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Cart with a Vertically Oriented Load

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Washington University in St. Louis

SCHOOL OF ENGINEERING & APPLIED SCIENCE

Executive Summary

A cart with a load oriented above the cart's base via it being mounted on a centrally located pole was designed and built per design specifications based upon existing codes and standards. The target market of this device is in the medical field, with comparative devices currently utilized in the support of systems which supply fluids intravenously to patients. The materials out of which the prototype was designed and fabricated are commonly available, while also selected for their common usage in the medical field due to their non-caustic nature and the relative ease with which they may be sterilized using environmentally friendly and non-toxic means. Studies into the mass-production of the device demonstrated applicability into the feasibility of mass-manufacture, with none of the manufacturing methods by which the prototype was made being unavailable to most contemporary manufacturing centers. The prototype of the device demonstrated successful completion of all prescribed design goals, and computer-aided simulations and analysis demonstrated significant factors of safety in all areas of concern. Future work will entail further modifications made to the base of the device, in regard to more optimally distributing the vertically oriented load, and more widely and evenly distributing the stresses within the frame of the device.

MEMS 411: Senior Design Project

Cart with Vertically Oriented Load (CWWOL)

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1 INTRODUCTION AND BACKGROUND INFORMATION

1.1 INITIAL PROJECT DESCRIPTION

Cart with a vertically oriented load which may have practical application in a medical setting. The design of this cart will consider possible environmental conditions which may introduce possibilities for tipping and slipping, such as different types of flooring and moments introduced by operators of varying height and weight. A defined load range will be positioned at a set height from the wheel base of the cart. The materials used in the cart's construction will also take possible environmental conditions into account.

1.2 EXISTING PRODUCTS

- 1.) Economy I.V. Pole

<https://www.amazon.com/Economy-I-V-Pole-Removable-Hook/dp/B000IDTD8O>



Figure 1: Example economy IV stand with 4 wheels and low center of gravity

This IV stand utilizes a wheelbase of four plastic wheels, such as one may find below certain office chairs. The bag capacity is 2-4, and the vertical orientation of the load is set into place using a screw-type locking mechanism.

- 2.) Blickman 1310 Chrome IV Stand

http://www.globalindustrial.com/p/medical-lab/service-carts/medical-stands/blickman-height-adjustable-chrome-iv-stand-with-tru-loc?infoParam.campaignId=T9F&gclid=EAIaIQobChMI_obVh_GQ1gIVA7nACh163wOEEAQYAyABEgKfKPD_BwE



Figure 2: Example IV stand on market with 4 wheels

The wheelbase of this IV pole utilizes four solid rubber wheels, and it is possible to lock them into place. The vertical orientation of the load is set into place using a hand-screw type locking mechanism.

3.) Blickman low center of gravity IV stand

<http://www.alimed.com/blickman-heavy-duty-iv-stands.html>



Figure 3: Example IV stand on market with low-center of gravity base

This IV pole's wheelbase consists of six solid rubber wheels, and the pole is set as close to the bottom of the wheelbase as possible to increase stability. The bag capacity is 4-8 bags, and the vertical orientation is set using a hand screw type locking mechanism.

1.3 RELEVANT PATENTS

- 1.) US4892279A Fully portable medical I.V. equipment stand/pole

<https://patents.google.com/patent/US4892279A/en?q=IV&q=pole>

U.S. Patent Jan. 9, 1990 Sheet 1 of 2 4,892,279

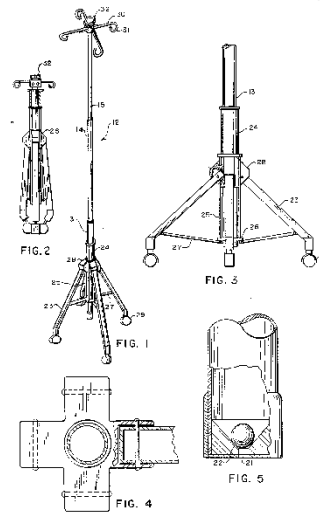


Figure 4: Example patent for modifications to IV stand 1

This patent relates to a form of wheelbase for an IV stand which collapses back into the IV pole to aid in storage and mobility. The design is similar to a camera tripod, and may also be used to set the pole into a recess behind the patient's bed in a receptacle similar to an umbrella stand.

2.) US5112019A Motorized IV pole assembly

<https://patents.google.com/patent/US5112019A/en?q=IV&q=pole>

U.S. Patent May 12, 1992 Sheet 1 of 7 5,112,019

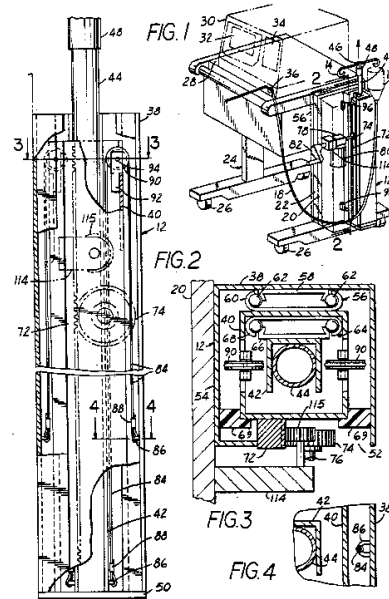


Figure 5: Example patent of IV stand modifications 2

This patent relates to a motorized IV stand, which utilizes electric motors and internally mounted linkage to adjust the height of a stand. Most stands used in hospital settings consist of manual height adjustment which is set into place using a form of a set-screw which is also manually operated.

1.4 CODES & STANDARDS

ISO 28620 4.4: Sterility and non-pyrogenicity: *All parts of the device in contact with the drug solution shall have been subjected to a validated sterilization process and be delivered sterile and non-pyrogenic, and be for single use only.*

This code relates to the device in that the materials out of which the device is constructed must be non-toxic and readily sterilized. Further consideration entails materials which may be sterilized through environmentally friendly means.

ISO 28620 4.3.5: Reservoir: *The reservoir of the device shall be designed so as to allow visual inspection of the solution.*

The reservoir of the device is readily observable by the operator.

ISO 28620 6.6: Resistance to traction of the entire device: *Apply a force of 15 N for 15 s between each of the ends of the device. At the end of this test, the device shall not show deterioration liable to affect its performance.*

When fully loaded, the device is noted to be subjected to more than 100N of force. This loading is accomplished with a significant factor of safety.

1.5 PROJECT SCOPE

The project relates to the design and construction of a cart with a vertically oriented load which may have practical application in a medical setting. The prototype of the device will be able to meet design requirements which will be modeled upon existing standards for medical devices. The project includes modeling using computer aided design software, and construction methods such as the use of water jet cutting.

1.6 PROJECT PLANNING

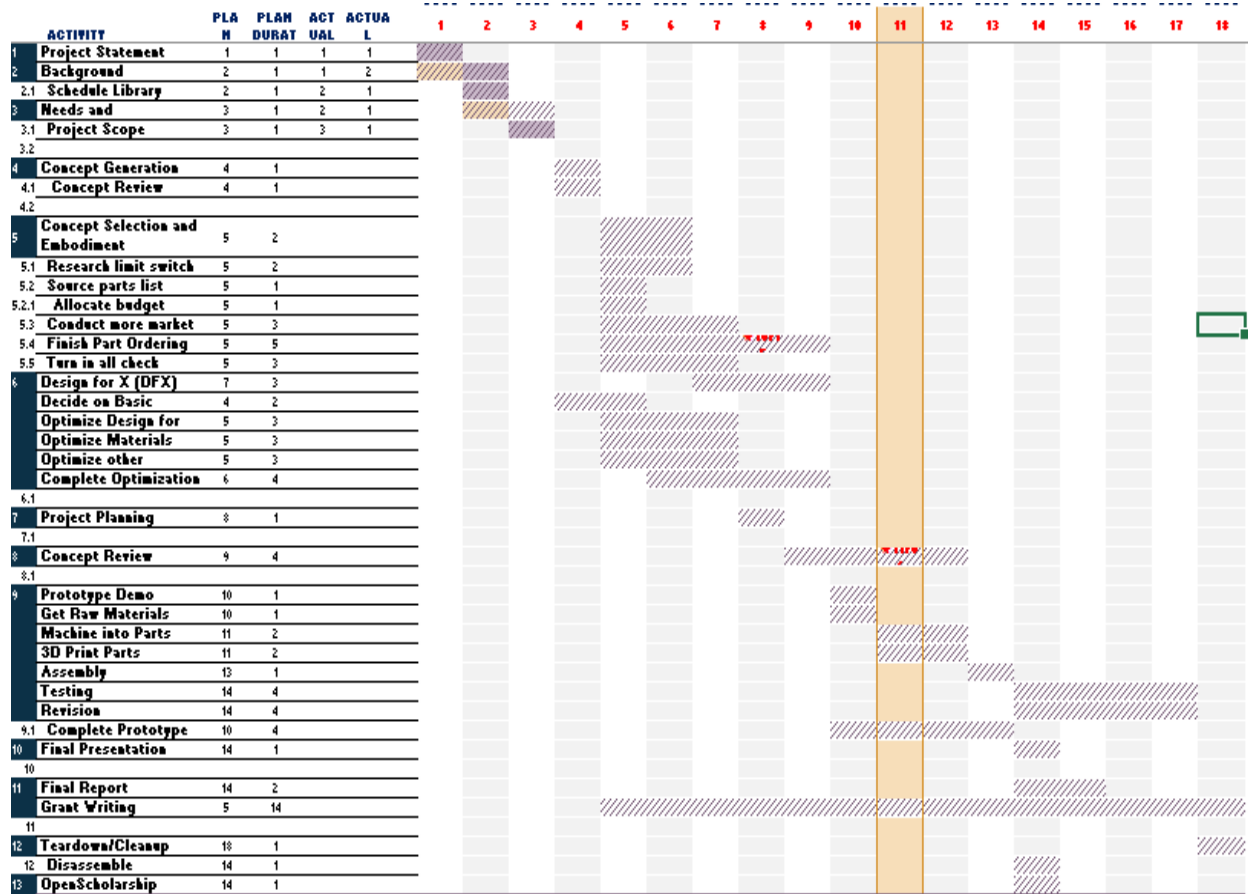


Figure 6: Planned project schedule in the form of a GANNT chart

1.7 REALISTIC CONSTRAINTS

Many technical, economic, social, environmental, and safety constraints must be considered in the design and construction of this device.

1.7.1 Functional

The device must accomplish its prescribed functions while maintaining a floor “footprint” of an 18x18” square, as this is the largest plate which may be ordered per the budget. The turn radius of the castor wheels beneath the base of the device must be taken into consideration, that they are not hindered through device geometry. The device must be capable of rolling across a surface one would expect to find in a medical setting, such as a laminate floor. The energy required to operate the IV pumps must be self-contained to the device, while the device itself need not be powered regarding its propulsion. The

materials which may be used in the device's construction should be chosen for their affordability, recyclability, reliability, and the ease with which they may be sterilized through environmentally friendly means.

1.7.2 Safety

The device must be capable of being operated by a physiologically average adult American male, and be sufficiently resistant to tipping to not represent an undue risk to patients or operators. The materials out of which the device is to be constructed must be non-toxic, and not prone to developing sharp edges following routine use's inherent wear and tear. Additionally, transportation of the device should not pose a potential hazard to either the patient or operator.

1.7.3 Quality

The quality of the device must be ensured through the prototype meeting design constraints which will be applied before construction commences in relation to existing standards for medical devices. A substantial factor of safety must be considered in modeling the device utilizing computer-aided means. Ideally, the device should safely and reasonably exceed design criteria.

1.7.4 Manufacturing

The constraints placed upon the construction of the device related to time, cost, and the means made available by which machining and manufacturing might take place. An unstated goal was to keep the machining of the components of the prototype to a minimum, relying instead upon the purchasing of pre-fabricated components whenever possible. The assembly of the device should be readily carried out by operators in field conditions who have received no specialized mechanical training. The transport and handling of the device and the materials out of which it is constructed should not pose environmental hazards, and should be accomplished with relative ease by a healthy and physiologically average adult American male.

1.7.5 Timing

The design, development, production, and deliver schedules must fall within budgetary and time constraints. For all, see Gantt chart.

1.7.6 Economic

The American healthcare market encompasses an estimated \$3 trillion market share, offering considerable opportunities for emerging medical technologies. The design, developing, and manufacturing costs of the device are constrained by an assigned budget and in relation to similar devices currently on market. The cost of manufacturing the prototype will inherently be higher than its streamlined mass-manufacture should it come to market. The manufacturing of the device should not entail overly exotic or complicated means, as this could entail prohibitively large-scale retooling of existing manufacturing centers.

1.7.7 Ergonomic

The needs of the user must be taken into consideration, with provided instructions offering clear and safe means by which the operator might transport, assemble, and operate the device. The ergonomic means by which an operator might most easily sterilize the device through steam cleaning entails a lack of difficult to reach crevices. The edges of the device should all be rounded, and all machined holes should be deburred to both provide an aesthetically appealing appearance and ensure the minimizing of potential injury.

1.7.8 Ecological

The recyclability and non-toxic nature of the materials out of which the device is constructed pose general environmental constraints. These constraints are to be taken into consideration alongside the requirement that the materials be readily sterilized through environmentally friendly means, namely through prolonged envelopment in high temperature steam.

1.7.9 Aesthetic

The shape, texture, and form of the device should appeal to its target customer base, and be a welcome addition in the healthcare environment. Prospective future developments in technology should readily incorporate with the design.

1.7.10 Life Cycle

The means of transport of the device as well as its operation and maintenance should be understandable to the operator of the device through universally understood instructions. The disposal and recyclability of the materials out of which the device is constructed pose a constraint in that the life cycle of the device may be extended as need be should it be constructed out of sufficiently recyclable materials.

1.7.11 Legal

Standing regulations in the manufacture of medical devices form the basis of the design constraints from which the device may be manufactured. The safety of the patient comes first in the overarching design of the device, and serves as the main ethical constraint to consider in its design and manufacture. The intellectual property which the device represents has been patented provisionally and is pending further utility patenting.

1.8 REVISED PROJECT DESCRIPTION

Cart which will be designed using dynamics calculations based off determined and known values such as a range of weight being oriented at a height above the wheelbase. Additional considerations to consider will be coefficients of friction and range of motion with varied types of wheels and flooring materials and conditions. Such environmental conditions may introduce possibilities for tipping and slipping, such as different types of flooring and moments about the wheelbase introduced by operators of varying height, weight, and age. A defined load range (0-8kg) will be positioned at a set height (0-2m) from the wheel base of the cart. The materials used in the cart’s construction will also take possible environmental conditions into account, such as stainless steel utilized to reduce effort in equipment sterilization.

2 CUSTOMER NEEDS & PRODUCT SPECIFICATIONS

2.1 CUSTOMER INTERVIEWS

Customer Data: Customer: Angela Richards (Age: 36)			
Address: Barnes Jewish Hospital, St. Louis, MO			
Date: 9/15/17			
Question	Customer Statement	Interpreted Need	Importance
What do you like about the current design of IV stands?	Current IV stands allow for the ready placement of bags, pumps, and lines.	Our product also needs to allow for the ready placement of bags, pumps and lines.	5

What do you dislike about the current design of IV stands?	Does not allow for control of patients. Not mobile enough. Lines can get tangled; power cords can get tangled. It is not safe sometimes.	<ul style="list-style-type: none"> • Cart must allow for control of patient. • Must allow for easy patient mobility. • Must be safe. • Allow for wire/cord management 	4 4 5 2
What types of surfaces would you say are the most challenging to traverse?	Carpet and pavements. Wet hospital floors are hard too. Must be able to traverse gaps (ex. Elevator)	<ul style="list-style-type: none"> • Should allow for free movement throughout a hospital. • Have capability to go outside 	4 2
How many bags do you usually use on an IV pole?	1 to 4, with 4 being an outlier.	Allow for up to 4 bags (about 4L, about 4kg)	3
How easy is it to clean/maintain IV poles?	It is very easy, we just disinfect it	<ul style="list-style-type: none"> • Should be easy to maintain and clean. • Has fewer places to collect dirt and bacteria 	5 3
What are your suggested improvements?	Make it more difficulty to accidentally tip over.	Make it harder to tip over	5

2.2 INTERPRETED CUSTOMER NEEDS

Need Number	Need	Importance
1	Allow for placement of bags, pumps, and lines	5
2	Allow for control of patient	4
3	Allow for easy patient mobility in hospital	4
4	Safety of patient	5
5	Allow for cord management	2
6	Capability to go outside	2

7	Allow for up to 4 bags	3
8	Easy to clean and maintain	5
9	Harder to tip over	5

2.3 TARGET SPECIFICATIONS

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1,7	How many bags?	# of bags	2-4	4
2	1	Vertical placement of bags/lines	meters	1-2	2
3	2	Distance patient is constrained to device	meters	<1	1
4	3,4	Maximum safe speed (in hospital)	m/s	0.447-0.9	0.9
5	5	Number of lines/cords that can be secured	# of cords	3-5	5
6	6,4	Maximum safe speed (out of hospital)	m/s	0.2235-0.5	0.5
7	9	Factors of safety (for expected loads)	unitless	2-4	3.5
8	8	Expected cleaning time after use	Minutes	<30	20

3 CONCEPT GENERATION

3.1 FUNCTIONAL DECOMPOSITION

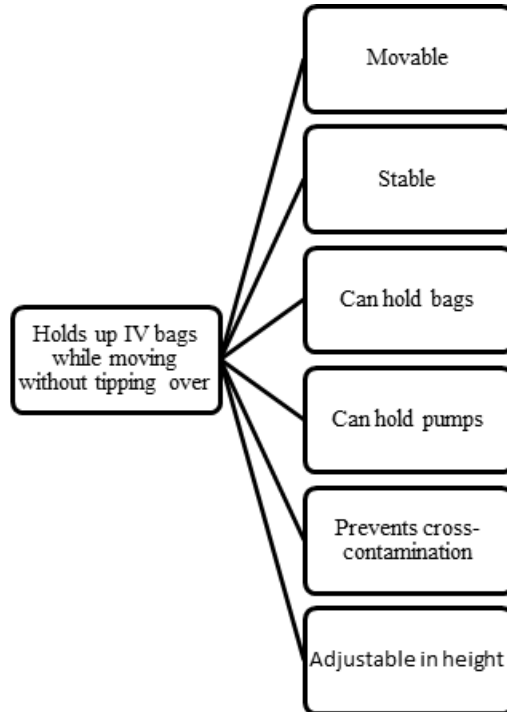


Figure 7: Function tree for Cart with Vertically Oriented Load

3.2 MORPHOLOGICAL CHART





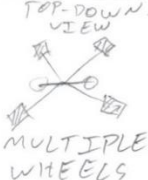










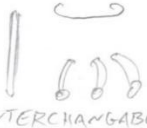


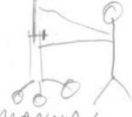


Movable	 WHEELED BASE	 TRACKED BASE	 WALKING STICK	 BACKPACK
Stable	TOP-DOWN VIEW  MULTIPLE WHEELS	 TRACKED	 "TRIPOD" BASE	 SEGWAY BASE
Can hold bags	 HOOKS	 DRONE MOUNTED	 MAGLEV	
Can hold pumps	 CLAMPS	 VELCRO	 ZIP-TIES	
Prevents cross contamination	 STERILIZABLE	 INTERCHANGABLE PARTS	 SPRAYABLE COATING AFTER EACH USE	 SELF-CLEANING MATERIAL
Adjustable in height	 MANUAL	 WALKING STICK	 DRONE	

Figure 8: Morphological chart for IV stand

3.3 CONCEPT #1 – “SEGWAY BASE”



Figure 9: Segway Base IV Stand

Description: A Segway base is used to maintain the orientation of the IV pole. A carrying handle is attached to the pole, which allows the operator to direct the pole’s movement more readily. A guard protects against the patient’s feet getting caught under the wheels.

Solutions:

1. Segway Base
2. Segway is gyroscopically stable
3. Hooks hold bags
4. Stand holds pumps
5. Holding bar is replaceable and stand is easily cleaned
6. Stand is manually adjustable

3.4 CONCEPT #2 – “DRONE MOUNTED IV SYSTEM”

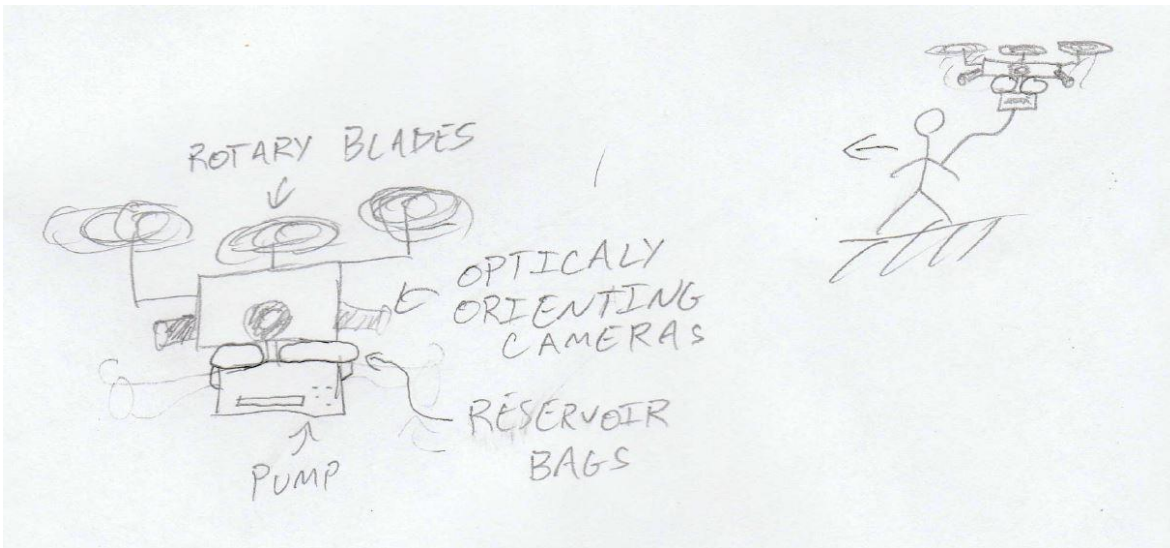


Figure 10: Drone Mounted IV Stand

Description: A drone maintains a safe distance from the patient and other obstacles through the use of cameras which acquire information on the drone’s surroundings optically. The undercarriage of the drone houses IV bags, below which the IV pump is mounted. Rotary blades provide lift for the drone and its payload.

Solutions:

1. Unit flies around
2. Sensors on drone will ensure bags are always upright and away from obstacles
3. Packaged under drone as load
4. Packaged under drone as load
5. Will avoid direct contact with most things
6. Unit flies around

3.5 CONCEPT #3 – “RFID IV COMPANION”

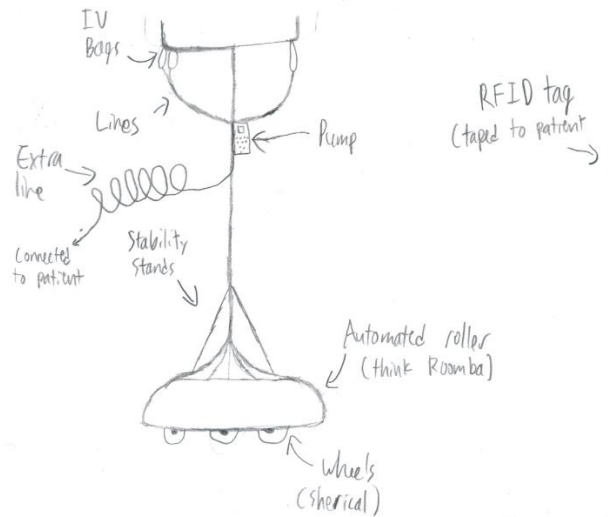


Figure 11: RFID Companion IV Stand

Description: An automated base will follow the user around the hospital, using an RFID tag that the patient will have taped to the arm. The base will have a battery and be rechargeable, in addition to having an internal layout of the hospital that it is in, such that patients can be monitored and the base will always avoid collision with walls, etc. A longer line will be utilized to give the patient more freedom, which will be adjustable. The charging can take place when the patient is in bed and resting.

Solutions:

1. Unit has automatic base
2. Contains supports and heavy base, lowers center of gravity
3. Hooks
4. Stand can hold pumps
5. Stand and hooks are easily cleanable
6. Manually adjustable

3.6 CONCEPT #4 – “AT-I-V (ALL TERRAIN IV)”

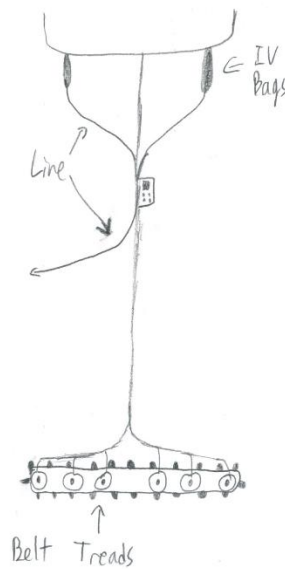


Figure 12: All Terrain IV Stand

Description: The base will consist of many small wheels inside a belt tread. The durable base will be able to handle many terrains, such as pavement or grassy fields. A major downside is that the IV stand will only go forwards and backwards, meaning the patient may have to manually turn the IV stand. However, it should be quite durable.

Solutions:

1. Has tank-like treads
2. Very stable base
3. Hooks hold bags
4. Stand can hold pumps
5. Stand is cleanable
6. Manually adjustable

3.7 CONCEPT #5 – “WALKING IV STAND”

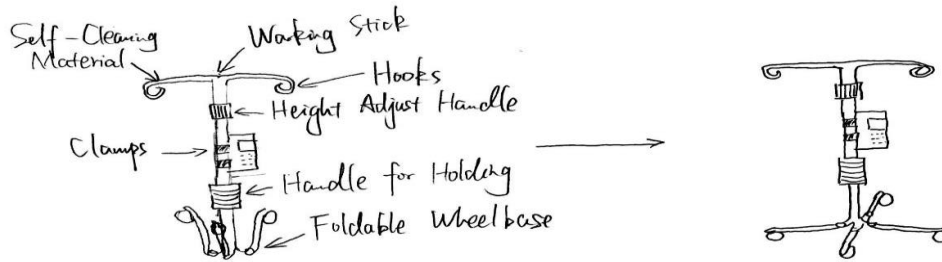


Figure 13: Walking IV Stand

Description: This IV stand has two modes. The first one is a hand-holding mode as shown in the first graph. It can be hold in hand, and it is good for walking outdoors. The second mode, standard mode, is shown in the second graph, and can be transferred from the hand-holding mode by extending the wheelbase. The standard mode is good for walking indoors.

Solutions:

1. Unit uses Walking Stick Design
2. Unit uses Walking Stick Design
3. Unit has Hooks
4. Unit has Clamps to hold Pumps
5. Unit is made of Self-cleaning Material
6. Unit uses Walking Stick Design and has Manual Height Adjustment Mechanism

3.8 CONCEPT #6 – “BACKPACK”

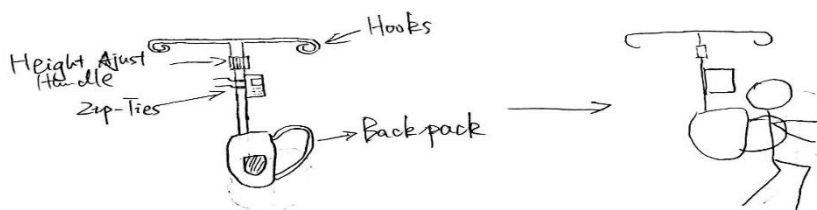


Figure 14: Backpack design

Description: This IV stand does not have a wheel-base, but can be mounted on a backpack. The Backpack IV stand can be carried around without any manipulation. The stability of this design will not be as stable as a standard IV stand. This backpack IV stand can be easily sterilized because it takes up less space.

Solutions:

1. Unit is Backpack Mounted
2. Unit is Backpack Mounted
3. Unit has Hooks
4. Unit uses Zip-ties to Hold Pumps
5. Unit is Sterilizable
6. Unit has Manual Height Adjustment

4 CONCEPT SELECTION

4.1 CONCEPT SCORING MATRIX

	Mechanical Safety	Cost of components	Number of bags that can be held	Control of patient	Maximum safe speed	Cleaning time	Number of cords that can be secured	Availability of parts	Manufacturability	Row Total	Weight Value	Weight (%)	
Mechanical safety	1.00	3.00	7.00	1.00	3.00	5.00	7.00	3.00	3.00	33.00	0.26	26.42%	
Cost of components	0.33	1.00	1.00	0.33	1.00	0.33	3.00	1.00	1.00	9.00	0.07	7.21%	
Number of bags that can be held	0.14	1.00	1.00	0.20	0.33	0.33	1.00	0.33	0.33	4.68	0.04	3.74%	
Control of patient	1.00	3.00	5.00	1.00	1.00	3.00	5.00	1.00	3.00	23.00	0.18	18.42%	
Maximum safe speed	0.33	1.00	3.00	1.00	1.00	3.00	3.00	1.00	1.00	14.33	0.11	11.48%	
Cleaning time	0.20	3.00	3.00	0.33	0.33	1.00	1.00	1.00	0.33	10.20	0.08	8.17%	
Number of cords that can be secured	0.14	0.33	1.00	0.20	0.33	1.00	1.00	0.33	0.33	4.68	0.04	3.74%	
Availability of parts	0.33	1.00	3.00	1.00	1.00	1.00	3.00	1.00	1.00	12.33	0.10	9.88%	
Manufacturability	0.33	1.00	3.00	0.33	1.00	3.00	3.00	1.00	1.00	13.67	0.11	10.94%	
										Column Total:	124.89	1.00	100%

Row criterion is _____ than/as column criterion

Numerical ratings: 9 – Extremely more important
 7 – Very strongly more important
 5 – Strongly more important
 3 – Moderately more important
 1 – Equally important
 1/3 -- Moderately less important
 1/5 -- Strongly less important
 1/7 -- Very strongly less important
 1/9 -- Extremely less important

Figure 15: Bonus analytic hierarchy process table

		Segway Base		Drone Mounted		RFID		Walking Stand		Reference		Cart	
Selection Criterion	Weight (%)	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Mechanical safety	26.42	2	0.53	3	0.79	4	1.06	1	0.26	3	0.79	4	1.06
Cost of components	7.21	4	0.29	2	0.14	2	0.14	3	0.22	3	0.22	3	0.22
Number of bags that can be hold	3.74	2	0.07	2	0.07	3	0.11	3	0.11	3	0.11	3	0.11
Control of patient	18.42	2	0.37	1	0.18	3	0.55	3	0.55	3	0.55	5	0.92
Maximum safe speed	11.48	4	0.46	4	0.46	4	0.46	4	0.46	3	0.34	4	0.46
Cleaning time	8.17	2	0.16	1	0.08	2	0.16	3	0.25	3	0.25	1	0.08
Number of cords that can be secured	3.74	3	0.11	3	0.11	3	0.11	3	0.11	3	0.11	3	0.11
Availability of part	9.88	2	0.20	4	0.40	3	0.30	3	0.30	3	0.30	3	0.30
Manufacturability	10.94	2	0.22	4	0.44	2	0.22	2	0.22	3	0.33	3	0.33
	Total score	2.411		2.682		3.116		2.477		3.000		3.584	
	Rank	6		4		2		5		3		1	

Figure 16: Weighted Scoring Matrix (WSM)

4.2 EXPLANATION OF WINNING CONCEPT SCORES

No. 1: Cart

This design comes to the first place in the concept selection process, due to its use in a clinical setting which we are not able to disclose due to public disclosure concerns. The score for the *mechanical safety* is 4 because the design is harder to tip over compared to the reference design. The *control of patient* scored 5, which is the highest out of all designs, because a handle is designed to improve the controllability. The *cleaning time* got only 1 because this design needs to be disassembled first to get cleaned. The process of disassembling and reassembling is time-consuming.

4.3 EXPLANATION OF SECOND-PLACE CONCEPT SCORES

No. 2: RFID

This design uses an automated base that will follow the user around in the hospital, using an RFID tag that the user will tap to the arm. This design is a bit worse than the reference design for *cost of components, cleaning time and manufacturability*, since the RFID design is more complicated than the reference one. The RFID design uses automated control system which costs higher and is harder to manufacture. The complexity of this design makes it harder to clean, but the cleaning time is still expected to be shorter than the Cart design because there are less components that need to be disassembled for the RFID design. The RFID design scored higher for *mechanical safety* and *maximum safe speed*, because it has higher stability and better designed base that allows higher safe speed. This

RFID design ranks higher than the reference design because it scores higher in the criterions that have much greater weight.

4.4 EXPLANATION OF THIRD-PLACE CONCEPT SCORES

No. 3: *Reference*

This design is an existing standard design for an IV Stand. It came up to be in the third place after the concept selection process. It ranked higher than the *Segway Base* and the *Drone Mounted* designs mainly due to the simplicity of its design. Simplicity generally has advantages for *cost of components*, *cleaning time*, *cost of components* and *manufacturability*. The *Reference* design is also better than the *Walking Stand* design, mainly due to *mechanical safety* criterion, which has the higher weight of all the criterions.

4.5 SUMMARY OF EVALUATION RESULTS

Section 4.5: Summary of Evaluation Results

Mechanical safety ranked highest in importance on our list, as the safety of the patient is paramount in both the ethical and practical application of our device. Due to public disclosure concerns, we may not specify why the control of the patient ranks second in importance, but the maximum speed of the device ranks third due to its relation to mechanical safety. The Manufacturability of the device relates to both its marketability and applicability as a prototype for this class, and so ranks fourth. The number of cords that can be secured and number of IV bags the device can hold weigh least heavily on our final determination, as the safety of the patient is foremost in the design criteria. These criteria are secondary to this, and most readily addressed with minor modifications. The results of this scoring matrix have answered a number of key questions related to the design of the device, and its fabrication in the form of a prototype will proceed with added safety features in relation to the ease with which it tips, and the type of wheels used in the construction being castors.

5 EMBODIMENT & FABRICATION PLAN

5.1 ISOMETRIC DRAWING WITH BILL OF MATERIALS

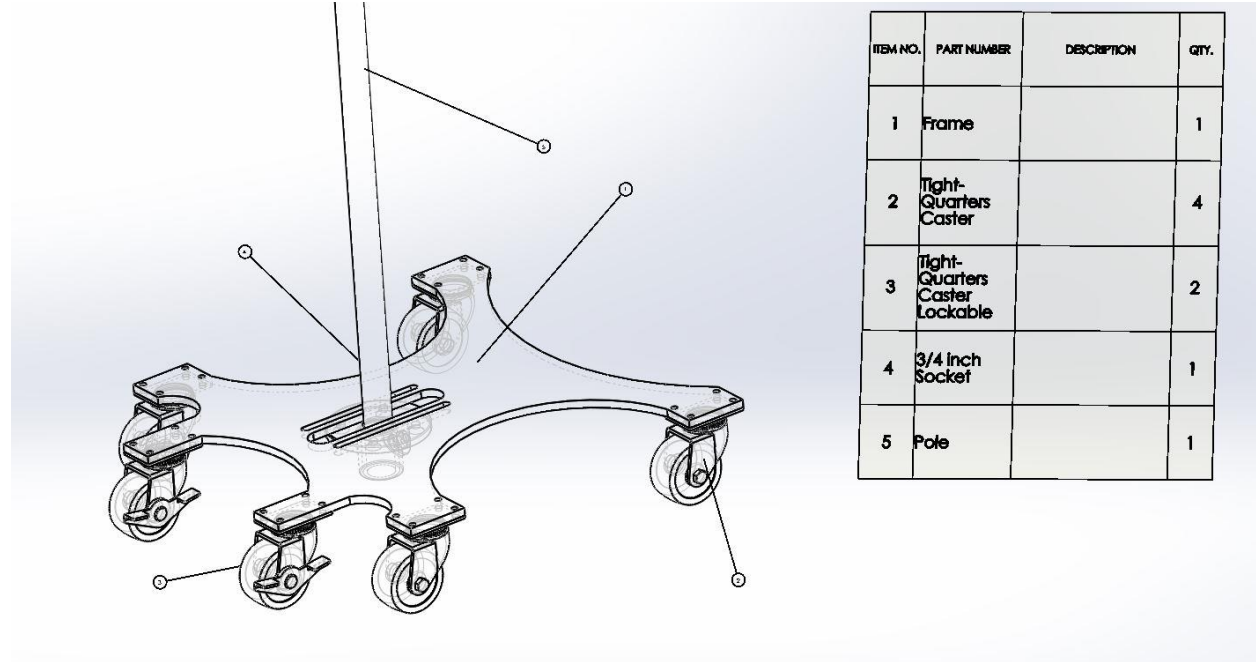


Figure 17: Isometric view of 3D model and bill of materials

5.2 EXPLODED VIEW

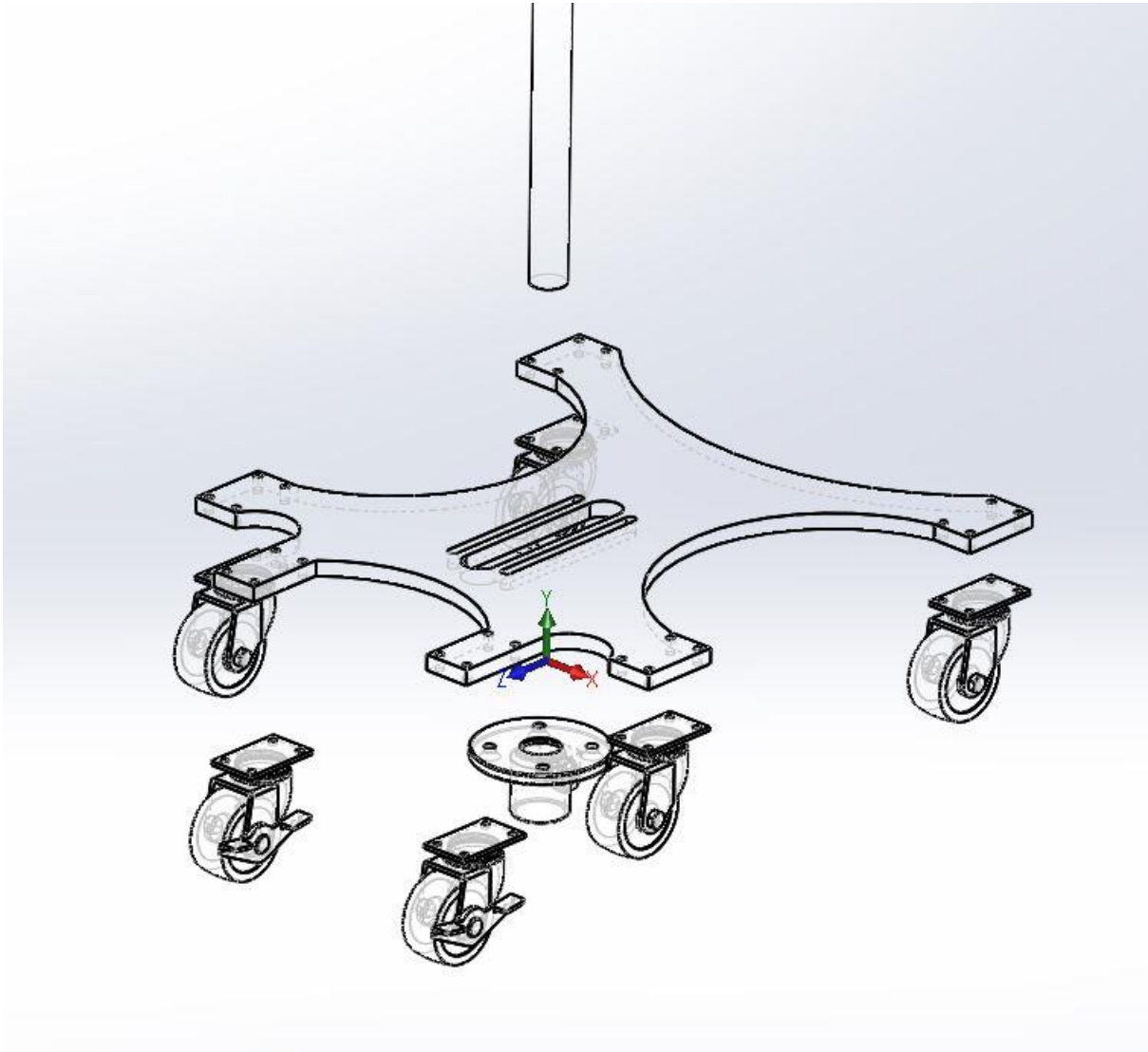


Figure 18: Exploded view of prototype

5.3 ADDITIONAL VIEWS

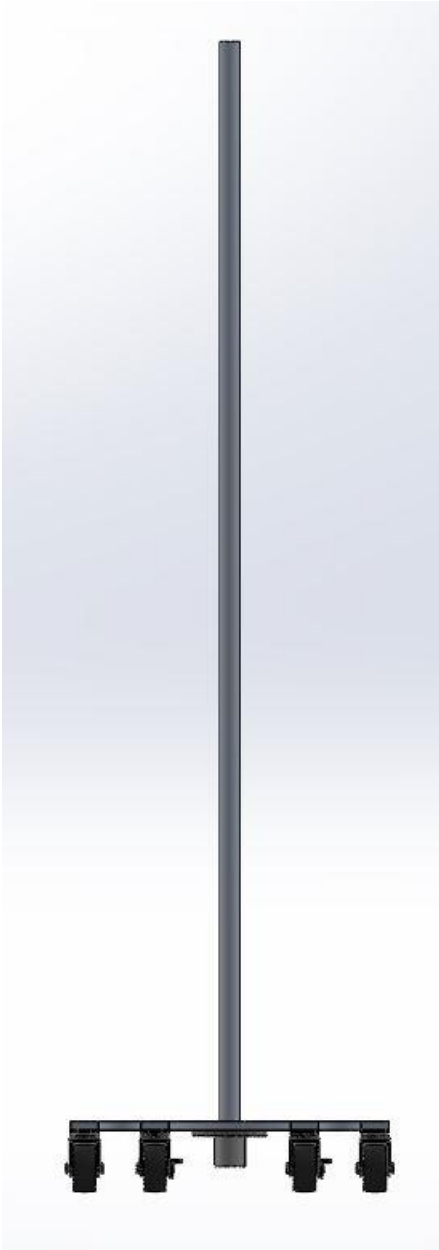


Figure 19: Front view of prototype

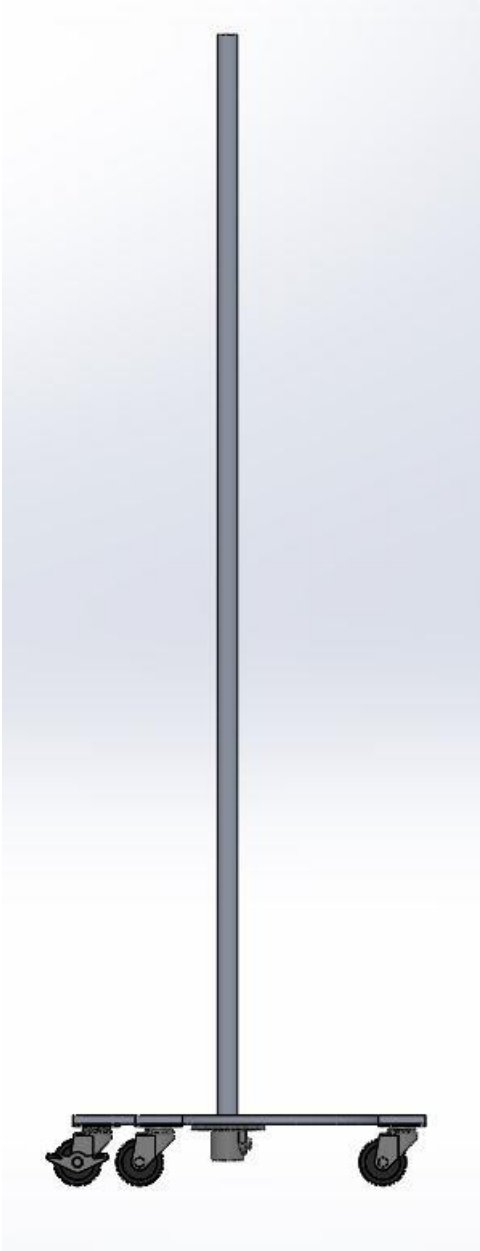


Figure 20: Right view of prototype



Figure 21: Top view of prototype

6 ENGINEERING ANALYSIS

6.1 ENGINEERING ANALYSIS RESULTS

6.1.1 Motivation

We performed stress and displacement analysis on our base because we needed to check that the base was stable enough to meet our performance goals. For stress, we did not want the base to yield under any of the predetermined loads or weights. For displacement, we did not want the base to deform too much under the preset loads and weights, because too much displacement would alter the geometry of the base, potentially weakening the stability of the entire system. The codes and standards on this field are relatively simple; they only determined factors of safety and dictated that the IV poles should not deform under certain loads. From our analysis, we got the maximum Von Mises stress and maximum allowed displacement in the plate. Using the Vin

Mises stress, we can check the yielding criteria of the plate, to make sure that the plate does not yield under the load. We expect to see that our design will easily withstand the preset loads, as the materials used are rather strong and the expected loads are small; leading to an expectation of small displacement.

6.1.2 Summary Statement of the Analysis

The engineering analysis was done using a finite element method. Basically, we used solid mechanics by assuming small deformations (strain). We also assumed no plasticity in the model. The material is assumed to be linearly elastic. From this, we exported our Solidworks model to a modeling software to place the model under the preset loads of 10 kg, from the top of the pole. Von Mises stress can be used as the yielding criteria if the Von Mises stress is less than the yielding stress. The result of the simulation yielded both the Von Mises stress, and the displacement experienced by the plate. We did not perform analysis on the rest of the IV pole, as the displacement and expended bending of the pole is negligible. Therefore, we focused on analyzing the base as it is the crux of our design. Below is a graphic depicting how to use the Von Mises stress.

https://en.wikipedia.org/wiki/Von_Mises_yield_criterion

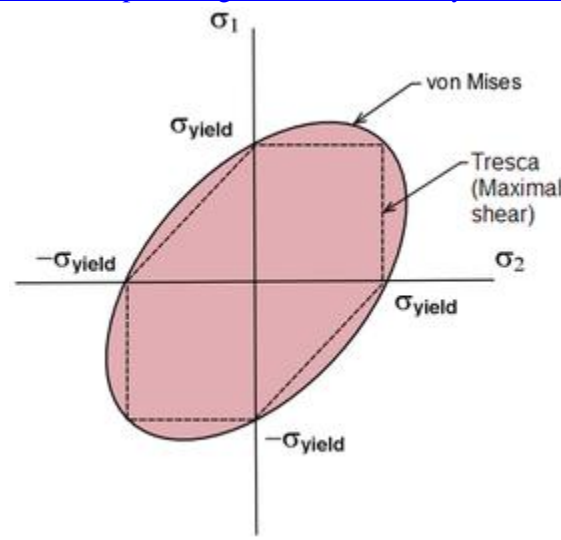


Figure 22 Von Mises yield criterion

6.1.3 Methodology

Our analysis was completely simulated, and there was no experimentation required. The program used was COMSOL. We began by uploading the 3D model from solidworks, and imported, then rebuilt the design into COMSOL. Then we set the material to be Aluminum 6063, since that is the material used in the prototype. The material properties of Aluminum used were; density = 2700 (kg/m³), Youngs Modulus = 69 GPa, and Poisson's ratio = 0.33. In the program, we used solid mechanics with the assumptions stated earlier in the previous section. We set symmetric boundary conditions to reduce the amount of computation needed, as our design was symmetric down an axis. We tested four different meshes, with increasing degrees of freedom. This was to ensure the convergence of quantities of interest (such as the Von Mises values). The degrees of

freedom are, from smallest to largest, 37161, 144831, 569043, 1466163. We set a boundary condition so that the supporting wheels could not experience shear force (shown in Figure 1 below), even though they would normally experience a normal force to support the base. The load was simulated as a distributed load around the connecting segment of the base. Specifically, it was distributed around the area that the nut of the bolt would be in contact with the base. A graphic is attached (Figure 3). The purple circles are the area over which the load is distributed. The magnitude of the loads are 100 N, but due to the symmetric nature of the analysis, the completed base would experience 200 N, or 20 kg. Finally, we set a node constraint in the Y direction to eliminate the free body motion of the plate.

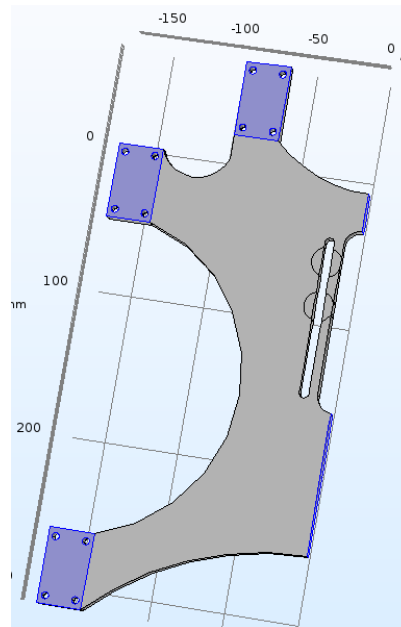


Figure 23 Supporting Wheels Boundary Conditions

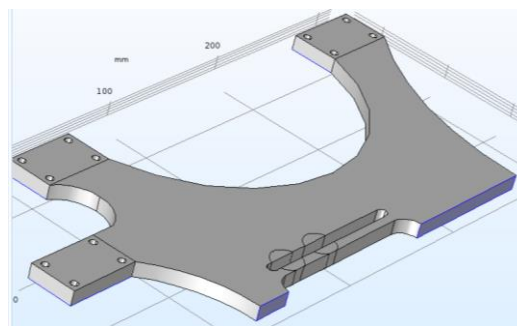


Figure 24 Symmetric Boundary Condition for Centerline

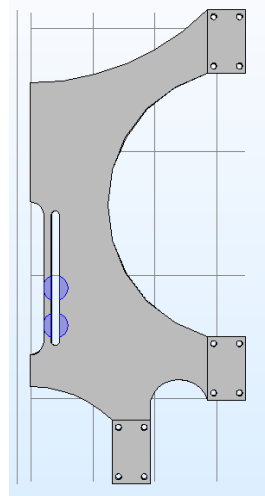


Figure 25 Load Distribution on Base

6.1.4 Results

Our result is that for a set load of 10 kg (100N), we have a factor of safety of 10. For the displacement analysis, the maximum displacement using the preset loads was close to 0.07 mm, which is certainly acceptable. This is actually performed on a half segment of the plate, because we assumed symmetry. This means, that for a load of 20 kg, our base would have a safety factor of 10 and only be displaced by 0.7 mm. Our results are well within the expected values, and make logical sense. The material is a metal and the predetermined loads are rather small, so it would have been surprising to find that an aluminum base be unable to handle the load of 10 kg. Our results show very small deformation, which is in line with our assumption that there will be small strains and no plasticity.

Table 1: Results of stress check simulation

DOF	37161	144831	569043	1466163
Von Mises Stress (MPa)	12.573	20.667	21.416	22.068
Displacement (mm)	0.068626	0.069352	0.069662	0.069918

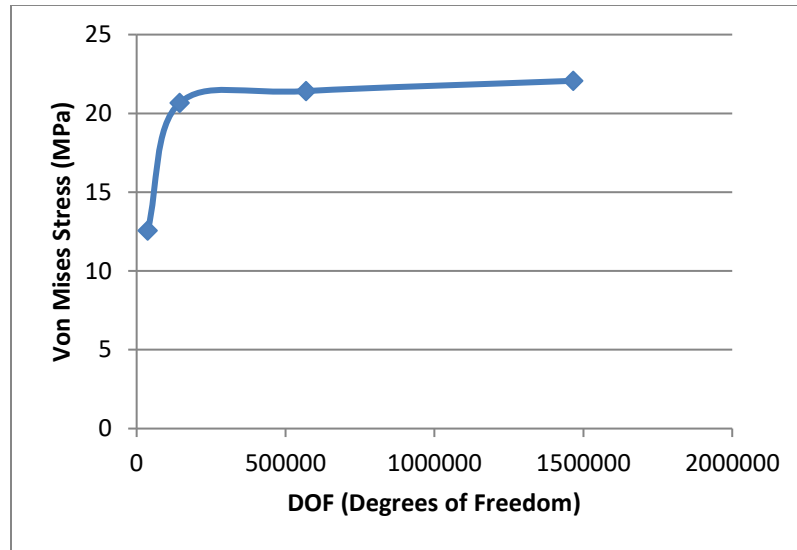


Figure 26 Von Mises Stress in relation to degrees of freedom

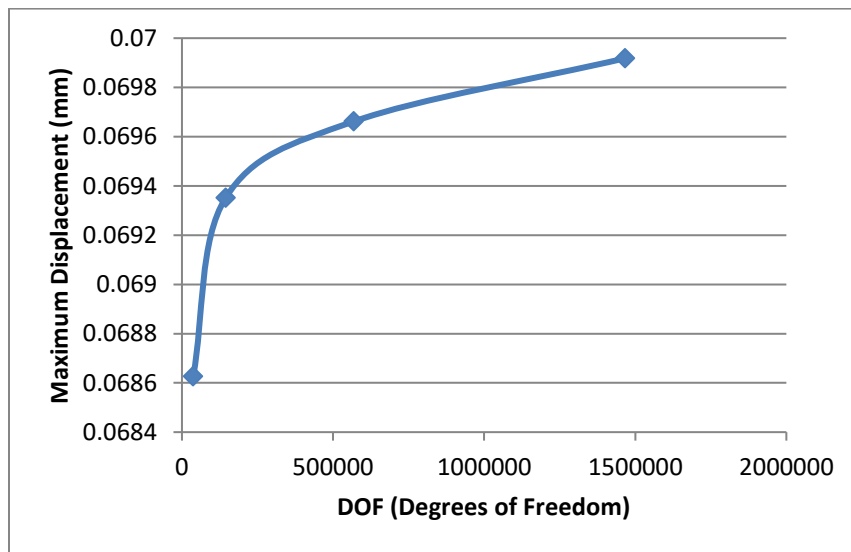


Figure 27 Maximum Displacement in relation to degrees of freedom

Above are two graphs depicting our results. As you can see, increasing the degree of freedom causes the values to converge to what can be considered their “true” values. As such, we will use the maximum DOF values.

Fig 4. From left to right – Top View Von Mises Stress Distribution, Bottom View Von Mises Stress Distribution

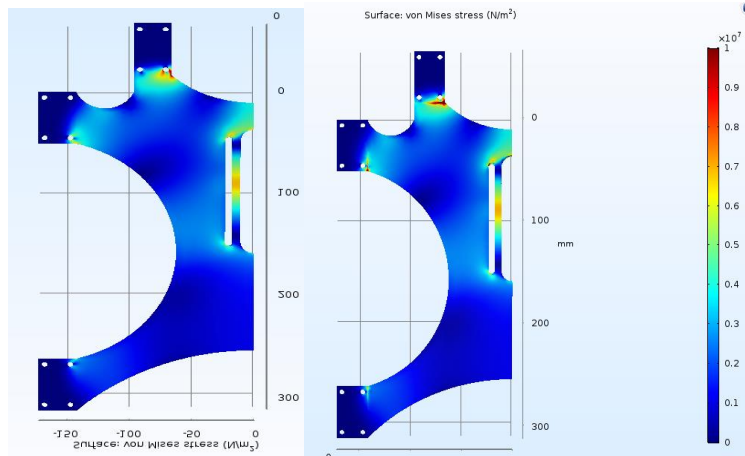


Figure 28 Displacement with a scaling factor of 270 (for visibility)

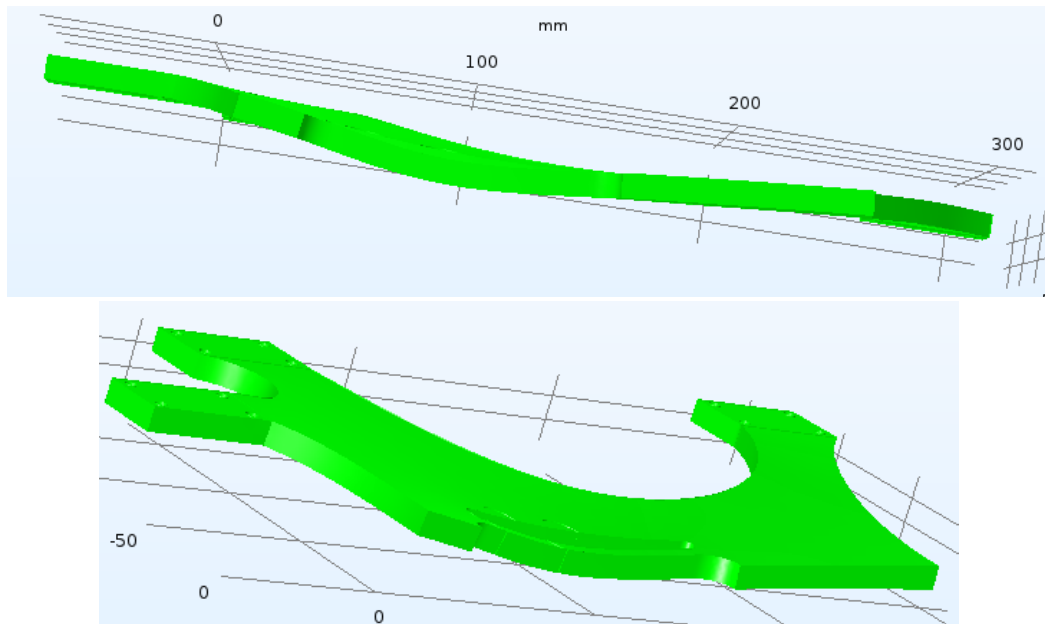


Figure 29 Split views of stress check simulation analysis

6.1.5 Significance

Looking at the stress distribution graph, we saw a concentration of stress on a screw hole near the front wheel (Figure 4). The stress magnitude is not very concerning, but we can look to alleviate the stress concentration by introducing a fillet on the design of the screw hole. Other than that minor point, our analysis was more of a check list, to make sure our design was solid. Having

found that the design is solid, we saw no need to change our original embodiment drawing. The results support that our design is good enough to meet our prototype requirements. Had there been an issue or concern, we could have looked to change the material of the base or the cross-sectional cutout to alleviate some stress, or to increase the overall yield stress. This is not the case for our design. Below is our embodiment drawing; it was not affected by our analysis so it is the same before and after.



Figure 30 Isometric view of computer aided design model of the device prototype

6.2 PRODUCT RISK ASSESSMENT

6.2.1 Risk Identification

Risk Name: Tipping over

Description: The risk is for the device to tip over from the load applied to the top of the pole. If the device were to ever become unstable and go on a tilt angle, it is possible that the added loads on the pole cause the device to tip over. This kind of failure is most likely to occur when an outside force impacts the device, creating a tilt angle. There would likely need to be an outside force that impacts the pole for this kind of failure to occur. We have designed our device such that without an initial impulse force, tipping cannot occur.

Impact: 3/4 – While there is a potential for something like denting or permanent damage, the device will most likely survive such an impact with no damage. The more important damage would occur to the IV bags or the attached pumps, which have weak connection points and are also much more fragile than the metal structure of our IV pole.

Likelihood: 3 – This is one of the more likely failures to occur, as human error is always possible and cannot be fully accounted for. However, we would like to think that the impulse needed is quite strong and it would not be easy to accidentally hit the IV pole as hard as would be needed.

Risk Name: Slipping on an inclined surface

Description: The risk is for this device to be left unattended and unlocked on a smooth inclined surface, and have the device begin to roll away. There is a feature of this device designed to combat this failure, which are the lockable back wheels. If there is a need for the caregiver or patient to step away from holding onto the IV pole, say to have a conversation, then the user can lock the back wheels so that no amount of slippage would cause the device to roll away. Also, it would be recommended to not use our device on such an inclined surface.

Impact: 1 – If caught before rolling too far away, the impact is minimal. However, if the rolling gets out of control, the device can actually disconnect an IV from a patient's arm, which is very annoying for both the hospital and the patient, as a process to reinsert the needle will be required. Still though, no permanent damage is expected.

Likelihood: 2 – If left unlocked, on an inclined surface that is steep enough, this failure will occur, with certainty. However as this is such a basic failure, any experienced caregiver or patient will have this in mind and anticipate the likelihood, so it can be expected that this will not be a major issue.

Risk Name: Material failure at the connection of pole and base

Description: The risk is for the connecting point between the rod and the base to fail, causing the IV pole to break. This means that the connecting nuts and bolts either come loose, or break completely. It can be assumed that this would likely not occur in normal circumstances. There would have to be events that make this risk more likely. Such events can include; oxidation and wear through improper care, or an impact that jolts the bolts loose.

Impact: 4 – This would be very bad for the IV pole, as this risk happening would mean that the pole needs repair before being usable once again. However, the main parts of the IV pole would be salvageable, if only the screw and nuts are needed to be replaced. Still, the initial impact would render the pole unusable before repair, so it can be considered a rather serious failure.

Likelihood: 1 – There is almost no reason that the IV pole should experience the events that increase the risk factor of this failure happening. That is why we assigned it such a low likelihood.

Risk Name: Rod breaking or bending

Description: The risk is for the IV pole to break or bend under the loads applied. This is very unlikely for this to happen, as the force would have to be incredibly large. Another way for this to happen could be prior damage that builds up in a certain location, but that is still rather unlikely.

Impact: 5 – If this happens, the rod would require replacement. It would not be a matter of repair, it would be a matter of replacing a core part of the IV pole.

Likelihood: 1 – This is incredibly unlikely to occur. There is no reason our product should experience the necessary force while in a hospital setting, so it would be a shock if this were to happen to one of the poles.

Risk Name: Hooks detaching from the top of rod

Description: The risk is that the load applied to the hooks in the form of IV bags causes the hooks to detach from the rest of the IV pole. This would normally not occur, but could be possible if the cyclic load is excessively applied without extra preventative care.

Impact: 5 – It seems minor, but this risk would make the IV pole unusable as its main purpose is to hold IV bags up. Also repair would require remaking the pole part, and is not a trivial repair. Such an incident would require a hypothetical patient to get a new stand.

Likelihood: 1 – If the product is used as recommended and the load on the hooks never exceeds that of a standard IV bag, this would almost never happen. There would have to be chronic misuse, which I think can be assumed to be unlikely, especially in a professional setting like a hospital.

Risk Name: Wheels jamming

Description: The risk is that grime and dirt builds up in the axel of the wheels, causing it to jam and roll inefficiently. I believe the wheels will also deteriorate over time, but that timeframe can be considered the lifetime of this product. So, the risk here would result from improper care and cleaning.

Impact: 2/3 – Depending on how severely mobility is impacted, the impact ranges. If it is squeaky and annoying, we can consider it a minor impact that just shows that the device needs maintenance. However, if the mobility is severely impacted, the device will not be able to travel with patients as needed, meaning it will fail in one of its core duties.

Likelihood: 1 – Assuming that the product is maintained and used as recommended, this risk happening would be an irregularity. Additionally, it is a gradual effect, so at any point along the progression if the wheels are noticed, the device can be sent in for maintenance and someone can clean/oil the axels.

6.2.2 Risk Heat Map

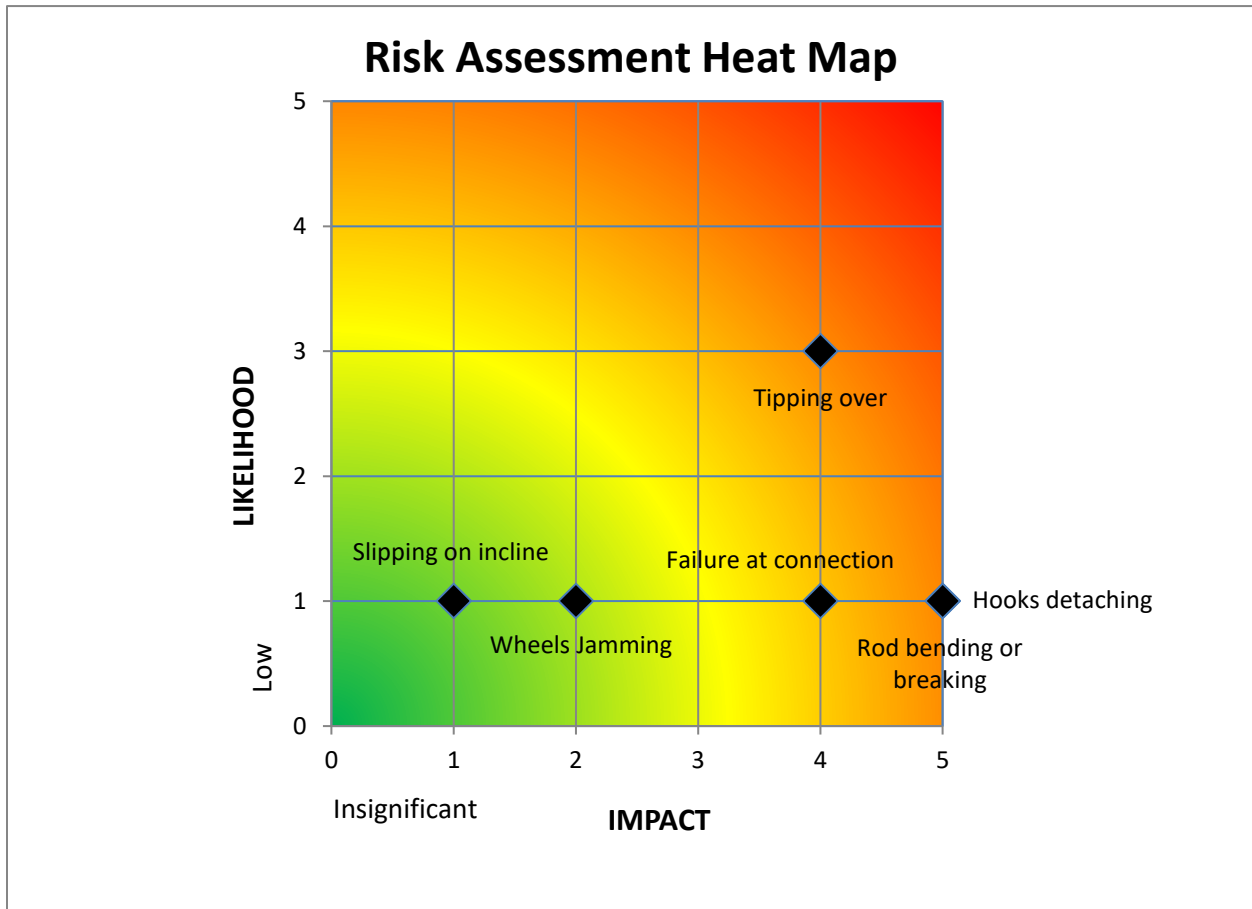


Figure 31 Risk Assessment Heat Map

6.2.3 Risk Prioritization

1. Tipping over
2. Rods bending or breaking
3. Hooks detaching
4. Failure at connection
5. Wheels jamming
6. Slipping on incline

7 DESIGN DOCUMENTATION

7.1 PERFORMANCE GOALS

1. CWVOL must be able to support a 3.15 Kg load which may be adjusted vertically 8 inches from the floor, and 8 inches from the top of the pole. Additionally, it must support a fixed 4Kg load at the top of the pole.
2. CWVOL must start rolling when oriented 15 degrees relative to a flat plane with castor wheels oriented as if rolling downhill.

3. CWVOL must be picked up and carried up a flight of stairs by a physiologically average adult American male due to the device weighing 8 kg or less unloaded.
4. CWVOL must return to vertical orientation following angular displacement of 20 degrees while unloaded.
5. CWVOL must return to vertical orientation following angular displacement of 15 degrees while fully loaded.

7.2 WORKING PROTOTYPE DEMONSTRATION

7.2.1 Performance Evaluation

The prototype functioned as desired, meeting all requirements.

7.2.2 Working Prototype – Video Link

https://www.youtube.com/watch?v=_6Luy_D8kRc&feature=youtu.be

7.2.3 Working Prototype – Additional Photos



Figure 32 Isometric view of fully loaded prototype

8 DISCUSSION

8.1 DESIGN FOR MANUFACTURING – PART REDESIGN FOR INJECTION MOLDING

8.1.1 Draft Analysis Results

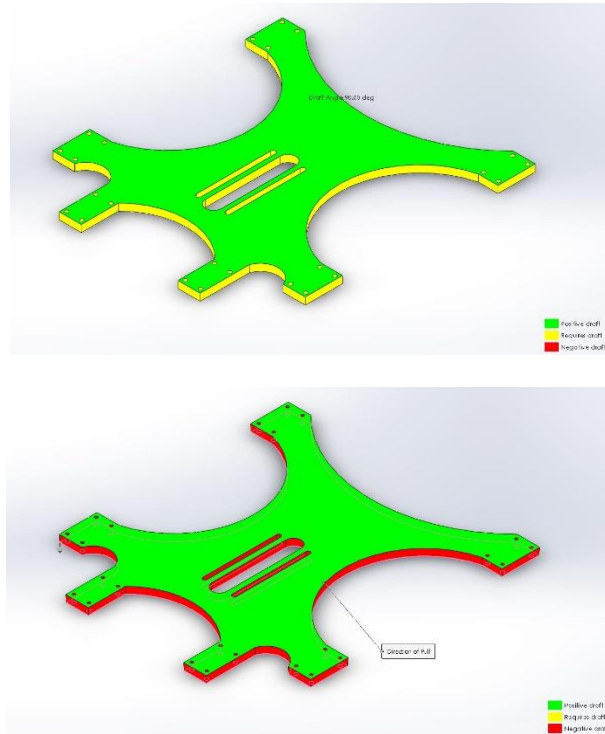


Figure 33 Before and after images from draft analysis

Before and After Images from draft analysis. Image generated using Solidworks and screenshots.

8.1.2 Explanation of Design Changes

It can be considered that our part is designed for milling; for a manufacturer to start from a flat plate and machine down to the final product. The general trend for parts is that the higher the volume of production, the cheaper it is to cast, and eventually it becomes more efficient to cast. However, our part is entirely a flat plate with some steady cross-sectional cut outs, so even at extremely high volumes of manufacture, it would be cheaper to machine over casting.

As expected, the draft analysis did not change the design much, or at all. This is in accordance with the expectation that milling will always be preferred over casting.

8.2 DESIGN FOR USABILITY – EFFECT OF IMPAIRMENTS ON USABILITY

8.2.1 Vision

Vision impairment will not affect the use of our device at all. If the impairment was so bad that the patient needed it, a caretaker would be assigned and the device would continue to be used as recommended, and safely.

8.2.2 Hearing

Hearing impairment will not affect the use of our device at all. If the impairment was so bad that the patient needed it, a caretaker would be assigned and the device would continue to be used as recommended, and safely.

8.2.3 Physical

Physical impairment will affect the use of our device, as it needs to be manually pushed around. However, because it has wheels, not a lot of strength is needed to operate it. If the patient's impairment were severe enough to need help, a caretaker would be assigned and it can be assumed that the patient would have minimal contact with the device. If the patient still needed to operate it however, there is no way for the device to harm the patient or the patient to misuse the device so badly that anyone is injured.

8.2.4 Language

Language impairment will not affect the use of our device at all. If the impairment was so bad that the patient needed it, a caretaker would be assigned and the device would continue to be used as recommended, and safely. But in no way would a language impairment affect the use of our device.

8.2 OVERALL EXPERIENCE

8.2.1 Does your final project result align with the initial project description?

The final product aligns with the initial project description.

8.2.2 Was the project more or less difficult than you had expected?

The project was neither more nor less difficult as was foreseen in the initial stages of development. Additional issues would have come up had access to a water jet cutting table been restricted, which would have severely limited manufacturability of the final prototype.

8.2.3 In what ways do you wish your final prototype would have performed better?

The prototype performed as desired, meeting all requirements. If required to specify areas of improvement, it would be ideal to have an even higher angle of tilt demonstrated for both a loaded and unloaded device before it tips over.

8.2.4 Was your group missing any critical information when you evaluated concepts?

The group was not missing any critical information when we evaluated concepts.

8.2.5 Were there additional engineering analyses that could have helped guide your design?

There was no additional engineering analysis which could have helped in the guiding of our design.

8.2.6 How did you identify your most relevant codes and standards and how did they influence revision of the design?

The most relevant codes and standards were identified in relation to the application of the device in a medical setting, which would entail a desire on the part of the healthcare provider to readily maintain a clean and safe environment for the patient. The base of the device was constructed from 6061 aluminum, and the IV pole was made of stainless steel. Materials such as cast iron are also used in similar medical devices, but they require coatings and other chemical treatments to maintain sanitary conditions. Though

being less expensive than the materials used in our device, they were excluded in lieu of the materials we used, which do not require such treatments.

8.2.7 What ethical considerations (from the Engineering Ethics and Design for Environment seminar) are relevant to your device? How could these considerations be addressed?

The materials from which the device is made are readily sourced from conflict-free zones, and bear no lasting deleterious environmental effects, all of them being recyclable. The device uses no paints or toxic chemicals as coatings, opting instead for non-corrosive materials which may be sterilized in a steam bath.

8.2.8 On which part(s) of the design process should your group have spent more time? Which parts required less time?

The optimal shape of the base could use further design work, though further work would take the form of modeling various geometries to optimize various conditions such as the distribution of stresses vs. stability. The IV pole itself took very little time, as it is a stock model used in wheelchairs and was purchased through Amazon.

8.2.9 Was there a task on your Gantt chart that was much harder than expected? Were there any that were much easier?

The writing of the utility patent is proving to be a very challenging and time-consuming process. The actual construction of the device took about 4 hours in total, which was much less than we had budgeted for.

8.2.10 Was there a component of your prototype that was significantly easier or harder to make/assemble than you expected?

The frame of the device was easy to make in that we used a water jet cutting table to cut the shape out of an 18x18", 0.375" thick sheet of 6061 aluminum in less than 20 minutes.

8.2.11 If your budget were increased to 10x its original amount, would your approach have changed? If so, in what specific ways?

Had our budget been increased in such a way, we would have cut the frame of the device out of a larger sheet of aluminum, though just as thick. We would also have changed the geometry of the frame of the device to address the enlarged shape and newly applied stresses.

8.2.12 If you were able to take the course again with the same project and group, what would you have done differently the second time around?

Had the stress analysis been conducted earlier on in the design process, more changes could have been made to the frame of the device. In retrospect, there was little need to postpone this analysis in the design process until it was conducted.

8.2.13 Were your team member's skills complementary?

Our team was exceptionally well functioning, and the skills of our members complemented one another nicely.

8.2.14 Was any needed skill missing from the group?

A law student specializing in patent law would have been useful in the writing of the utility patent for the device.

8.2.15 Has the project enhanced your design skills?

The project has enhanced my design skills, through certification in the use of the waterjet cutting table. Additionally, the use of simulating software other than Solidworks brought new aspects to the design process.

8.2.16 Would you now feel more comfortable accepting a design project assignment at a job?

Yes, specifically in the application of these design processes in designing and building devices to be applied in the medical field.

8.2.17 Are there projects you would attempt now that you would not have attempted before?

Yes, the use of a waterjet cutting table and simulating software to provide a reasonable estimate of device performance pre-testing has opened up new avenues for future projects to progress to successful completion.

9 APPENDIX A - PARTS LIST



630-600-3600
 630-834-9427 (fax)
 chi.sales@mcmaster.com

Receipt

Billed to
 ATTENTION: JOHN CASHIN
 JOHN CASHIN



Shipped to
 John Cashin



Purchase Order	PARTS LIST
Paid	\$198.68
Invoice	48277080
Invoice Date	10/17/17

Information About Your Payment



John Cashin placed this order.

Line	Product	Ordered	Shipped	Balance	Price	Total
1	4936T186 Galvanized Iron Slip-on Rail Fitting, 3-1/8" Flange Diameter Rail End for 1" Rail OD	1 Each	1	0	8.69 Each	8.69
2	22785T41 Tight-Quarters Swivel Caster with 2" Diameter Soft Rubber Wheel	4 Each	4	0	3.43 Each	13.72
3	22785T46 Tight-Quarters Swivel Caster with Brake and 2" Diameter Soft Rubber Wheel	2 Each	2	0	4.48 Each	8.96
4	90604A242 Stainless Steel Combination Slotted/Phillips Rounded Head Screws, 10-24 Thread Size, 1/2" Long, Packs of 50	1 Pack	1	0	4.95 Per Pack	4.95
5	90585A358 316 Stainless Steel Hex Drive Flat Head Screw, 82 Degree Countersink Angle, 1/4"-20 Thread Size, 5/8" Long, Packs of 10	1 Pack	1	0	4.06 Per Pack	4.06
6	94842A101 Medium-Strength Steel Flange Nut, Grade 5, Zinc-Plated, 1/4"-20 Thread Size, Packs of 100	1 Pack	1	0	8.14 Per Pack	8.14
7	89155K28 Oversized 6061 Aluminum Sheet, 3/8" Thick, 18" x 18"	1 Each	1	0	134.00 Each	134.00
8	93776A391 18-8 Stainless Steel Serrated Flange Locknut, 10-24 Thread Size, Packs of 50	1 Pack	1	0	4.90 Per Pack	4.90

Merchandise	187.42
Shipping	11.26
Total	\$198.68
Payment Received 10/18/17	(198.68)
Balance Due	\$0.00

Packing List	Shipped	Weight	Carrier	Tracking
2143626-01	10/17/17	19 lb	UPS Ground	1Z6028360338197153

Federal ID 36-1458720

McMaster-Carr Supply Company

Page 1 of 1

Figure 34: Parts list from McMaster-Carr.



Final Details for Order #114-7589566-7081828
[Print this page for your records.](#)

Order Placed: October 17, 2017
Amazon.com order number: 114-7589566-7081828
Order Total: \$33.88

Shipped on October 18, 2017	
Items Ordered 1 of: Drive Medical Universal Wheelchair Telescoping I. V. Pole Sold by: Amazon.com LLC Condition: New	Price \$33.88
Shipping Address: John Cashin [Redacted]	Item(s) Subtotal: \$33.88 Shipping & Handling: \$0.00 ----- Total before tax: \$33.88 Sales Tax: \$0.00 -----
Shipping Speed: Two-Day Shipping	Total for This Shipment: \$33.88 -----
Payment information	
Payment Method: [Redacted]	Item(s) Subtotal: \$33.88 Shipping & Handling: \$0.00 -----
Billing address John Cashin [Redacted]	Total before tax: \$33.88 Estimated tax to be collected: \$0.00 -----
	Grand Total: \$33.88
Credit Card transactions	[Redacted] October 18, 2017: \$33.88

Figure 35: Image from Amazon showing ordered IV pole.

10 APPENDIX C - CAD MODELS

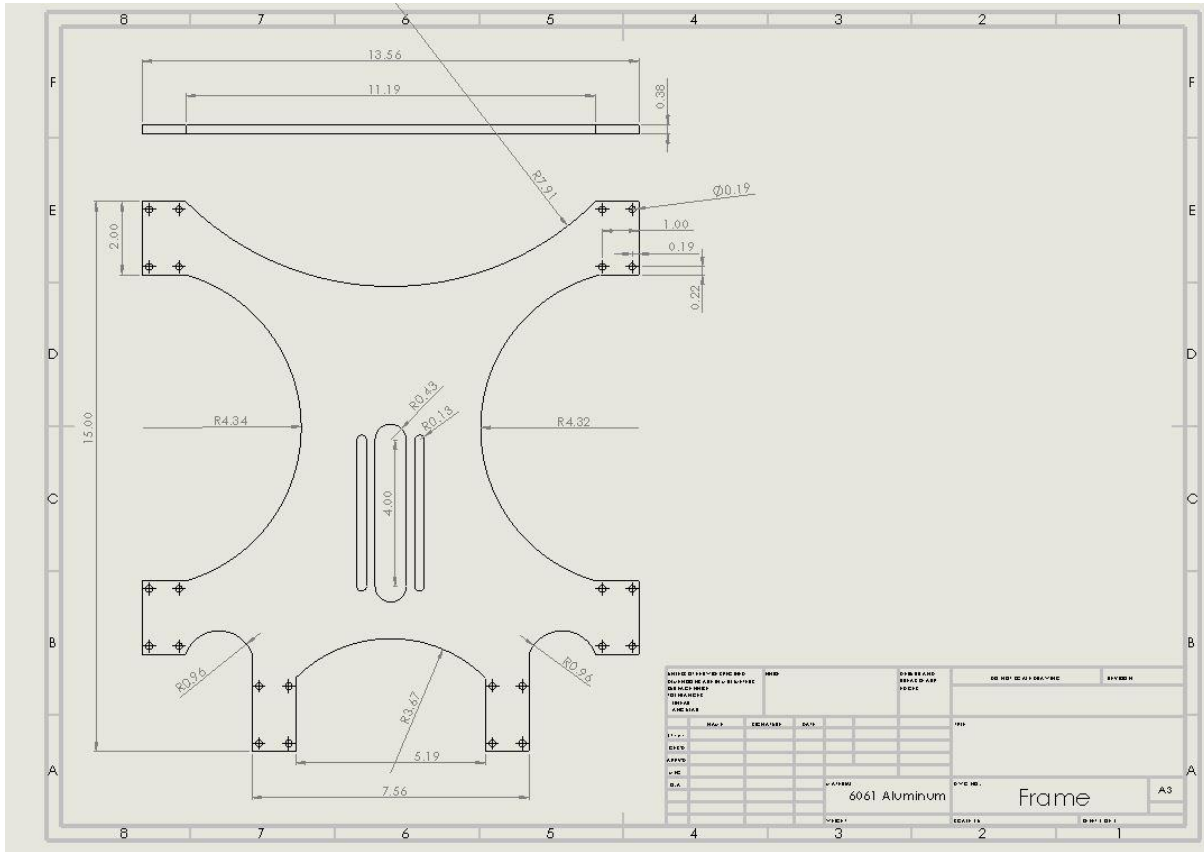


Figure 36: Dimensioned drawing of frame to be fabricated

11 ANNOTATED BIBLIOGRAPHY