method</td><td colspan="2">

</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>- Consistent with current design.
- Pan is easy to purchase.
- Easy to use.</td><td>- Deployment is not perfect.
- Difficult to install envelope deployment design.</td></tr>
<tr><td colspan="3"></td></tr>
</table>

APPENDIX B: REFERENCES

[1] "Design Techniques," class notes for MECH 4322, Department of Mechanical Engineering, University of Manitoba, 2014.

[2] SolidCreativity. (n.d.). *TRIZ40* [Online]. Available: http://www.triz40.com/TRIZ_GB.php [October 20, 2014].

Procedural Table Equipment Retrofit
Appendix C: Document of Approval

DOCUMENT OF APPROVAL

I, Michael Hamilton, the Engineering Lead for the Procedural Table Equipment Retrofit Project, verify that I reviewed the final design submitted to me by the University of Manitoba Engineering student group 24. I have advised them of any concerns that I have regarding the functionality of the design and have informed them of any recommendations that I have. I approve the submission of the final design.

Michael Hamilton (Regional Clinical EIT): ______ Date: Nov 24, 2014

Olivia Essex: ______ Date: November 24, 2014

Cody Bjornsson: ______ Date: November 24, 2014

Devin Windeatt: ______ Date: November 24, 2014

Thomas Sawadski: ______ Date: November 24, 2014