Accessible Weight Scale for Seated Users
Project B38
Final Report

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"TAKING A STAND,
SO THAT OTHERS CAN SIT"

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Project Objective Statement:

Design an accessible toilet seat weight scale able to monitor daily weight fluctuations of seated users by May 1, 2008, with a budget of $2,000.

Background:

There are products currently on the market that are accessible to seated users (i.e. wheelchair users, users with balance issues and other disabilities). These scales meet the needs of seated users in a healthcare facility setting. They are not useful, however, for users who require weight monitoring on a daily basis. For these people it would be beneficial to have an accessible scale that is affordable and intended for in-home use.

The competition idea for a toilet or shower seat weight scale was inspired by the 2004-2005 weight scale competition entry by Catholic University design team composing of: Thomas Seacrist, Lindsay DiRomualdo, Gowhar Iravani, Matthew Carnavos, and Binh Tran, PhD (Faculty Advisor).[1]

Design Competition Guidelines:

Problem:

Many people with health problems experience frequent weight fluctuations and would benefit from daily weight monitoring but are not able to use traditional standing scales. Wheelchair-accessible weight scales on the market today are generally larger in size and more expensive than traditional standing scales, making them less accessible for in-home use.

[1] http://www.rerc-ami.org/ami/projects/d/2/2/year2/

Project Aim:

Design an affordable and easy-to-use weight scale that is integrated into a standard toilet seat, for home use. The device may also offer support to individuals for transferring on and off.

Project Specifications:

The weight scale should be accurate (to 1/5 pound), capable of weighing 500+ pounds, have a display that can communicate multiple stored readings, contain integrated balance aides (e.g., hand rails, grab bars), make a weight measurement within 10 seconds, and provide output in multiple modal formats. The weight scale should be easy to power, operate, and sanitize.[2] The product must also meet the needs of the individuals on the hypothetical client list provided.

Applicable Standards:

ASTM F446-85 Consumer Safety Specifications for Grab Bars and Accessories Installed in the Bathing area

1.1 This consumer safety specification covers performance requirements, test methods, and levels of performance to ensure satisfactory functioning of the grab bars and accessory items (not including plumbing controls) during reasonable use to assist a person entering, leaving, or moving within the bathing area.

1.2 This consumer safety specification is intended to reduce the number of accidents by specifying requirements for grab bars and accessories designed to decrease the probability of slips and falls.

1.5 The following precautionary caveat pertains only to the test method portion, Section 7, of this specification. This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Regulatory Issues:

This device would be classified as a Class 1 medical device according to the FDA. Class 1 devices present the least risk to the patient. Although an identical device does not yet exist, we decided upon this classification based on the classifications of similar devices such as manual wheelchairs, walkers, and weight scales. This Class 1 classification should apply since our product is a combination of components similar to those seen on wheelchairs and in weight scales.

[2] http://www.rerc-ami.org/ami/projects/d/2/2/announce/index.aspx

Generated Design Concepts:

Option #1:
Option #1 combines:

- LCD display
- Printed record of weight readings
- Arm balance aids that are attached to the sensing mechanism
- Straight bar foot balance aid
- Strain gage sensors
- Five sensors placed at intervals around the sensing mechanism
- Overall placement between the toilet seat and toilet rim

Option #1 allows for the sensor mechanism to be placed conveniently between the seat and rim, therefore not hindering movement of the toilet seat. Using as many strain gage sensors as needed (estimate: 5) will allow the product to weigh individuals up to 500 lbs accurately. Having the balance aids attached to the sensing mechanism allows the user to stay in contact with the aids while still receiving a correct weight reading.

Option #2:
Option #2 combines:

- LCD display
- Memory card for storage of weight readings
- Arm balance aids that are attached to the sensing mechanism
- Separate right and left foot balance aids
- Strain gage sensors
- Five sensors placed at intervals around the sensing mechanism
- Overall placement as a replacement of the normal toilet seat

Option #2 has the sensor mechanism built as a replacement for a normal toilet seat. Using as many strain gage sensors as needed (estimate: 5) will allow the product to weigh individuals up to 500 lbs accurately. Having the balance aids attached to the sensing mechanism allows the user to stay in contact with the aids while still receiving a correct weight reading. Having the balance aids coupled to the sensor mechanism will make the product cumbersome to move if the seat needs to be lifted or moved.

Option #3:
Option #3 combines:

- LCD display
- Memory card for storage of weight readings
- Arm balance aids that are attached to the ground
- Straight bar foot balance aid
- Strain gage sensors
- Five sensors placed at intervals around the sensing mechanism
- Overall placement as a replacement of the normal toilet seat

Option #3 has the sensor mechanism built as a replacement for a normal toilet seat. Using as many strain gage sensors as needed (estimate: 5) will allow the product to weigh individuals up to 500 lbs accurately. The arm balance aids are attached to the ground so the user must let go of them in order to get a correct weight reading. Having the arm balance aids attached to the ground will make the sensing mechanism easier move if the seat needs to be lifted or adjusted.

Option #1 was chosen as our final design and the basis for our prototype.

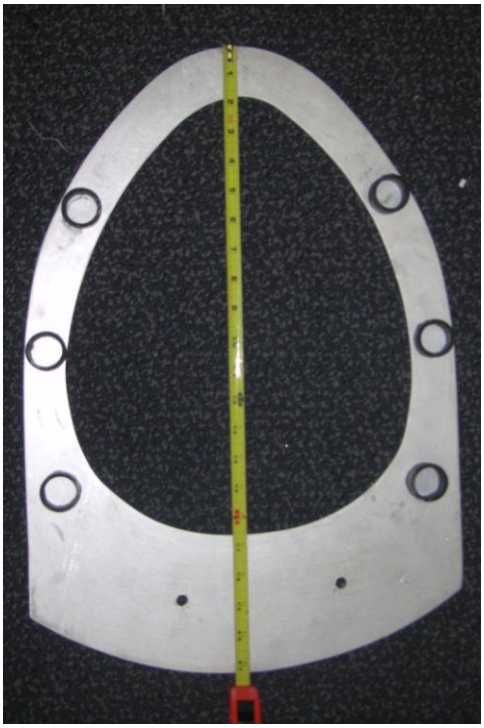
Functional Characteristics of the Final Design:

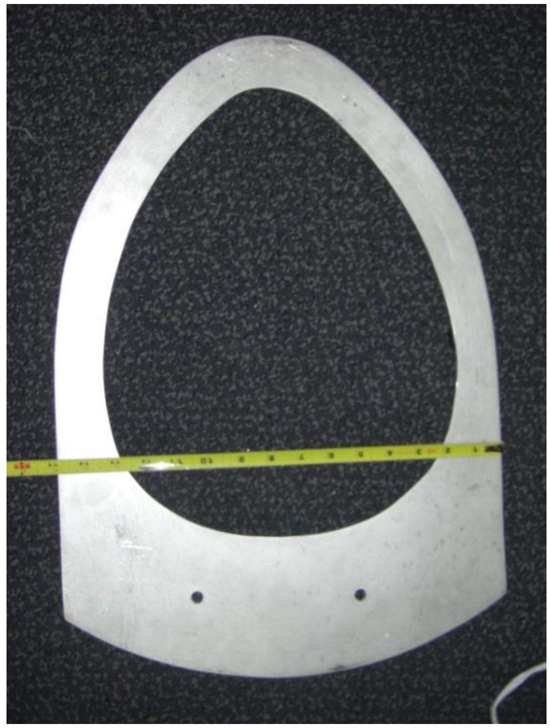
Mechanical System Description:

The current prototype is composed of two ¼ inch thick aluminum plates that will eventually have sensors between them to measure a subject's weight. There are two arm rests, also made of ¼ inch thick aluminum, that use a four bar mechanism attached to the top plate. There is cushioning where the subject's arm will come in contact with the mechanism. There is also a leg rest, made of ¼ inch thick hollow aluminum bar, attached to the top plate with cushioning where the subject's feet will be placed. Both the arms and leg apparatus are being mildly improved from the version that is shown in the image. Locks were added to secure the arm rests in fully upright and partially upright positions.

Mechanical Components

Length of plate: Width of plate:

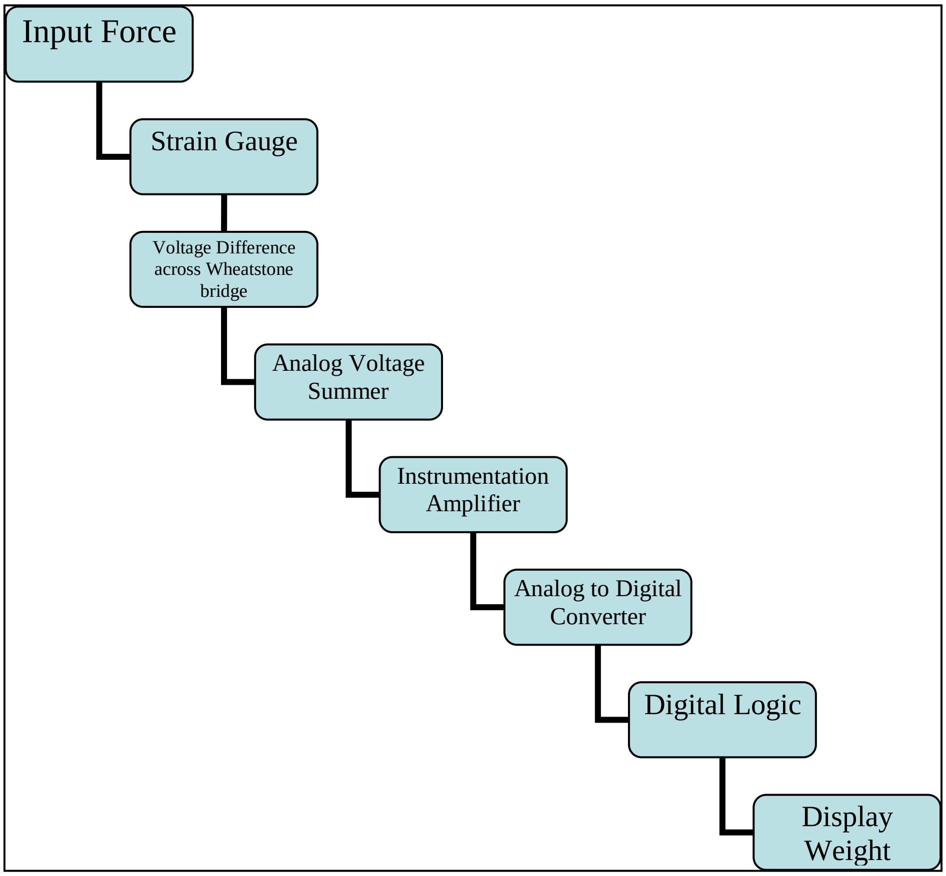




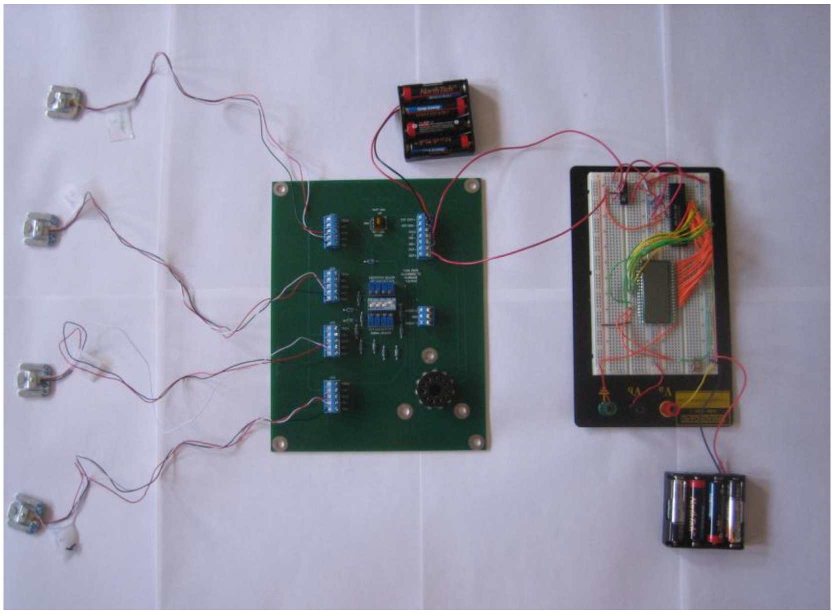
Total height of system:

First Electrical System Description:

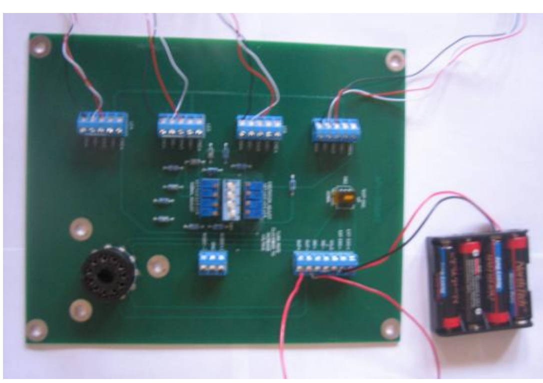
The logical process of incorporating the strain gauges into our system is shown below as a step process of the system that we wanted to use to handle our weights.

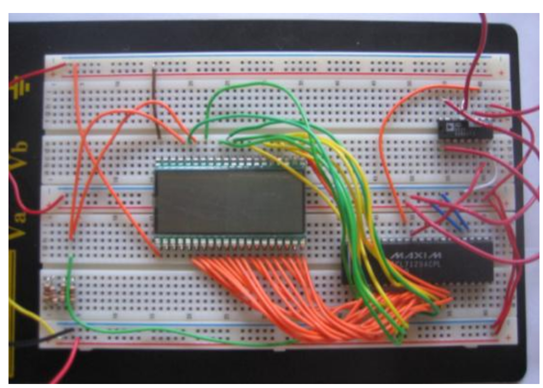


The electrical system is composed of four strain gage sensors taken from a "Biggest Loser" scale. The sensors are set up as a half Wheatstone bridge with a 1 kΩ resistance across each strain gage and a 2 kΩ resistance across both strain gages. The strain gages are connected to a circuit which contains the other half of the Wheatstone bridge. The strain gauges, when put into a Wheatstone bridge, will change the output voltage across the bridge when a force is applied to them. We needed to take that voltage and change the small signal, on the mV level, into a cleaner larger signal that we could adjust easier. To do this an instrumentation amplifier would be the best choice for amplification and signal conditioning. After the signal would be amplified we would use an A/D converter to change the analog voltage in to a digital signal so that we can use digital logic circuits to then display our final weight. Instead of using our own resistors and potentiometers to create the bridge circuits needed for summing we decided to use the API SUM-000 summing board which sums the voltages from each of our four strain gauges and is easy calibrate with the provided potentiometers on the board.

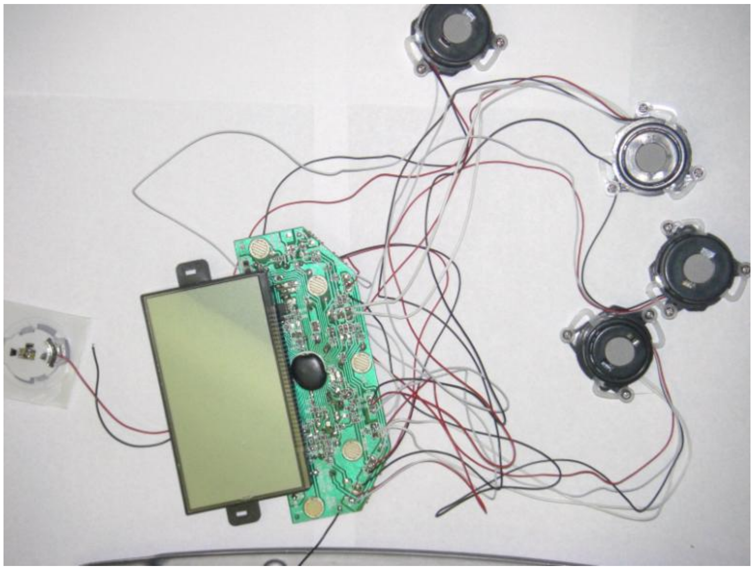


From this summed signal we then used the AD625JN from Analog Devices. This chip is a Programmable gain Instrumentation Amplifier with a 16 DIP interface. We needed to have an amplifier that we could program our own gain into so that we could change our voltage to a weight. We would find out the slope of our Weight to Voltage curve after testing and use that to calibrate the voltage. This amplifier also has a very good noise protection to condition the signal into a more crisp and precise signal. From here we needed to convert the voltage into a digital signal and send that to a digital display driver. We decided to do this in one step with the ICL7129 from Maxim Electronics, which is a analog to digital converter and a 4-1/2 digit display driver. This micro controller will convert the voltage to digital and then send it through a decoder and a multiplexer to properly drive our LCD display. For our external excitation in the circuit we used two sets of four battery holders. Each battery is 1.5 V and they are all connected in series giving is a total of 6 V for each pack. This voltage will be applied to the summing board, the display and chips as the power source.





Final Electrical System Description:



Some of the integral parts for our first electrical system were held up during shipment and held in customs for a little longer then a week, which put us behind schedule. After finally receiving our parts we spent a large amount of time wiring the components together and incorporating them into our summing system only to find that we could not get it to read properly. With only a couple of weeks left until the project deadline, our team decided to implemented our backup plan. We used the entire electrical system from one of the scales that we had purchased. We had already done testing on all of the sensors so that we knew they would be linear. Instead of creating our own circuit board, we used the circuit board and display that came with the scale which consisted of an external 3.5 V lithium battery connected to the board. The board also has an operational amplifier along with numerous resistors and capacitors which make up the bridges and regulators for the voltages in the system. These are sent to a central microcontroller which drives the LCD display attached to the board. We then implemented this electrical system into our mechanical system.

Customer Needs:

Interaction With Customers:

We identified our customers as people who need to be weighed often and who cannot use a traditional standing scale. Our customers also include the caretakers of potential users of seated weight scales. This includes nurses, healthcare providers, assisted living aids, etc.

For our interviews, we sent an e-mail to an employee of IndependenceFirst, which is a center for people with disabilities. After explaining our product, she was able to send out an e-mail to the IndependenceFirst community. Two people replied and were willing to share their opinions through a phone interview. We also contacted several nurses via e-mail. We received a reply from one nurse and we are waiting on replies from five more. We also contacted family members who would be potential customers and interviewed them over the phone. One interview was done in person with a rehabilitation engineer from the Medical Device Usability and Accessibility Lab at Marquette University.

According to the design competition guidelines our project should satisfy the needs of a hypothetical client list. We made a brief list of the disabilities of these clients and took them into consideration when developing and ranking the needs statements.

Interview Questions:

1. What is your name, profession, disability, etc?

2. How do you normally get weighed (or weigh patients)? How often? How often do you think you should be weighed?

3. What do you like/dislike about this method? (any adaptive equipment used that is helpful, etc.

4. What do you like/dislike about the equipment or method you currently use for showering and/or ‘toileting’?

5. What features would you like to see in the display? (movable vs. fixed, location, maximum amount of time for a reading, audible readout, etc.)

6. From what you have heard about our product, what is(are) the most important feature(s) you would like to see included?

7. Would you buy this product if it were more expensive than a traditional scale? If it were larger? (etc.)

8. After hearing a little about our product, are there any improvements you would like to add?

9. Do you have any additional comments?

Ranking of Needs Based on Interview Responses:

Safety:

***Scale is able to be used while sitting with grab bars for balancing.
!Scale is comfortable and safe.
**Scale has adjustable hand rails for loading and unloading users.
**Scale is easily fixed by users.
*The scale has nothing to step over.
*The scale has a footrest similar to a wheelchair.
***Scale is safely secured with grab bars and hand rails.
**Toilet seat is raised for easier access on and off of scale.
***!Scale is safe with no potential hazards existing.

Sanitation:

***The scale is sanitary.
**The scale is easy to clean.

Accessibility:

**The scale has a wider platform and is easier to balance with side rails.
***Scale is accessible to all types of patients.
***Scale is easy to maneuver on and off of.
**Scale is accessible at all times of the day.
*The scale can be used as often as desired.
**Scale has one side open for easy access.

Cost:

***Scale is affordable to all users.
*Scale is more expensive then standing scale if easier to use.
The scale is cheaper than a traditional scale.

Display:

**Scale has large numbers for easy reading.
**The scale has a bright display.
**Scale has moveable display and fast weight readout.
***The scale is accurate.
*The scale has the capability to perform audio readings.
**The scale has a display that is placed in the user's desired position.
***The scale has a visible, fixed display.
*The scale displays weight in 3 to 4 seconds.
*Scale displays current weight and an average for the week.
**Scale has a daily readout of weight measurements for the past 24 hours.

Aesthetics:

***Scale is small enough to fit into a normal size bathroom.
***The scale is accessible in size.
*The scale is easy to detach and store.
***The scale can be used as a normal toilet seat.
*The scale is aesthetically pleasing and durable.

*The lid of the raised toilet seat has the ability to be closed
**The foot rest folds for storage when scale not in use.
*The scale system is the size of a normal sized household toilet.
*Scale is portable.
*There are several scales to be used for several patients.
**Scale is adaptable to take things such as braces off.
***The original toilet seat is replaced by scale.

Needs Based on Hypothetical Client List:

Client Name	**Customer Statement**	**Interpret Need**
Phylis is an active 77-year-old woman with rheumatoid arthritis who also has age-related macular degeneration and hearing loss.	Needs a scale that has loud audible and large display readings.	Scale has large display reading and audible weight reading.
	Scale should be easy to use by all.	Scale is easy to use.
Aaron is a 23-year-old man, a returning Iraq war veteran, with an arm amputation above the elbow, chronic neck pain and recurring headaches.	Scale must be easy to get on and off of.	Scale is easily accessible.
	Scale must have good support for balance.	Scale has arm rails for support.
Keisha is an 84-year-old woman who recently had a stroke, She has also experienced some memory loss after the stroke, had minor hearing loss	Scale should have a readout for users to remember there weight.	Scale has a daily readout of weight measurements for the past 24 hours.
	Scale should have large display reading.	Scale has large weight display.
Jerry is an 82-year-old man with Parkinson's disease, he also has difficulty with urinary control.	Scale should be easy to clean.	Scale is sanitary and easy to clean.

Jamie is a 42-year-old woman with a T11 spinal cord injury. She would like to have better control of her urinary function while participating in athletic activities.	Scale should be easily accessible. Should be able to get onto and off of like any other handicap toilet seat.	Scale is easily accessible.
	Toilet seat should be raised.	Scale has a raised toilet seat.
Betty is a 65-year-old woman who has limited and asymmetrical lower extremity range of motion due to a bad hip.	Scale should be easily accessible.	Scale is easily accessible.
Violet is a 32-year-old woman of short stature who is on blood pressure medication.	Scale should be easy to get onto and off of.	Scale is easily accessible.
Paul is a 43-year-old man with diabetes. The diabetes has caused neuropathy in his hands and feet, which eventually necessitated two below-the-knee amputations, and some loss of vision.	Scale should be able to be used by patient with no legs.	Scale should be easy to use for all types of patients.
	Scale should have audible readout of weight.	Scale has audible readout of weight measurements.

Summary of Key Needs:

Scale is able to be used while sitting with grab bars for balancing.
Scale is safely secured with grab bars and hand rails.
Scale is safe with no potential hazards existing.
The scale is sanitary.
Scale is accessible to all types of patients.
Scale is easy to maneuver on and off of.
Scale is affordable to all users.
The scale is accurate.
The scale has a visible, fixed display.
Scale is small enough to fit into a normal size bathroom.
The scale is accessible in size.
The scale can be used as a normal toilet seat.

Customer Needs Addressed by Final Design:

The following are the most important customer needs (in bold) along with how they were addressed by our final design:

Scale is able to be used while sitting with grab bars for balancing
Scale is safely secured with grab bars and hand rails
Scale has adjustable hand rails for loading and unloading users

The final prototype incorporates grab bars that operate as a four-link mechanism so that they can be easily adjusted while sitting on the seat.

Toilet seat is raised for easier access on and off of scale

The entire sensing mechanism raises the toilet seat ___ in. from its original position.

Scale is safe with no potential hazards existing

Foam was placed over the aluminum in places where the subject will come in contact with the mechanism.

The scale is sanitary
The scale is easy to clean

The aluminum on the scale allows for easy cleaning. However, the electrical components are not encased in a water-tight unit. If the prototype was mass produced, this issue would need to be resolved. This is not major for our prototype since it is not connected to any plumbing lines and will not actually be used as a toilet.

Scale is accessible to all types of patients
Scale is easy to maneuver on and off of

The arm rests can be adjusted individually to allow for height adjustability as well as easier transfer on and off the scale. The leg rest is close to the scale so that it will not hinder transfer on and off the scale.

Scale is affordable to all users

The scale cost $600.00 to produce a working prototype. If it were mass produced and put on the market, it would cost much less. Hopefully, it would be under $200.00 and insurance would cover some of the cost.

Scale has large numbers for easy reading
The scale has a bright display
The scale has a visible, fixed display
The scale displays weight in 3 to 4 seconds

The display is a 2” LCD display with extra large number readout. The weight reading is displayed a few seconds after weight is placed on the scale.

The scale is accurate

According to testing done on the scale using known weights, there is no statistically significant difference between the weight readout and the actual weight of the object. The scale is accurate to 0.2 lbs.

Scale is small enough to fit into a normal size bathroom
The scale is accessible in size
The scale can be used as a normal toilet seat

The scale mechanism is easily attached to a common bathroom toilet in between the toilet rim and toilet seat. A toilet seat of the user's preference can be placed above the sensing mechanism. The arm and leg rests are compact and should easily fit within the space allotted in a normal bathroom.

Safety Evaluation and Risk Analysis:

Mechanical Analysis

The goal of the mechanical analysis is to ensure the mechanical components, such as the arm balance aids the sensor interface and foot rest attached to the scale to be safe for the extreme user (maximum weight allowance), when the device is being utilized as intended. To determine whether the device is safe for all intended users the assumed subject is to weigh 500 lbs and that the system has a Factor of Safety of two, meaning the device can withstand two times the force that can be applied by the heaviest user (1000 lbs). Using a standard biomechanical anthropometric data on limb lengths and masses, it can be determined that the arm is 6.0% of the person's weight and the leg is 9.0 % of the person's weight.

Weight of Arm = 500 lbs x 0.06 = 30 lbs
Weight of Leg = 500 lbs x 0.09 = 45 lbs

The equations used include:

$$\sum F_x = ma = 0 \qquad \sum F_y = ma = 0 \qquad \sum M_? = r \times f = 0 \qquad \sigma = \frac{My}{I} + \frac{P}{A}$$

The standards for the aluminum used are for 6066 Aluminum which follows ASTM B221 Standards for all forms (bar, sheet, wire etc.) Found on Matweb.com. (See Appendix F)

Yield Stress = 83 MPa
Shear Stress = 97 MPa
The standards for the Stainless Steel Bolts used are: (See Appendix F)

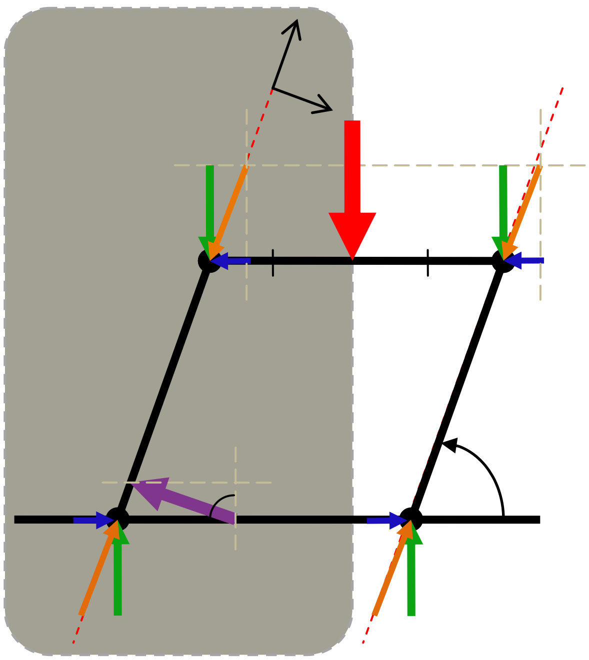
Yield Stress = 401 MPa

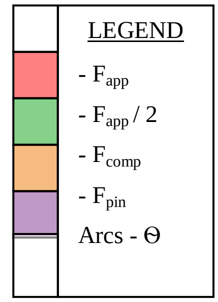
The intended use for which the calculations below are to be made is during loading, 75% of the user's weight distributed through the arm rest. In addition to the resting position of the users being weighed. Note that failure occurs in the system when stresses surpass the yield stress and not the ultimate stress.

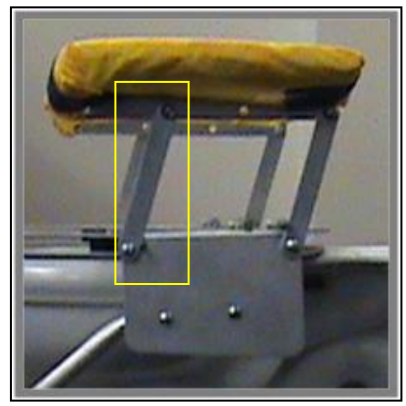
The specific calculations for the system include: Axial and shear forces of the balance aids and their attachments. The linkages and interface will also be investigated in bending due to the non-axial (perpendicular) forces, and maximum internal moments were determined. See Appendix E for the dimensions used for calculations. Below are the decompositions and force distributions for each component. Following that is a chart summarizing the results of each calculation in comparison to the ASTM standards set out for Aluminum 6066. Note: the results from this section are only for weights applied for intended use of the system.

Arm Support Linkage

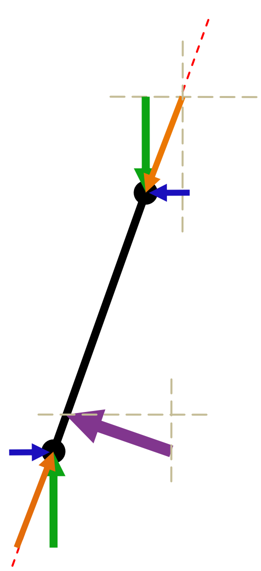
- Compression of the Side Linkages
- Maximum Moment of the side bar linkages
- Stress at Location of Maximum Moment



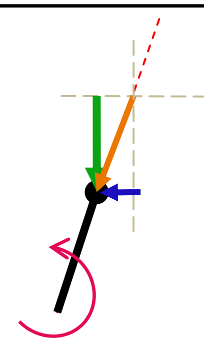




Forces on the Four-Bar Linkage



Single Link of the Four-Bar

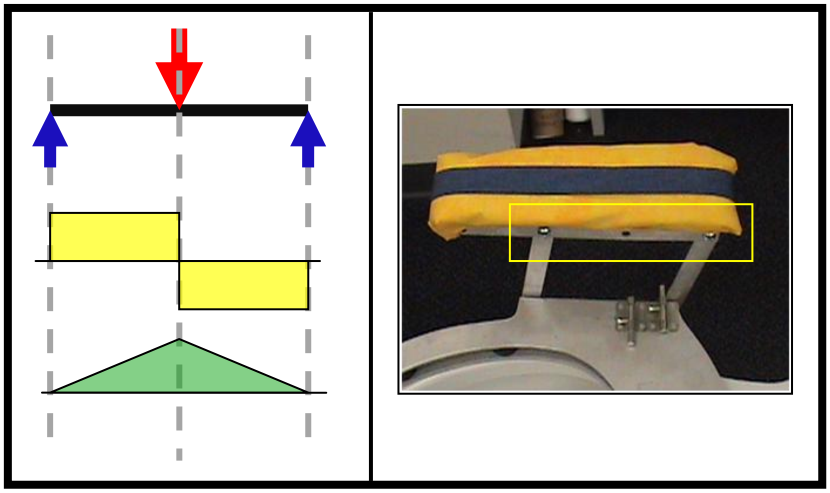


Cut Linkage at a Point

$$A = L \times w$$

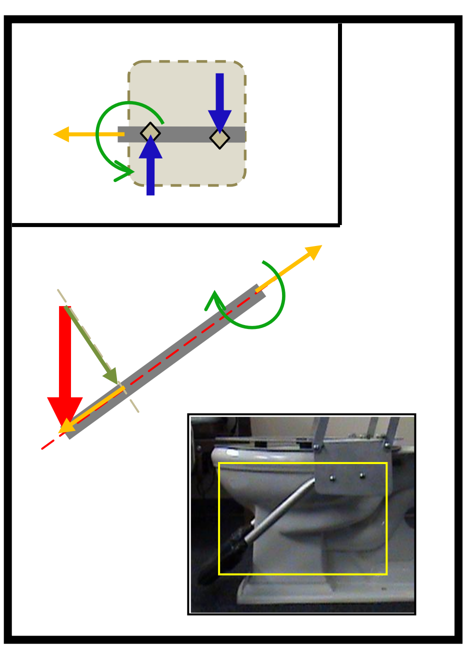
Cross Sectional Area of the Linkage

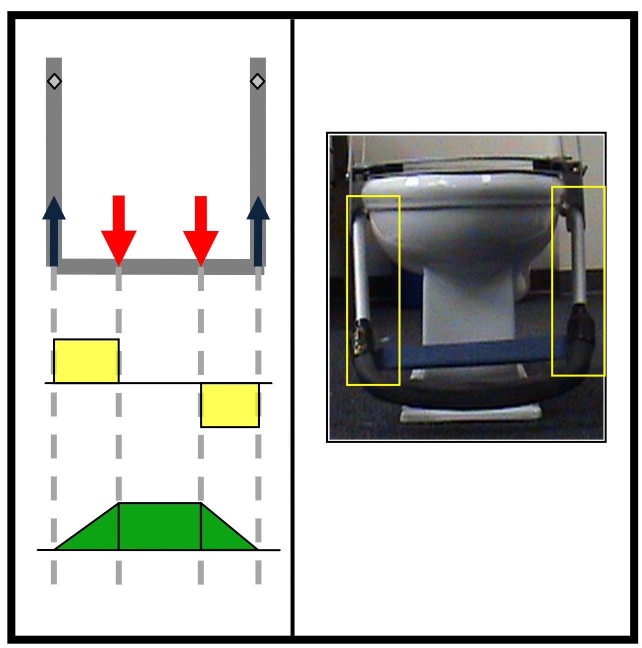
Arm Rest in Bending **- Shear and Moment Diagram**



Potential forces that the arm supports may have to endure would be 75% of the person's weight while loading and unloading. 500 lbs x 0.75 (75 % of body weight). See calculations. Failure occurs when yielding occurs, not at the ultimate stress failure. A potential mode of failure may be that the person applies the force in a non vertical direction by pushing out on grab bars causing the vertical side links to bent and buckle. Another issue could potentially be due to uneven loading. This could happen if the user only puts weight on one arm balance aid.

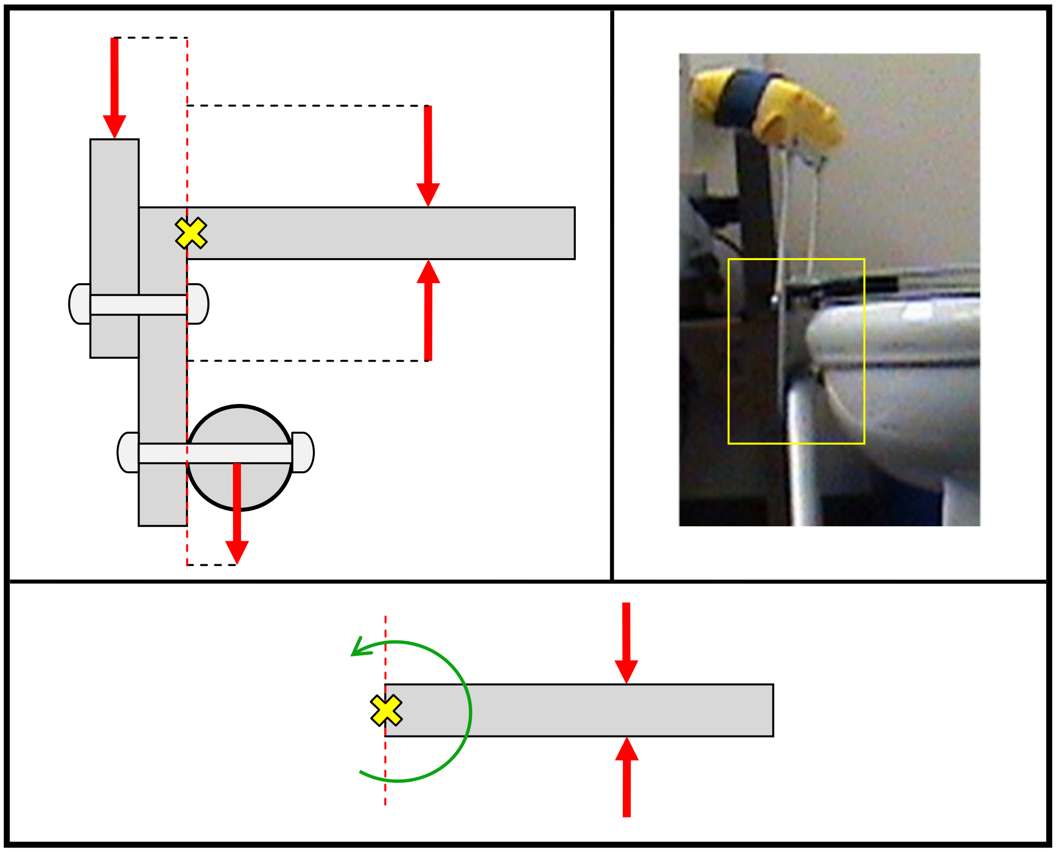
Leg Support - Bending Moment at Cut and on Foot Rest Cross Bar (Max)
- Force of Tension on Support
- Shear Force at Bolts
- Stress at Bend and at Bolts





Accidental step on the leg rest's cross bar could potentially cause the device to fail. The predicted location of failure is at both the joints and the location of the cut in the figure above. This is due to an increased moment caused by a larger force. This increased force will increase the tension force in the support bars.

Plate in Tension **- Moment at 90 degree L-Bend (marked with a yellow X)**
- Shear Force
- Max Stress



The shear and moment created at this point was calculated to determine if the maximum force of 75% of the weight of the used can be held and if the FOS holds for this component. Potential misuse of this component could be if the user applies their body weight at a rapid pace and thus causing the plate to yield or fracture.

There are several, potential design issues that need to be addressed when looking at the Think Tank system. The system must be considered when it is not being used correctly. In doing this the potentially weakest point should be investigated. For the arm rests if they are impacted from the side or front. The leg rests if a user stands on them, or is not gentle when placing their feet on the crossbar. If deformation in the cross bar occur the foot rest could become useless because it would be contacting the ground, thus weight will be transferred through the floor.

Summary Of Results:

Component	Value	Resultant Stress Location	Resultant Stress Value	Factor of Safety
Cross Bar Linkage (Arms Supports)				
Vertical Reaction Force	187.5 lbs	Shear Stress at Bolts	23.6 MPa	17
Max Bending Momenet	- 682.5 lb.in	Stress at Max Moment	99.5 MPa	0.83
Side Linkage (Arm Supports)				
Compressive Force	187.0 lbs	Axial Stress at Pin (Max)	49 MPa	8.1
Moment at Pin	234.38 lb.in	Shear Stress at Bolts	286.9 MPa	1.39
Force at Pin	375 lbs			
Reaction Force at (B)y	167.9 lbs			
Reaction Force at (B)x	374 lbs			
Shear force at Bolt	410 lbs			
Cross Bar (Foot Support)				
Max Bending Moment	- 750 lb.in	Max Shear Stress	54.9 MPa	1.8
Reaction Forces	187.5 lbs	Axial Stress	59.95 MPa	1.4
Side Bar (Foot Support)				(not maximal loading)
Tensile Force	250 lbs	Axial Stress at Bend	1.2 MPa	70
Moment at Bend	- 3347.5 lb.in	Shear Stress at Bolt 1	112.36 MPa	3.6
Force at Bolt 1	1060.47 lbs	Shear Stress at Bolt 2	112.38 MPa	3.6
Force at Bolt 2	-928 lbs			
Moment at Bolt 1	2737.6 lb.in			
Moment at Bolt 2	2499.11 lb.in			
Interface L- Bend				
Moment at L-Bend	- 10 lb.in	Shear Stress at Bend	0.956 MPa	87
Shear Force and L Bend	20 lb			

It can be noted that For the Leg Support that if the maximal weight (500 lbs) is applied to the foot rest (not intented use weight). The Stresses Placed axially on the cross bar would not support the weight and yielding would commence. For the arm support the factor of safety of 2 for the shear force caused by axial stress does not meet the requirements. This would require redesigning the support to meet this standard. For the side components of the foor support the factor of safety would also not be fulfilled for maximal use. The forces and stresses calculated for intended use were very minimal. The Factor of safety equaled two or greater, for these components. The mechanical aspects of this device will need further development.

Applicable Legal Issues:

There are patent issues with the electrical components of our prototype. If we wanted to patent our prototype, we would patent the concept and the mechanical components, but not the electrical components. All of the electrical components come from the "Biggest Loser™" scale made by Taylor®, product number 7334.

Some other legal issues would include injury to the user due to falling, skin abrasions, or harsh contact with mechanical components. Other injuries may occur from misusing the device. To prevent any legal issues, a detailed instructional manual of how to use the device would be included with a retail product. This would have a disclaimer releasing the company from any legal issues regarding injuries to the user from inappropriate use of the product. The mechanical components are designed to be easily used by people with various abilities in order to reduce the risk of injuries.

Economic Analysis:

Project Cost	
Item	**Cost**
Sensors	$80.00
Raw Materials	$200.00
Display	$10.00
Electronic Components	$250.00
Additional Costs	$73.00
Total Cost to Complete Project	**$613.00**

Our original economic goal was to design a working prototype under $2000.00 that could be mass produced at a cost of $100.00 per unit and sold for $200.00. The total cost to design and produce our prototype was $613.00. Since a manufacturing facility would be purchasing the materials in bulk at a reduced price, the cost to produce a single unit will be much less than the $600.00 it cost our team. Therefore, we feel that we have met our economic goals.

The sensors were purchased as a part of a "Biggest Loser" scale that met our requirements for the competition (weight and accuracy). Three of these scales were purchased so that there would be enough sensors in case any were broken or lost. The first two scales were purchased for $39.00 each and the third scale was purchased on sale for $9.00. The raw materials were purchased from Miller Compressing and Ace Hardware for $200.00. Two ¼ in. thick aluminum tubes and a ¼ in. thick aluminum plate were purchased from Miller Compressing to use for the prototype. Screws for the arm rests and sensor mechanism were purchased from Ace Hardware. The display was purchased for $10.00. Electronic components, including an analog/digital converter, a summing board, and resistors were purchased at a cost of $250.00. Additional costs for our project came to a total of $73.00. This went towards materials for the prototype made in December and toward materials needed by the MIAD students. Including the labor costs for building the device a final cost of less than $ 200.00 would be feasible.

Parts List

Final System		
Part	**Manufacturer**	**Contact Information**
¼ in. thick, 1 in. diameter Aluminum Tubing	Miller Compressing Company	http://www.millercompressing.com/
¼ in. Aluminum Plate	Miller Compressing Company	http://www.millercompressing.com/
Assorted Nuts, Bolts, Locks & Washers	Ace Hardware	http://www.acehardware.com/home/index.jsp
"Biggest Loser™" Weight Scale	Taylor®, product number 7334	http://www.target.com/
Foam and Fabric	Michaels	http://www.michaels.com/art/online/home
Toilet	Kohler	http://www.kohler.com/
First Electrical System		
Part	**Manufacturer**	**Contact Information**
4 Strain Gauges	Taylor®, product number 7334	http://www.target.com/
API Sum-000	Absolute Process Instruments	http://www.api-usa.com
Instrumentation Amplifier	Analog Devices	http://www.analogdevices.com
A/D Converter	Maxim	http://www.maxim-ic.com
4 ½ Digit LCD Display	Futurelec	http://www.futurelec.com
Breadboard	Circuit Specialists	http://www.circuitspecialists.com
Batteries	Energizer	http://www.energizer.com
Battery Case	Radio Shack	http://www.radioshack.com
Wires	Unknown	Bookmarq – Marquette University

Testing:

Loading of Sensors:

The objective of this experiment was to determine if the sensors were linear in their load-extension graphs. If there was not a linear relationship, then new sensors that had a linear relationship would need to be purchased. To determine if the sensors had a linear relationship, the MTS machine in the biomechanics lab was used to apply a known load. The maximum load was set to 120 lbs or 125 lbs for each sensor. The sensors were placed individually on the MTS machine and loaded using an extension rate of 0.01 in/min. After the test was finished, the output of the program was the load and elongation data. This data was then put into Excel and graphed. Sensors 1, 3, 4, 5, 6, 7, & 8 were tested. Sensor 2 was not tested because the MIAD students used when designing the prototype.

The graphs (see Appendix A) show that the sensors have a linear relationship between applied load and elongation. This means that the strain gages of each sensor will have a linear relationship with applied load and deformation. All of these graphs of the sensors show a nonlinear portion of the curve before the load gets to ~30 lb_f. This is due fact that the bottom of the sensors is not flat. There is a little bump that prevents the sensors from laying flat on their own. Once the MTS machine had applied 30 lb_f, the sensors straightened out and the relationship was linear. To prevent this problem from occurring in our prototype, we will use an interface mechanism that came with the original scale and sensors so that they will be flat when the initial load is applied.

Sensor Voltage Output Testing, Using Known, Standardized Loads

The system would be comprised of four strain gages each placed in a Wheatstone bridge configuration (half bridge) and then summed using API-SUM000 summing board. The objective of this test is to determine the relationship between known loads and the voltage output on a multi-meter. Over the range of 500 lbs. 6 weight increments ranging from 75 to 500 pounds would be chosen. The testing configuration would be as follows: the sensors will be enclosed by the sensor interface to prevent shifting or fracture of the transducers due to overloading. The four sensors would be placed in a square measuring one foot by one foot. A thin rigid aluminum plate would then be placed centrally, covering all four sensors, and the system would be zeroed to ensure that the plate is not factored into the load voltage data. Next the aluminum plate would be carefully loaded using weighted plates of known values. The voltage would be recorded and the actual weight of the plate would be taken using a digital scale accurate to 0.01 lbs. For each trial the sensors would be unloaded to ensure that the strain gages did not undergo plastic deformation. If the results are non-linear new sensors would be purchased. This test was not able to be performed due to issues with the electrical components.

Linear Voltage Outputs Converted to Weight in Pounds

The system would be comprised of four strain gages each placed in a Wheatstone bridge configuration (half bridge) and then summed using an API-SUM000 summing board, followed by amplification and analog to digital conversion. This would allow for an output on the display screen. The objective of this test would be to determine whether the weight displayed on the output screen was correct when comparing it to the actual weight being measured for the sensor configuration. The four sensors would be placed in a square measuring one foot by one foot. A thin rigid aluminum plate would then be placed centrally, covering all four sensors, and the system would be zeroed, to ensure that the weight of the plate was not factored output load. Next the aluminum plate would be carefully loaded using weighted plates of known values. The weight would be recorded from the digital display screen and the actual weight of the plate would be taken using a digital scale accurate to $\pm$0.01 lbs., for comparison purposes. For each trial the sensors would be unloaded to ensure that the strain gages did not undergo plastic deformation.

The unloaded weights would then be weighed for comparison purposes. This test was not able to be performed due to issues with the electrical components.

Actual Weight vs. Measured Weight by the Scale System

The system for this test included a four strain gage sensor and display system integrated into the compression sandwich mechanism. The sensors and their interfaces were positioned and adhered to the stability mechanism and the entire mechanism was attached to the toilet bowl. The objective of this test is to determine if there is a discrepancy between the actual weight of a load and the weight measured by the system. First the system, including the sandwich, arm rests and foot supports was zeroed. This was done to ensure that the weight of the system was not included in the output. The system was then carefully loaded using weighted plates of known values. The weight output was recorded from the digital display screen and the actual weight of the plate was taken using a digital scale accurate to 0.01 lbs., for comparison purposes. For each trial the sensors were unloaded to ensure that the strain gages did not undergo plastic deformation.

Object Weighed	**Think Tank Output (lbs)**	**Actual Weight (lbs)**
25 lb weight	25.0	25.0
Person A	122.2	122.2
Person B + 45 lb weight	225.4	225.4
Person B	195.2	195.0
Person C	183.2	183.2
Person C + Person B	378.4	378.2

From the testing results, it can be proven that there is no statistically significant difference between the actual weights of the objects and the Think Tank weight reading output.

Human Subject Testing Protocol:

See Appendix B for IRB approval certificate and consent form.

Subjects will be approached and asked to participate through face-to-face conversation. If they are interested in participating, subjects will be given the informed consent form to sign. After the consent form is signed, the subject will be assigned a code number (known only to the principal investigator) to keep their identity private. The consent form and code number information will be stored in a locked cabinet in Cramer Hall, Room 138, which is only accessible to the principal investigator. The subject will be asked to come to Cramer Hall, Room 138, at a convenient time for a private 15-20 minute testing session. During this session, the subject will be asked to sit on a toilet (detached from any plumbing or electrical components) that has a prototype weight scale mechanism attached. The subject will be asked to adjust and use the arm and leg rests. To help simulate certain disability conditions, they will be asked to try to see how much of these tasks they could complete with one arm and while wearing thick gloves. After giving the subject ample time to adjust the arm and leg rests under various conditions, the subject will be asked to fill out a questionnaire. This questionnaire will include questions regarding the subject's likes and dislikes regarding the prototype. Once finished, the subject will be thanked for their time and the data will be stored in Cramer Hall, Room 138. The data will only be accessible to the investigators.

Questionnaire Summary:

	Likes	**Dislikes/Improvements**	**Changes Made After Testing**
Arm Rests	Easy to maneuver and change location	A bit too stiff	Loosened bolts slightly
	Ability to operate one at a time	A locking mechanism should be incorporated	Incorporated locks in two positions so height can be changed
	Ability to lower armrest to enable transfer on/off the toilet	Should have more than one position	Added cushioning to arm rests and covered it with fabric
	Will be useful for patients who need extra support	Could be more useful if they folded backwards	
	Good positioning relative to the seat	Make them more comfortable	
		Should be slightly wider	
Leg Rests	Good distance from the toilet	Not adjustable	Added back strap to leg rest to prevent the legs from touching the toilet and for added support
	Good height from the floor	Too close to the toilet	
	Relatively comfortable	Could be used inappropriately as a step	
	Supported legs well	Have more support for patient's legs	
Overall System	Easy to get on/off the system		
	System easily removed from toilet		

Improvements Made Based on IRB Human Subject Testing Results

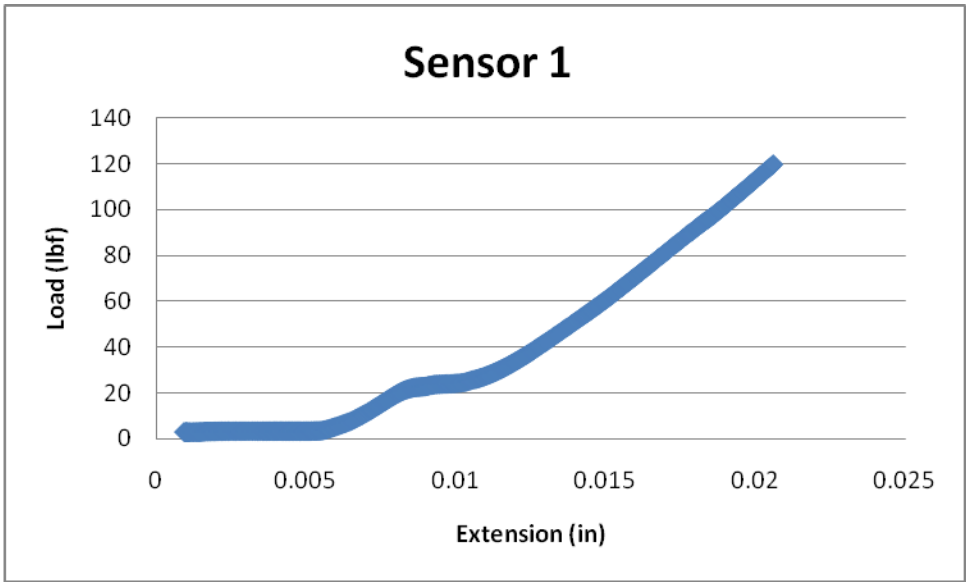
Based on responses from the subjects who participated in our study, we made several minor changes to our system. Locking devices were incorporated to secure the arm rests at two different upright positions. Extra padding was added to the arm rests to make them more comfortable. The bolts for the arm rests were loosened slightly so that they could be adjusted more easily. Materials were added to the leg rest to prevent the user's legs from contacting the toilet and for added support.

Future Design Improvements

If we were to pass the ThinkTank prototype on to a future senior design team, there are some improvements that we would suggest. With the ThinkTank as a baseline prototype, more time, and added resources, changes could be made to make the design safer, more sanitary, and more user friendly. The electrical components could be encased in a waterproof design and the wires to the display could be extended. Ideally, the display would be wireless. The display could be improved by having multiple modal outputs to accommodate all users. The mechanical components should be waterproof and easy to clean. The foot rest could be enhanced so that it is adjustable for all heights. Lastly, the base the base could be widened to accommodate larger users. Preferably, the width could also be made adjustable.

Appendix A:

Experimental Graphs:



Figrure 1: Load-Extension Curve for Sensor 1

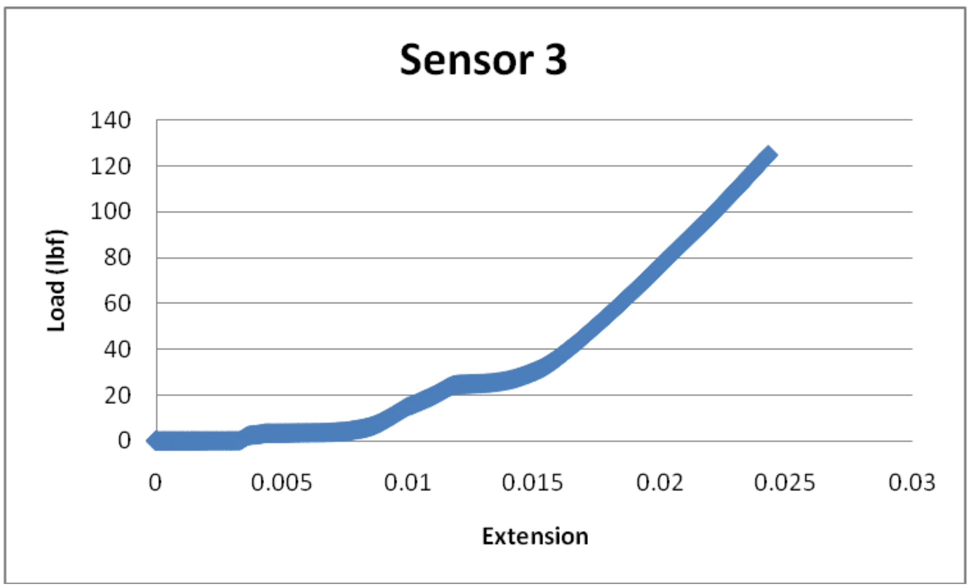


Figure 2: Load-Extension Curve for Sensor 3

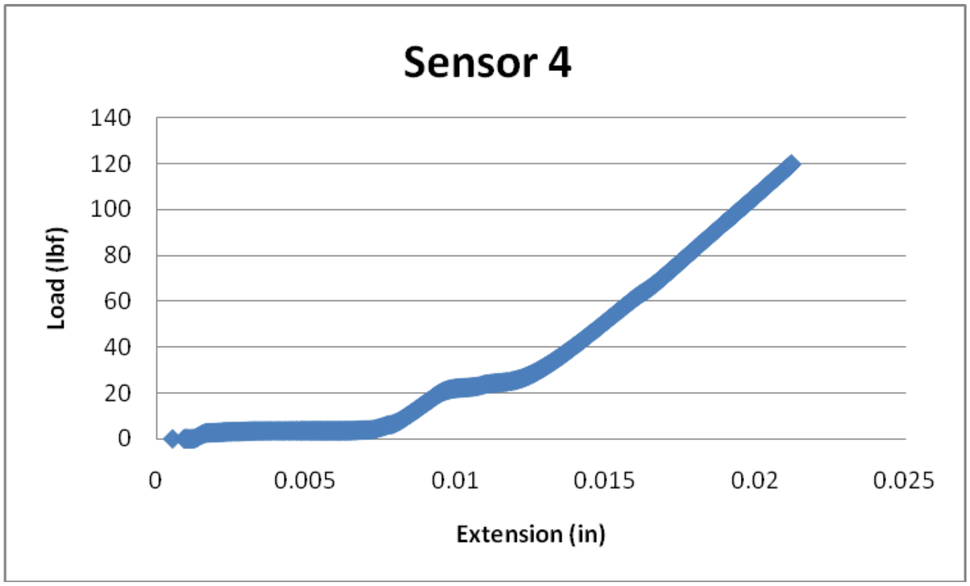


Figure 3: Load-Extension Curve for Sensor 4

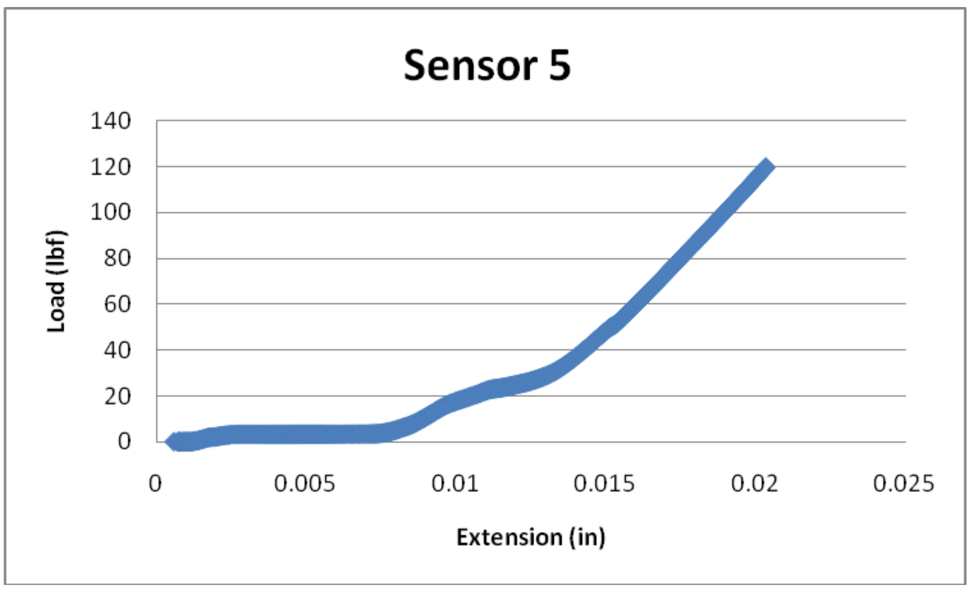


Figure 4: Load-Extension Curve for Sensor 5

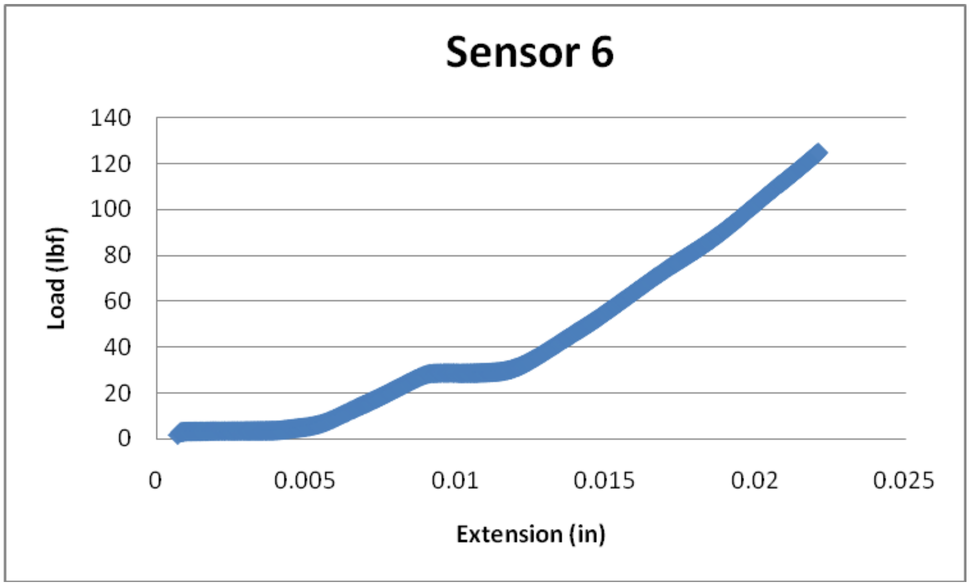


Figure 5: Load-Extension Curve for Sensor 6

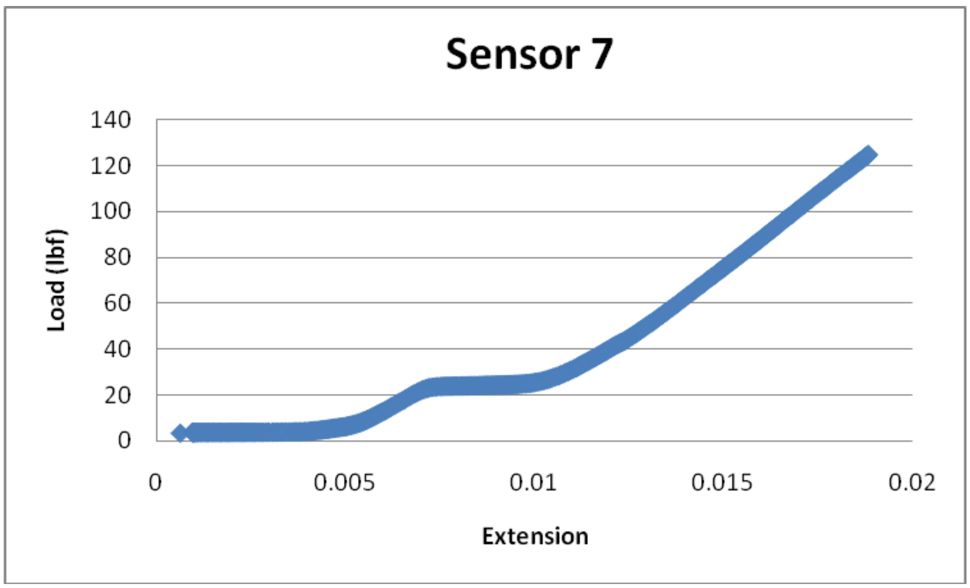


Figure 6: Load-Extension Curve for Sensor 6

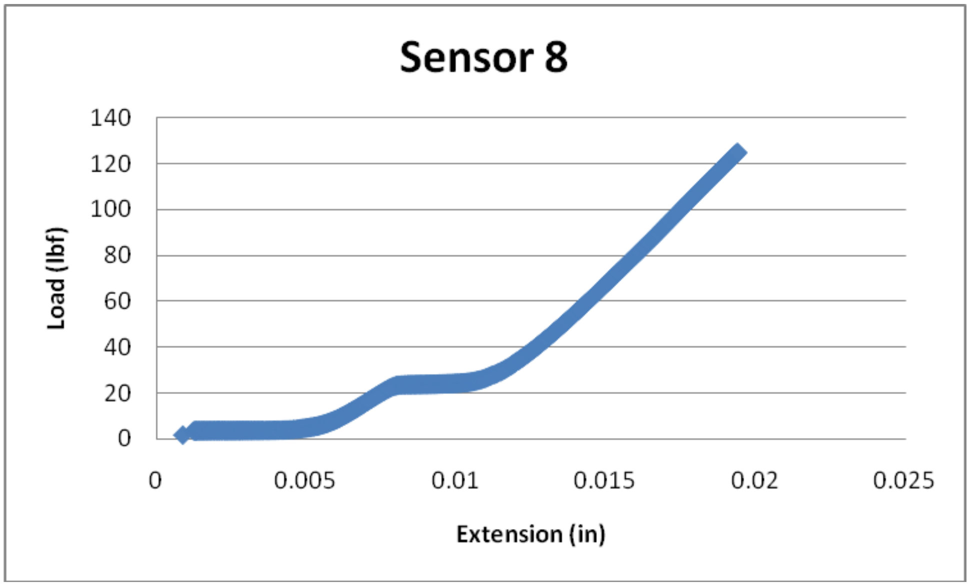


Figure 7: Load-Extension Curve for Sesnor 8

Appendix B:

IRB Approval Form:

OFFICE OF RESEARCH COMPLIANCE

MARQUETTE UNIVERSITY

April 18, 2008

Ms. Kaitlyn Darcy
Biomedical Engineering

Dear Ms. Darcy:

Your protocol number HR-1603, titled, *"Accessible Weight Scale for Seated Users"* was expedited on April 18, 2008, by a member of the Marquette University Institutional Review Board.

Your IRB approved informed consent form is attached to this letter. Use the stamped copies of this form when recruiting research participants.

You are approved to recruit a total of 10 subjects. Any changes to your protocol must be requested in writing by submitting an IRB Protocol Amendment Form, which can be found at: http://www.marquette.edu/researchcompliance/research/irbforms.shtml. All changes must receive IRB review before being initiated, except when necessary to eliminate apparent immediate hazards to the human subjects. Any public advertising of this project requires prior IRB approval. If there are any adverse events, please notify the Marquette University IRB immediately.

Your approval is valid until April 17, 2009. Prior to this date, you will be contacted regarding continuing IRB review.

Please note that completion of the NIH training tutorial is required for all human subject research investigators. Please forward a copy of the training certificate for Mariel Ponseti to the Office of Research Compliance as soon as possible.

If you have any questions or concerns, please do not hesitate to contact me. Thank you for your time and cooperation.

Sincerely,

Amanda J Ahrndt

Amanda J. Ahrndt, RN, MS, MSN
Research Compliance Analyst

cc: Dr. John Grych, IRB Chair
ORSP – Reference #71059
Dr. Jack Winters, Biomedical Engineering

ROOM 102 560 NORTH 16TH STREET P.O. BOX 1881 MILWAUKEE, WISCONSIN 53201-1881 TELEPHONE (414) 288-7570 FAX (414) 288-6281

Consent Form:

MARQUETTE UNIVERSITY
AGREEMENT OF CONSENT FOR RESEARCH PARTICIPANTS
Accessible Weight Scale for Seated Users
Kaitlyn Darcy
Undergraduate, Biomedical Engineering

You have been invited to participate in this research study. Before you agree to participate, it is important that you read and understand the following information. Participation is completely voluntary. Please ask questions about anything you do not understand before deciding whether or not to participate.

PURPOSE: I understand that the purpose of this research study is to provide feedback opinions that will be taken into account in the redesigning of a toilet seat weight scale prototype. I understand that I will be one of up to 10 participants in this research study.

PROCEDURES: I understand that I will be asked to sit on a toilet that is designed to measure my weight while I sit on it, but is not hooked up to plumbing or any electrical components. The weighing system is connected to a base anchored between the toilet seat and toilet rim. While sitting on it, I will be asked to adjust the arm and leg rests. I may be asked to repeat this task sequence several times, under conditions that somewhat simulate disability, such as trying to complete the task using only one hand, or while wearing thick gloves or a simple knee or elbow brace. I will be asked to fill out a short questionnaire regarding my opinions on the ease of use of the components. I understand that my name will not be attached in any direct way to the research study results and that a code name will be assigned.

DURATION: I understand that my participation will consist of one 15 to 20 minute private session in Cramer Hall, Room 138.

RISKS: I understand that the risks associated with participation in this study include minimal risks that are no more than I would encounter through sitting on a toilet or chair with arm and leg rests. These risks may include falling off the toilet or tripping over balance aids such as leg rests. Any contact points will be padded and there will be supervision and an investigator present to assist if necessary.

BENEFITS: I understand that the benefits associated with participation in this study include indirect benefits. The opinions I provide will be used in the design of a weight scale that can be easily used by people who are unable to use a standard standing scale and would like to monitor their weight on a daily basis.

CONFIDENTIALITY: I understand that all information I reveal in this study will be kept confidential. All my data will be assigned an arbitrary code name rather than using my name or other information that could identify me as an individual. When the results of the study are published, I will not be identified by name. I understand that the data will be destroyed by shredding paper documents and deleting electronic files three years after the completion of the study. The data will be stored in a locked cabinet accessible only to the principal investigator and

Page 1 of 2

____
Participant Initials
and Date

her advisor. The data will only be used for this senior design competition. It will not be used in future research. Your research records may be inspected by the Marquette University Institutional Review Board or its designees, the RERC-AMI, and (as allowable by law) state and federal agencies.

VOLUNTARY NATURE OF PARTICIPATION: I understand that participating in this study is completely voluntary and that I may withdraw from the study and stop participating at any time without penalty or loss of benefits to which I am otherwise entitled. If I wish to withdraw I will contact the principal investigator by phone, e-mail, or in person. I understand that if I withdraw at any point during the study my data will not be used in any way. The data will be stored in a locked cabinet with other study data and will be destroyed in three years.

CONTACT INFORMATION: If I have any questions about this research project, I can contact Kaitlyn Darcy, Mariel Ponseti or Dr. Jack Winters (project advisor).

Kaitlyn Darcy	Mariel Ponseti	Jack Winters
kaitlyn.darcy@mu.edu	mariel.ponseti@mu.edu	414.288.6640
616.490.0307	504.908.2111	

If I have questions or concerns about my rights as a research participant, I can contact Marquette University's Office of Research Compliance at (414) 288-7570.

I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE RESEARCH PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT.

______________________________ __________________
Participant's Signature Date

____
Participant's Name

______________________________ __________________
Researcher's Signature Date

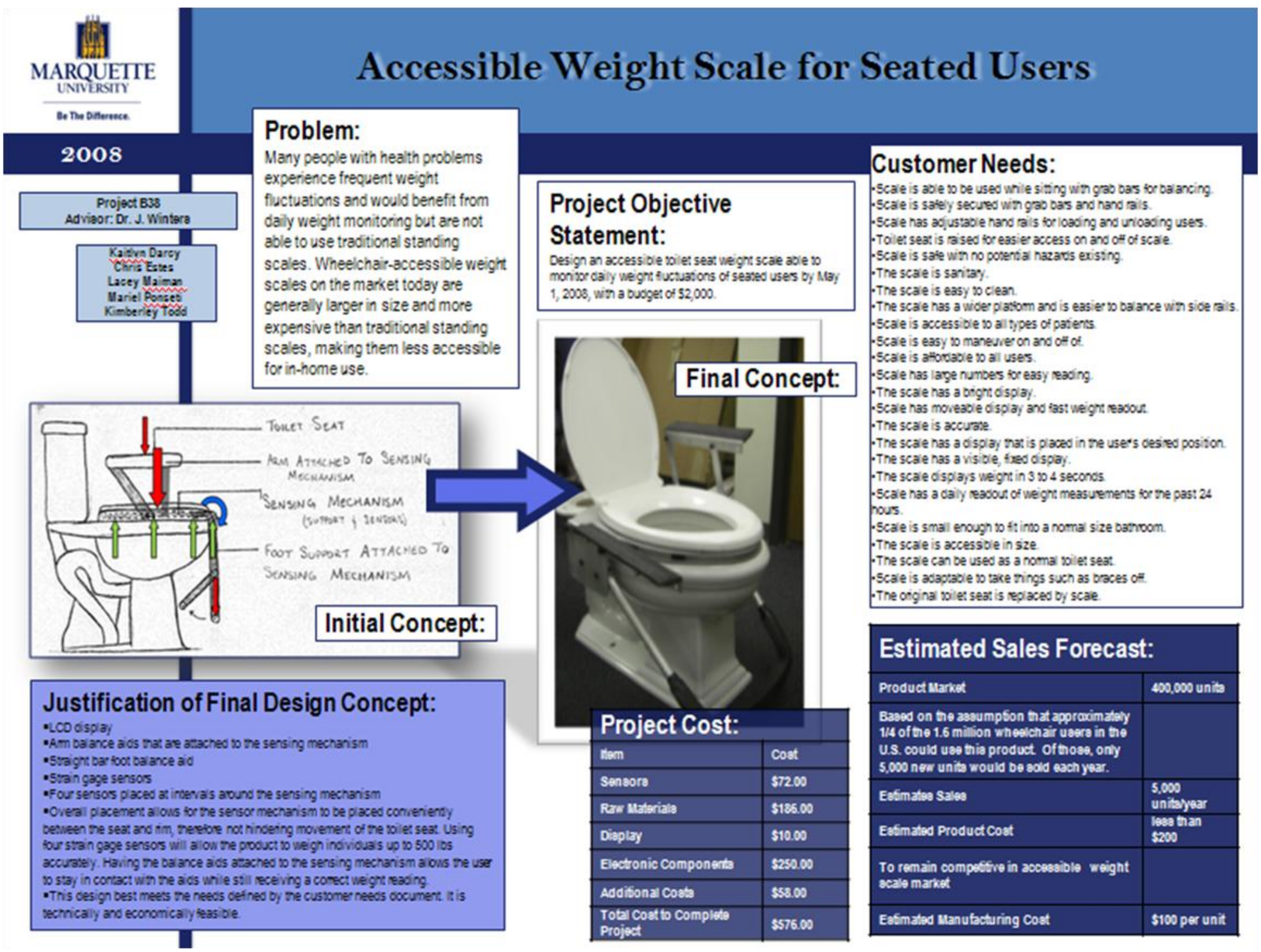
____
Participant Code Number

Page 2 of 2

Appendix D:

Awards

First place in Biomedical Engineering as well as the College of Engineering in the Senior Design Poster Competition:

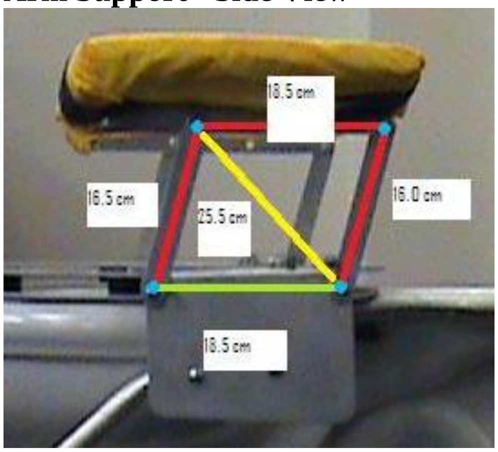


Appendix E:

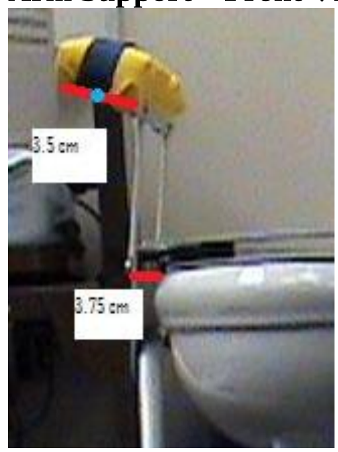
Mechanical Analysis

Dimensions for the Prototype – Used for Calculations

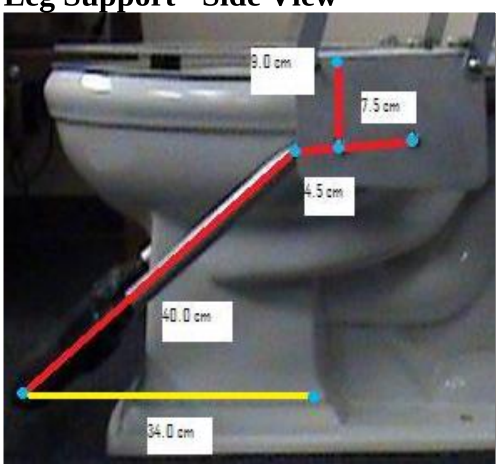
Arm Support - Side View



Arm Support – Front View



Leg Support - Side View



Leg Support – Front View

Interface / Toilet Seat – Overhead View