Accessible Weight Scale

Team 2

Eric Bernstein
Maria Elescano
Julie Rosario
Matthew Veilleux

Contact:

Rehabilitation Engineering Research Center on Accessible Medical Instrumentation
National Student Design Competition
John Enderle
860-486-5521
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Abstract

Many people are required to closely monitor their weight in order to track the progress of certain medical conditions. Diabetes patients must know their weight to determine insulin dosages and renal failure patients must know their weight to make sure they are not retaining excess fluids. However, patients who are restricted to wheelchairs are not able to use the same scales that normal people use to obtain this information. Therefore, a scale capable of accommodating a full wheelchair is necessary for these patients to remain healthy. To measure this weight, a large platform scale is required with high resolution and a high maximum load. Also, since many times a nurse or doctor reading the scale is not on the actual platform, a wireless display could allow reading of the weight far away from the platform. An accessible wireless wheelchair scale would benefit many patients and clinicians.

Introduction

An accessible weight scale that can be used either at home by handicapped persons or at a health care facility would be of great use to many patients. The weight scale is accessible to patients who suffer from a variety of disabilities, such as patients with limited movement of the extremities, general frailty, paraplegics, wheelchair users, or those in need of a cane or a walker. Patients suffering from renal failure, heart failure, diabetes, multiple sclerosis, or others who need to monitor their weight regularly can also benefit from this device.

The weight scale will have a ramp to make it wheelchair accessible and will have removable side support bars for those patients in need of additional support to stand. In order to avoid rolling accidents, the weight scale will have stops maintaining the wheelchair and other walking instruments in place. To accommodate patients with poor eyesight the output will be easy to read. Wireless functionality will allow remote users to control and view the final weight output.

Statement of need
Many clients suffer from paralysis, renal failure, heart failure, multiple sclerosis, stroke, diabetes, and heart attack, and need to monitor their weight regularly. The following is a description of these conditions and why weight monitoring is important:

- **Renal failure** is a loss of the ability of the kidneys to excrete wastes, concentrate urine, and conserve electrolytes. Those suffering from kidney failure need to measure their weight often because their body may be retaining excess fluid.

- **Heart failure** is a condition where the heart cannot pump enough blood throughout the body. The weakening of the heart’s pumping ability causes buildup of fluid in the feet, ankles, and legs. Weighing oneself is necessary because a sudden weight gain could mean extra fluid building up in the body.

- **Multiple sclerosis (MS)** is a chronic, energy-taxing, debilitating disease that affects the brain and spinal cord. Those with this illness weigh themselves often since weight gain is common in people who are less active, since fewer calories are burned.

- **A stroke** is a complication that affects the blood vessels that supply blood to the brain. Being overweight increases the chance of developing high blood pressure, heart disease, atherosclerosis and diabetes — all of which increase stroke risk.

- **Diabetes** is an illness where either the body does not produce enough insulin or the cells ignore the insulin. Insulin is necessary for the body to be able to use sugar. Being overweight or obese is a leading risk factor for developing type 2 diabetes.

- **A heart attack** occurs when the blood supply to part of the heart muscle itself is severely reduced or stopped. Maintaining appropriate body weight improves cardiovascular health.
This report will detail current wheelchair weight products and patents available on the market. Three different designs will be examined followed by an in depth description of the optimal design. Engineering standards, health, safety, and ethics will also be considered. Finally, a basic project timeline will be proposed.

**Product Research**

**-Market**

Market research shows the price range for similar weight scale designs to be between $1,500 and $3,000.\(^1\) Many of the scales found were offered from Detecto Medical Supplies. Some of the common features are AC or battery power, a LCD, and portability. To compete with the other products on the market, our scale should accommodate as much of these features as possible.

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Cost</th>
<th>Features</th>
<th>Max Weight</th>
<th>Platform Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detecto</td>
<td>6550</td>
<td>2860.99</td>
<td>LCD display, Keypad, Tare, Battery Powered</td>
<td>800lb</td>
<td>28”Wx28”L</td>
</tr>
<tr>
<td>Detecto</td>
<td>25495</td>
<td>1254.93</td>
<td>Mechanical, dual sided balance, removable ramp</td>
<td>350lb</td>
<td>30”Wx 26”L</td>
</tr>
<tr>
<td>Tanita</td>
<td>PWC 620</td>
<td>Not listed</td>
<td>Battery or AC power source, foldable, wheels for easy mobility, tare, adjustable leveling feet</td>
<td>440lb</td>
<td>40”Wx36.25”Dx4”H</td>
</tr>
<tr>
<td>Health O Meter</td>
<td>2450KL</td>
<td>1495</td>
<td>Rail, motion sensing weighing technology, foldable,</td>
<td>600lb</td>
<td>Small</td>
</tr>
<tr>
<td>Detecto</td>
<td>475</td>
<td>865.49</td>
<td>Lift-away arms and footrest, portability, transport.</td>
<td>350lb</td>
<td>Chair Scale: N/A</td>
</tr>
</tbody>
</table>

\(^1\) [www.itinscales.com/phealth1.htm](http://www.itinscales.com/phealth1.htm)
-Similar Projects

Two similar products were found in the NSF Engineering Senior Design Projects to Aid Persons with Disabilities. The first is “A Scale for Weighing a Client While in the Wheelchair” (1999). This design is that of a portable scale, with a cost of only $300. It has two LED displays that come from two bathroom scales that are mechanically attached to the platform. For this scale, assistance is needed because a calculator is used to compute the users weight, and the weight of the wheelchair must the known.

The second design is “Visual Output Weight Scale for Wheelchair Users” (2004). This device uses load cells, which allows for more accurate measurements. It too, is a portable weight scale, with an estimated cost of $1,155. It allows the user to calibrate the weight of the wheelchair, or manually enter its weight. No assistance is needed to use this scale.

-Patent Opportunities

There is great opportunity for obtaining a patent for our design, since only one patent for a similar design was found after searching the United States Patent and Trademark Office. The patent for this device, Wheelchair Portable Scale Apparatus, was filed on March 19, 2003, and the patent number is D489,279.
First Design:

Differences - This design uses an alternative miniature button load cell (figure ) to measure the load at four corner locations on the plate. Other major differences include lack of wireless capabilities and a thinner plate to decrease cost.

Figure

Advantage - The advantage of this type of cell is the low profile that creates a smaller ramp angle and will generate less material costs. One platform and four small plates used instead of a two large plates.

Disadvantages – The miniature button load cells are extremely expensive and the benefits are outweighed by the cost.

2 http://www.omega.com/ppt/pptsc.asp?ref=LCM302
Figure
Second Design:

Differences - The second design incorporates a wireless component to transfer the output from the load cells to the display.

Advantages - Wireless information transference allows the display to move freely up to 100 feet away from the scale. A wireless transfer would prove useful for physicians wishing to record stored weight values and adds aesthetic value to the scale by removing unnecessary wires. Less exposed wires increases the general safety of the scale as well.

Disadvantages – Miniature button load cells and wireless make for high costs.
Third Design:
Differences – Thin film load cells (figure) attached to a large central column. No wireless.

Figure

Advantages – Low cost. Thin film load cells are approximately ¼ of the price of a miniature button load cell.

Disadvantages – Central column may make the scale unstable. Two plates will increase cost needlessly.
Optimal Design:

Overview

The optimum design is a combination of designs III and II. While a wireless lcd display will be expensive, the cost can be alleviated by using thin film load cells in a four column fashion to provide stability and obviate the need for a second support plate.

Objective

The scale design has several critical components. The device will have a platform resting on four small circular beams with one thin film load cell attached to each one. The load cells convert the mechanical force into an electrical signal. The electronic signal, from the measuring device, is then interpreted by a microcontroller, which decodes the desired user input from a keypad. Finally, the weight value will be displayed to either a computer or an LCD for interpretation by the user.

The ramp, also made out of aluminum alloy, has a small angle in order to facilitate access to the scale. The top of the upper platform plate, the bottom of the lower platform plate, and the top of the ramp, have a significant coat of rubber in order to provide friction. Stops, made out of aluminum alloy, and a side bar support, made out of steel, are designed for safety issues.

Mechanical Design

The weight scale will be designed to sustain a maximum weight of 500 lb; for the design we will be using a factor of safety of 1.2, which means that the maximum weight we will be using for the calculations is 600 lb. The scale platform will have dimensions large enough to accommodate a standard adult sized wheelchair (26in X 36in). The scale ramp will have a small angle of inclination for easy access. The scale will have one side support bar that will be able to sustain the maximum weight applied to the platform. The LCD display will be paced on top of a rectangular beam, which will also be able to sustain the weight applied to the platform. The stops, to avoid rolling accidents, will be placed around the platform of the scale. The following is a side view of the weight scale.

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3 http://www.usdoj.gov/crt/ada/descript/reg3a/figA3ds.htm
Note: Stops will be around the three sides of the platform but the side stops have been left out to show position of the circular beams and strain gages.

Mechanical Analysis

-Platform Analysis

As mentioned before, the platform will have to sheets or plates, one on top and one below the cylinders; the plate below will be thinner to minimize costs.
Top Plate:
\[ t_p = 0.2 \text{ in} \]
\[ L_p = 36 \text{ in} \]
\[ W_p = 36 \text{ in} \]

Bottom Plate:
\[ t_p = 0.032 \text{ in} \]
\[ L_p = 36 \text{ in} \]
\[ W_p = 36 \text{ in} \]
For a plate or sheet the *flexural rigidity* is

\[ D = \frac{Et^3}{12(1-v^2)}, \]

where E is the modulus of elasticity and t is the thickness of the cross section. The flexural rigidity for a narrow beam is equal to EI, where I is the moment of inertia. For a rectangular cross section of one unit width this equation becomes Et^3/12. A plate therefore, manifests greater stiffness than a narrow beam by a factor of 1/(1-v^2) or about 10%.\(^4\) Therefore, for the scale platform, a narrow beam will be used as an approximation for the calculation of the bending stress, since the plate is stiffer than the beam.

**Approximation with a beam:**

---

\(^4\) Ugural and Fenster. *Advanced Strength and Applied Elasticity.*
W = Weight of Platform = 50 lb
P = Weight of Patient + Weight of Wheelchair = 600 lb
R = Reactions at strain gages
M1 = Moment about point 1
Fy = Force in the y-direction

**Summation of Forces and Moments:**

\[ 17 \text{ in} = 1.42 \text{ ft} \quad 34 \text{ in} = 2.83 \text{ ft} \]

\[ \sum F_y = P + W - R_1 - R_2 = 0 \quad \Rightarrow R_1 + R_2 = 650 \text{ lb} \]

\[ \sum M_1 = 650 * 1.42 - R_2 * 2.83 = 0 \quad \Rightarrow R_2 = 325 \text{ lb} \quad \Rightarrow R_1 = 325 \text{ lb} \]

**Calculation of Stress:**

To calculate the stress a small area of unit width will be used.
σ = Bending Stress
M = Max Moment = (Load/2) * Arm
I = Moment of Inertia
c = Largest Distance from Neutral Axis

c = 0.2 / 2 = 0.1 in
I = 1*(0.2^3)/12 = 6.667e-4 in^4
M = (600 lb/2) * 18 in = 5400 lb*in

\[
\sigma = \frac{Mc}{I} = \frac{5525 \times 0.1}{6.667e-4} = 828,709 \text{ psi}
\]

Aluminum / Thermoplastic Composite Sheet with yield strength of 10 ksi and a maximum capacity load of 1850 lbs would be used for the Top Platform. Aluminum Alloy 6061 Sheet with yield strength of 40,000 psi, would be used for the Bottom Platform.

-Cylinder Analysis
As mentioned above each cylinder will have one strain gage attached to them, and these will be placed in a vertical position.
Calculation of Cylinder Diameter:

In order to design the cylinder we must calculate the smallest diameter allowed before buckling occurs. The cylinder has been simplified for this calculation by not including the cut at the bottom and the gap for the plate.
P = Weight of person + Weight of wheelchair + Weight of top plate $\cong 650$ lb

$L_c$ = Height of circular beam

$I = \text{Moment of inertia} = 0.25\pi c^4$

$A = \text{Cross-sectional area} = \pi c^2$

$r = \text{Radius of gyration}$

c = Largest Distance from Neutral Axis

d = diameter of beam

\[
r = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.25\pi c^4}{\pi c^2}} = \frac{c}{2}
\]

For the design of the short circular beam we will be using aluminum alloy 6061. For most columns the specifications of the Aluminum Association provide two formulas to calculate allowable stress for columns under centric loading, one for short beams and one for long beams.\(^5\)

For short columns the equation is:

\[
\sigma_{\text{all}} = [20.2 - 0.126(L_c/r)] \text{ ksi}
\]

and since stress = load divided by cross-sectional area or $P/A$, therefore:

\[
20.2 - 0.126\left(\frac{L_c}{r}\right) = \frac{P}{A}
\]

\[
\Rightarrow 20.2 - 0.126\left(\frac{3}{c^2/2}\right) = \frac{0.650}{\pi c^2}
\]

\[
\Rightarrow c = 0.122 \text{ in} \quad \text{and} \quad d = 2c = 2*(0.122) = 0.243 \text{ in}
\]

---

This is the smallest diameter can be used to support the centric load without failure under bucking. For this design a 3 in diameter will be used. Hence the radius used to calculate the allowable stress will be 1.5 inches:

\[
\sigma_{all} = 20.2 - 0.126 \left( \frac{3}{1.5} \right)^2 \approx 19.7 \text{ ksi}
\]

For the circular beam aluminum alloy 6061, with a yield strength of 35,000 psi will be used.

-Ramp Analysis
The angle of inclination of the ramp will be equal to 10° for easy access to the scale; with the height and the angle we can calculate the bottom length of the ramp.

**Ramp Angle Calculation**

\[ h_r = 3.232 \text{ in} \]
\[ \theta = 10^\circ \]
\[ L_r = \frac{h_r}{\tan \theta} = \frac{3.232}{\tan(10)} = 18.33 \text{ in} \]

To ensure a safe ramp, bending and frictional forces will be calculated using a worse case scenario. In this case let’s assume that the whole body weight (P) is located at the center of the ramp as indicated in the figure below.

**Ramp Reactions**

\[ P_x = 598 \text{ lb} \]
\[ P_y = 600 \text{ lbs.} \]
\[ \alpha = 85.24^\circ \]
\[ P = 600 \sin \alpha = 598 \text{ lb} \]
\[ P_x = 600 \cos \alpha = 49.8 \text{ lb} \]

\[ F_s = \text{Frictional Force} \]

**Summation of Forces and Moments:**

\[ \Sigma F_x = P_x - F_s = 0; \quad \Rightarrow F_s = P_x = 49.8 \text{ lb} \]
The frictional force is equal to the normal force times the coefficient of friction ($\mu$); therefore, we have that the required coefficient of friction for a static ramp is:

$$\mu = \frac{F_s}{P_y} = \frac{49.8}{600} = 0.0825.$$  

This coefficient of friction is smaller than that for rubber against ice (which is 0.15), which means that our scale will stay static almost anywhere it is placed. The bottom of the platform and the ramp will be coated with a rubber spray.

**Calculation of Stress:**

$c = \frac{0.25}{2} = 0.125 \text{ in}$

$I = 1*0.25^3/12 = .0013 \text{ in}$

$M = (698 \text{ lb}/2) * 4.01\text{ in} = 2802 \text{ lb*in}$

$$\sigma = \frac{Mc}{I} = \frac{2802 * .125}{.0013} = 268,961 \text{ psi}$$

Aluminum Alloy 6061 rectangular bar with a yield strength of 35,000 psi, will be used for the ramp.
Side Bar Support Analysis:

In order to analyze for the worst case, all the load (P) would be assumed to be located at the center of the bar as shown by the figure below.
Summation of Forces and Moments:

\[ P_y = W = 600 \text{ lb} \]

\[ P = \frac{W}{\cos 45^\circ} = \frac{600}{\cos 45^\circ} \cong 850 \text{ lbs} \]

\[ + \sum F_y = 0 : 850 - R_A - R_B = 0 \]

\[ 25\text{in} = 2.08\text{ft} \quad \quad 12.5\text{in} = 1.04\text{ft} \]

\[ \sum M_A = 0:850(1.04) - R_B(2.08) = 0 \]

\[ \Rightarrow R_A = R_B \cong 425\text{lb} \]

Calculation of Stress:

\[ M = \frac{123 \times 850}{2} = 5525 \text{ lb} \ast \text{in} \quad c = 1.00 \text{ in} \]

\[ I = \frac{1}{4} \pi r^4 = (.25 \pi *1^4) - (.25 \pi * .75^4) = .5369 \text{ in}^4 \]

\[ \sigma = \frac{Mc}{I} = \frac{5525 \times 1}{.5369} = 10,291 \text{ psi} \]

Steel Shim Bushing Stock Alloy 4130 with yield strength of 54,000 psi, would be used for the Side Bar Support. As shown the required strength is much less than the material’s strength.

- Stops
As mentioned before stops will be used to prevent rolling accidents. They will be soldered or welded around the platform. Aluminum Alloy 6061 Bar with yield strength of 35,000 psi, would be used for the Stops. The soldering material between metals and ceramics has a yield strength range of 44,000 to 116,000 psi, and an ultimate strength range of 51,000 to 150,000 psi. The welding product, Dura-FIX Rod, is made of a zinc base that welds metals, and it has a tensile strength of 47,000 psi, a compression strength of 75,000 psi, and a shear strength of 34,000 psi.

Load analysis

Using Autodesk Inventor © a load analysis was performed on the plate and cylinders to ensure the deformation is within reasonable limits.
Figure 1.1 shows the relative deformation of the plate with an off-center load of 1000 lbs. It is not visually to scale but the bar to the right indicates the maximum deformation in the center is less than a quarter of an inch, which is more than acceptable.
Figure 1.2

The cylinder will have a portion of the bottom removed to allow for a significant and measurable amount of deformation. The Thin Film S100 load cell from SMD sensors seen in figure .1 will be attached to the inside of the cylinder via drilled holes. Maximum deflection with a load of 500 lbs approaches .768 E-3 inches. In reality, the load will never come close to 500lbs as it is divided somewhat evenly between four cylinders. Additional tests were performed to ensure adequate deflection could be caused by smaller loads. One hundred and two hundred lbs caused deformations of .173E-3 inches
and .345E-3 inches respectively. Finally, the cylinder will join with the platform through a small cut out portion located .2 inches from the ground.

**Additional Parts**

- Support bar mount

![Figure 123](image)

The mounts for the side support bars simply must be thick and tall enough to properly constrain the side bars.
The hinge will be simple with holes drilled to connect it to the platform and ramp.
The final platform is very close to the ground. The side supports will be removable via the welded fittings on the plate. Welding will also be the best method for attaching the safety stops and columns but the ramp will be attached with hinges to give it a small degree of freedom.
Load cells

-Strain Gauges

The use of load cells in electronic weight systems is nearly ubiquitous. At its most basic form, a load cell is simply a force transducer that converts a load into an electrical signal via a strain gauge. The strain gauge consists of a thin metallic foil that has been bonded to a dielectric layer. Dielectric materials transmit electrical force using induction rather than conduction. They do not make good conductors but can support an electrostatic field. When a force is applied to a strain gauge the resistance of the gauge changes proportionally. If a voltage is applied during loading the change in resistance will alter the output voltage in a linear manner and the output can be used to calculate the applied force. However, the strain gauge is a delicate thin piece of wire and it cannot be deformed directly without failing. It must be mounted to a strain element using an adhesive. The shape of the strain element can vary; typically beams, rings, or columns are used depending on the function. The adhesives used and the mounting method will have the greatest effect on the quality of the load cell. If there is not a good bond between the two it will introduce errors into the calculations. The strain element and gauge are usually housed in a metal casing to prevent damage during use.

A Wheatstone-Bridge is the only internal electrical component of the load cell. Each of the four legs is connect to a separate strain gauge and when an input voltage is applied the gain in the output becomes proportional to the load. The Wheatstone-bridge also serves to make the voltage output semi-linear.

In addition to the cell there are some peripheral components that allow the device to interface with a computer. The most common addition is an analog to digital converter
that allows the cell to communicate directly with the computer. There may also be indicators, extra cables, printers and scoreboards that are used with the cell.  

There are myriad types of load cells on the market but for the aforementioned design the cost must be kept to a minimum so the S100 Thin Film Load Cell (.4 lbs-force, .022inch deflection) was chosen. With a cost of only $140, using these cells will reduce the overall cost of the project by several hundred dollars. The disadvantage is the high profile of the cell which makes it difficult to mount on a floor scale. The specifications of this cell are as follows:

-Performance

Hysteresis < 0.03 % R.O.
Long Term Stability < 0.01 % R.O. / Year
Nonlinearity < 0.05 % R.O.
NonRepeatability < 0.05 % R.O.
Creep/Creep Recovery, 30 minutes < 0.05 % R.O.
Static Overload
  Safe 200 % R.C.
  Ultimate 500 % R.C.
Temp. Effect on Zero Balance < 0.03 % R.O. / °C
Temp. Effect on Output < 0.03 % Reading / °C

6 http://www.measurespec.com/tips/principles.htm
7 http://www.smdsensors.com/detail_pgs/s100.htm
Operating Temp. Range  -10°C to 70°C

**Electrical**
- Rated Output (R.O.)  1.0 mV / V nominal
- Zero Balance  1 mV / V

**Excitation**
- Recommended  10 V ac or dc
- Maximum  15 V ac or dc

**Bridge Resistance**
- Input  1,000 Ω
- Output  1,000 Ω

**Insulation Resistance**  >1,000 Meg Ω @ 50Vdc

**Electrical Termination**  Stranded PVC wire, 10 x 0.1 mm (approx. 28 AWG)
- 4 wires, 11.5" (300 mm) long

**Mechanical (Please order in Newtons, e.g. S100-5N)**
- Rated Capacity, Newtons  0.5, 1, 2, 5, 10, 20, 50, 125
- Rated Capacity, kg-force  0.05, 0.1, 0.2, 0.5, 1, 2, 5, 12.5
- Rated Capacity, lbs-force  0.1, 0.2, 0.4, 1, 2, 4, 10, 25

One S100 will be mounted to each of the four columns (see design figures). As the cylinders are loaded it will deform slightly and the S100’s will measure the amount of deformation and send the data to the processor.
S100 model Autodesk

This model created in Autodesk Inventor was utilized in the final scale model for appropriate sizing.

-Power Systems

To convert the voltage coming out of the power supply into the desired 10 volts dc a linear voltage regulator will be employed. The regulator needs to be designed to meet two requirements: it must provide at least 250 mA of current and reduce the 12V power source to around 10 volts dc. The LMS1587 satisfies both of these conditions. One
specified resistor and one potentiometer to control the output voltage according to the equation:

\[ V_{OUT} = V_{REF} \left(1 + \frac{R_2}{R_1}\right) + I_{ADJ} R_2 \]

FIGURE 1. Basic Adjustable Regulator

Scale Platform Power System

Scale Display Power System

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A major upgrade of the second design of the weight scale is the incorporation of a wireless link between the scale platform and the visual display. As a result, two separate power systems must be developed. Since the platform section of the scale will remain relatively stationary, it will operate off of purely AC power. This will ensure that the special power requirements of the strain gauges are achieved without having to use many +9V batteries. The display section will operate primarily from battery power to facilitate full wireless functionality; however it will also have the capability to operate from AC power. Since the electronic components in both the platform and display section only require positive five volt supplies, the only differences would be the input to the regulator. Also, the fluctuation in the +5V supply should not be large enough to damage the electronic components.

To achieve a DC power level from an AC wall outlet, a power supply transformer will convert the 120 V 60 Hz signal into a 12V signal. The Phihong PSA-31U is a 20-30 Watt power supply with a DC output of 12V and a maximum output current of 2.5 A. The peak to peak ripple of this device is only 120 mV, which is very stable, however an additional regulator can step the voltage down to the final 5V and provide additional power signal stability. In order to connect to the wall, the device requires an AC cord that is compliant with the IEC320 C13 grounded input terminal and a typical American wall
outlet. Connecting the DC output of the supply to an electronic board requires a standard 2.1 mm ID, 5.5 OD, and 10mm length coaxial power connector.

The DC battery requirements for the display device should not require more than a single 9V battery. However, to enable the LCD backlight, an additional 9V battery would be required. The uncertainty of the DC requirements can be better addressed when the device is assembled and the supply current can be measured. At this stage of design, the DC power systems simply need to be design with the proper voltage requirements and a significantly large current accommodation. Additional 9V batteries can be placed in parallel to meet any of the necessary current supplies.

Linear voltage regulators are offered by a variety of companies and are available in many different output voltages. ON Semiconductor produces a 5V regulator with a 3A maximum output current capability. Since, the AC power supply can only provide a maximum of 2.5A the regulator adequately suits our output requirements. The regulator provides a line regulation of 1mV and a load regulation of 10 mV; these values are significantly small enough to prevent damage to the electronic components. Input into the voltage regulator will require a .33 uF capacitor since the AC power supply filter could be a significant distance from the linear regulator. Also to prevent back current from damaging the batteries or the AC supply, 6A diodes will be placed to allow current to flow only from the batteries to the linear regulator or from the AC supply to the linear regulator. After the current limiting diodes, a SPDT slide switch will provide a power switch functionality to disconnect the power input to the linear regulator. The output of the linear regulator will have a 10 uF electrolytic capacitor which improves the transient response of the system during power-up and avoids harmful voltage spikes. It is also
important that the inputs and output of the voltage regulator share a common ground, otherwise the regulator may not function within the specifications listed on the datasheet. Additional .1 uF capacitors will be connected between the power and ground pins of the electronic components to provide additional regulation of voltage spikes. This configuration should adequately convert either an AC or DC power signal to a 5V power signal compatible with the chips used in our design.

**Strain Gauge Amplifier**

In order to analyze the output of the whetstone bridge sensor in the strain gauge, an instrumentation amplifier is required. An instrumentation amplifier will amplify the difference voltage being produced when the bridge resistors change as a function of load. In the figure above, the voltage V8 signifies the difference voltage between the outputs of
the bridge. However, since we will not know the proper output characteristics of the bridge circuit until we have the proper strain gauge, the resistance values of the circuit above are not correct.

Following the instrumentation amplifiers from each of the strain gauges, a low pass filter is required to remove any AC component noise that may have entered the system from outside sources. Ideally, the cutoff frequency should be placed around thirty or forty Hertz to remove noise created by the sixty Hertz power lines. For the amplifiers used in this design, we will use the Microchip MCP616 op-amp or equivalent multi op-amp packages. This device operates with a single supply voltage therefore eliminating any additional power supply components. Also, since the output of the op-amp can only swing between the supply rails, the output from any of the op-amps cannot exceed five volts, which could otherwise damage the microcontroller. Therefore, diode limiting circuitry for over or under voltage protection is not required.

**Platform Microcontroller**
A PIC16F737 microcontroller was selected for this device for a variety of reasons. It contains eleven on board A/D converters which allows for multiple load cells if required. An internal oscillator block simplifies oscillator selection to a simple programmable selection. A USART interface allows the processor to access a computer through a serial port when the proper RS-232 interface chip is used. The SPI bus permits expansion of the device by allowing it to communicate with peripheral devices. And the multitude of general purpose I/O ports allows for an interface to the keypad and LCD display. Additionally, the 16F737 is equipped with Microchips low power nanowatt technology to limit the power dissipation and increase electrical life when operating on battery power.

After careful consideration, digital transmission was selected over possible wireless transmission of the output from the strain gauges because it greatly reduces error.
rates in the transmission of the data. As a result, a microcontroller will be required to convert the analog output into a digital form, and then transmit that data over the wireless link. The output from the strain gauge amplifiers will be connected to the A/D converter ports. Since there are ten free A/D converter ports on the microcontroller, we can accommodate data collection from up to ten strain gauges or load cells. The ICD ports will remain free for in-circuit debugging and programming using the Microchip ICD 2.

Analysis of the wireless devices on the market led us to the conclusion that Linx Technologies produced the best products to meet our specifications. Although we will most likely require single directional data transmission, the Linx SC-PA series allows bidirectional transmission of USART data. This series also comes pre-certified by the FCC as long as it is used with certain antennas. This feature drastically simplifies signal power consideration. Also, the device has an integrated antenna connector to fit many of Linx’s antenna products. For antenna selection, we had to decide between an internal helical and an external whip antenna. After careful consideration we decided to use a whip antenna because the helical antenna detunes badly when in proximity of large metal objects. Since our entire scale is a large metal object, this will create a worst case interference condition. The whip antenna also detunes, but placing it closer to the platform does not have as much of an interfering effect. The major disadvantage of the whip antenna is that since it is external, it may be damaged by unexpected use of the scale.

With the exception of the USART data lines, this wireless device only requires three other inputs and a single output. The RSSI line, or the received signal strength indicator line, can be used to evaluate the presence of noise affecting the wireless
transmission. Using an A/D converter port the microcontroller can determine if the signal strength is providing an inadequate signal. User notification of this information can indicate that the receiver and transmitter must be moved closer together. A power down line allows the microcontroller to control current usage in the device by shutting it down when it is not needed. The RX and TX enable lines are opposite of each other and must be set appropriately during receive or transmission cycles. Finally, if the signal power is too high, an extra resistor can connect the LVLADJ line to ground in order to reduce signal power by up to 5 dB. Using this device, data can be transmitted wirelessly in the same manner as if the two microcontrollers were connected using a serial port.

**Display Microcontroller**
The display electronics of the scale will consist of another PIC16F737 connected to a keypad, a series of 7 segment LCD displays, and another wireless transceiver. To receive the wireless signal, we used the same Linx antenna and receiver combination that was used for the platform electronics. Since the signal is only being transmitted between two PICs, it does not require a MAX 232 at either the transmitting or receiving end. Because of the amount of noise inherent in wireless transmission, some sort of error checking algorithm will need to be implemented in the software design to prevent spurious signals.

The keypad is a standard blank legend sixteen button keypad offered by Grayhill. A self-adhesive legend will be used to indicate the desired functions of each key. A clear plastic cover will also protect the keypad from possible environmental damage. When a key on the pad is pressed, two pins of the key pad are connected. Using a series of pull-up resistors and a simple software algorithm, the microcontroller can decode which key was pressed. When each of four of the PIC outputs are pulsed high, the PIC will listen of four input lines. If a key is pressed, when its corresponding column is pulsed, its corresponding row will be pulled high. Successive scanning of the keys in this manner will allow to user to change the microcontroller program flow.

Reading the final output weight can pose a problem for people who are either far away from the display or have poor vision. For this reason, we decided to use extra large 2.21” seven segment LCD displays. Although this eliminates the character functionality of a character LCD, it allows for a significant increase in display size. Since the only major features we wish to accommodate are data scrolling and subtracting an input weight, the sacrifice of characters in the display is negligible. Since each character
requires seven input lines, a special driver chip will be needed for each character. Using the CD4543B chip by Texas Instruments, only a single latch line is required for each character along with four data bus lines. Also, since the chips are driving an LCD instead of a series of LEDs, the phase line of the chips and the backplane of the LCD must be pulsed with a square wave input. Using this technique, only eight data lines are required to clock in all of the proper character values to the four numerical characters required by our display.

Software

Platform Program Flow

Since the platform microcontroller is simply transmitting the load cell information to the display without any calculations, this program is relatively simple. First an A/D conversion is performed on each of the load cell inputs. Next, a wireless signal is compiled which indicates the value of the load cell conversion, which load cell was being
converted, and some sort of integrated parity of error checking. While the exact error checking algorithm has not been decided, it will be required since the Linx wireless devices do not incorporate and error detection circuitry. Finally, the message is sent to the USART transmit buffer for transmission across the wireless link.

Display Program Flow
The display program actually calculates the final weight based on the load cell outputs and the specified user parameters decoded from the keypad. When the wireless message from the platform is received, an error checking algorithm along with the received signal strength determines whether the received signal was valid. If a signal was invalid, the entire message will be thrown away and the processor will wait until the next message is received. Once a valid message is received, the processor calculates the proper weight based on the zero setting, the current value of the scale, and the desired wheelchair subtraction weight. The microcontroller then runs the key scanning algorithm to determine what action the user wants the microcontroller to perform. Finally, based on the input, the microcontroller displays the final weight, wheelchair weight, or stored memory values on the LCD display. The details concerning exactly how the final weight will be calculated requires analysis of the load cells used along with calibration data. Also, the restrictions placed on the menu system due to the use of non-character LCD’s prevent the user from seeing anything other than numbers from the microcontroller. Therefore, the control interface will most likely operate similar to an alarm clock where holding a button down allows the user to enter the value for certain variables, such as the wheelchair weight.
Engineering Standards

With all mechanical designs the engineer should keep in mind a large factor of safety. Components can not just be designed to minimally support the loads specified in the product description, rather they must go a certain factor above this depending on the application. Furthermore, this device is for use by humans with disabilities and as such it must also adhere to special medical requirements. The Americans With Disabilities Act (ADA) states that ramps for wheelchairs need to have a slope of less than 8. Further health considerations will be expressed in following sections. The National Society of Professional Engineers ® provides a good guideline for product design and fabrication within ethical constraints. It is entitled the NSPE Code of Ethics for Engineers. A few fundamental rules include:

“1. Hold paramount the safety, health and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.”

These laws were kept in mind during the entire design process.

http://www.nspe.org/ethics/eh1-code.asp
Constraints

The constraints for this project fall into several categories: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. There are several scales on the market already, so economic concerns played a large role in the design. The scale stands out because it is wireless and has desirable electronic components with a high degree of accuracy. The power consumption is low to reduce operating costs and the product itself should cost no more than $2000. To minimize the harmful environmental effects that are inherent in any manufacturing process, the amount of silicon and batteries used is as small as possible. Silicon waste is quickly becoming a concern as computers are replaced every few years and typically are not recycled. Battery disposal has long been detrimental to the environment because the materials are toxic, so rechargeable batteries will be used in the completed scale. Power consumption also becomes an issue; the scale will turn off automatically and the electronic components absorb as little power as possible. The materials were selected for their durability weight and cost. They are light and strong enough to support the load without deforming too much but are also cost efficient. Selection of recyclable materials limits the impact the scale will have on the environment at the end of its operational lifetime. The timeline for this project is relatively short and manufacturing the designed parts will no doubt take a good portion of the time. The parts therefore are designed with a consideration for fabrication time. Handicapped individuals necessitate a design in which there are two safe holds: a stop for the wheelchair and sturdy hand rails. Social and political factors do not pose any foreseeable design constraints or issues at this time.
Health and Safety:

In any project design involving human interaction safety is of utmost importance. Special consideration was taken to ensure that the scale will be safe and reliable even for someone living alone and confined to a wheelchair. The scale will have no exposed electrical work of any kind and fail-safes designed to prevent electrical shock will be incorporated into the circuitry. In addition wireless standards for hospitals must be followed. The American Society for Healthcare Engineering and the American Hospital Association working with the Federal Communications Commission established a dedicated frequency spectrum for all health care wireless telemetry. Since the scale is designed to permit hospital use the electromagnetic interference will be kept to a minimum to prevent the malfunctioning of other medical equipment.

Welded joints and other joined mechanical components have to be tightened to specifications and solid. To the aim of general safety for the operator, wheelchair stops and a support bar are incorporated into the design. The stops prevent the chair from rolling off the scale resulting in injury to the user, while the support bar helps steady those in wheelchairs and people with walkers or other locomotion impairments. Both of these components can sustain well over the maximum weight of the person outlined in the proposal. The ramp leading to the scale will also have rubber grips added to prevent the wheels of the chair from slipping during ascent. As mentioned previously the ramp must also adhere to the minimum inclination guidelines established by the ADA.

Batteries, though usually safe, can pose hazards if not cased properly due to the acid inside. Again, good connections must be made to prevent overheating of the battery and surrounding casing.
Budget

-Mechanical Parts Budget

The following chart indicates the materials selected for our scale design that complied with our design specifications. **Total Mechanical Cost: $411.10.**

<table>
<thead>
<tr>
<th>Part's Name</th>
<th>Manufacturer</th>
<th>Material</th>
<th>Description</th>
<th>Part's Number</th>
<th>Yield Strength (psi)</th>
<th>Density (lb/in^3)</th>
<th>Dimensions</th>
<th>Units</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Platform</td>
<td>McMaster-Carr</td>
<td>Aluminum/Thermoplastic Composite</td>
<td>Aluminum Sheet</td>
<td>2888K14</td>
<td>10,000</td>
<td>0.1</td>
<td>.2&quot; T, 36&quot; X 36&quot;</td>
<td>1</td>
<td>$100.00</td>
</tr>
<tr>
<td>Bottom Platform</td>
<td>McMaster-Carr</td>
<td>Alloy 6061</td>
<td>Aluminum Sheet</td>
<td>89015K71</td>
<td>40,000</td>
<td>0.098</td>
<td>.032&quot;T, 36&quot; X 36&quot;</td>
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<tr>
<td>Cylinder</td>
<td>McMaster-Carr</td>
<td>Alloy 6061</td>
<td>Aluminum Discs</td>
<td>1610T31</td>
<td>35,000</td>
<td>0.098</td>
<td>3&quot;T, 3&quot;D</td>
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<td>$73.96</td>
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<tr>
<td>Ramp</td>
<td>McMaster-Carr</td>
<td>Alloy 6061</td>
<td>Aluminum Rectangular Bar</td>
<td>8975K444</td>
<td>35,000</td>
<td>0.098</td>
<td>1/4&quot;T, 8&quot;L, 3&quot;W</td>
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<td>$39.47</td>
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<tr>
<td>Side Bar</td>
<td>McMaster-Carr</td>
<td>Alloy 4130</td>
<td>Steel Shim Bushing Stock</td>
<td>8305T12</td>
<td>54,000</td>
<td>0.284</td>
<td>1&quot; ID, 1.47&quot; OD, 10' L</td>
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<td>Stop</td>
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<td>Alloy 6061</td>
<td>Aluminum Rectangular Bar</td>
<td>8975K833</td>
<td>35,000</td>
<td>0.098</td>
<td>1/8&quot; T, 3&quot; W, 3' L</td>
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<tr>
<td>LCD Bar</td>
<td>McMaster-Carr</td>
<td>Alloy 6063</td>
<td>Aluminum Square Tube</td>
<td>88875K46</td>
<td>16,000</td>
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<td>3&quot; X 3&quot;, .125&quot; Wall, 6' L</td>
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<td>$40.17</td>
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<tr>
<td>Rubber Coat</td>
<td>Premium Coatings</td>
<td>Asphalt emulsion, halogenated elastomer &amp; water</td>
<td>Liquid Spray Rubber</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>$35.00</td>
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</table>
# Electronics Budget

<table>
<thead>
<tr>
<th>Description</th>
<th>Stock num</th>
<th>Cost</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 V 2.5A External Power supply</td>
<td>(Allied) 653-0348</td>
<td>$27.59</td>
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<td>Coaxial DC power connector (compatibility?)</td>
<td>(Allied) 283-1510</td>
<td>$1.11</td>
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<tr>
<td>Detachable Power Cord 9’10”</td>
<td>(Digi-Key) Q105-ND</td>
<td>$4.50</td>
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<tr>
<td>6A diode</td>
<td>(Allied) 266-0086</td>
<td>.46</td>
<td>4</td>
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<tr>
<td>6A 28VDC slide switch SPDT (power)</td>
<td>(Allied) 676-0250</td>
<td>$3.13</td>
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<tr>
<td>+5V 3A linear regulator</td>
<td>(Allied) 568-4682</td>
<td>$3.12</td>
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<tr>
<td>.33 uF ceramic axial</td>
<td>(Digikey) 1213phct-ND</td>
<td>$3.06 for 10</td>
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<tr>
<td>.1 uF ceramic axial</td>
<td>(Digikey) 1210phct-ND</td>
<td>$1.15 for 10</td>
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<tr>
<td>+8V 3A linear regulator</td>
<td>(Allied) 568-4690</td>
<td>$3.28</td>
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</tr>
<tr>
<td>9V battery holder</td>
<td>(Allied) 839-1294</td>
<td>$1.05</td>
<td>4</td>
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<tr>
<td>10 uF aluminum electrolytic capacitor</td>
<td>(Allied) 613-0124</td>
<td>$0.05</td>
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<td>4x4 blank keypad</td>
<td>(digikey) GH5019-ND</td>
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<td>Medium Print self-adhesive keypad letter sheet</td>
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<td>Clear protective keypad overlay</td>
<td>(digikey) GH-5026-ND</td>
<td>$14.94</td>
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<tr>
<td>2.21” LCD 7 seg display</td>
<td>(digikey) 67-1507-ND</td>
<td>$10.56</td>
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<td>BCD 7-seg LCD driver</td>
<td>(digikey) 296-2079-5-ND</td>
<td>$0.45</td>
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<tr>
<td>RH ¼ wave whip antenna</td>
<td>(digikey) ANT-916-CW-RH-ND</td>
<td>$6.32</td>
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<tr>
<td>Wireless Tx/Rx</td>
<td>(Digikey) TR-916-SC-PA-ND</td>
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<tr>
<td>MCP619</td>
<td>(microchip)</td>
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<tr>
<td>PIC16F737</td>
<td>(microchip)</td>
<td>$3.35</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$302.53</strong></td>
<td></td>
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</tbody>
</table>
Load Cells  =  4x$140 = $560

Total project cost = $302.53 + $411.10 + $560 = $1273.63
Timeline
Conclusion

This weight scale is intended to improve on other similar scales currently on the market. Our design can be easily operated without any assistance required. The device will have a ramp for wheelchair access, and removable support bars to stand. The display will wireless with easily read characters. Thin film load cells proved the best viable option for weight measurement and when they are affixed to four columns the scale will be sturdy and in close proximity to the ground. These features will be implemented while remaining within a budget of $2,000; comparable scales presently on sale, cost up to $3,000.

References


www.mcmaster.com
www.smdsensors.com
www.omega.com
http://www.nspe.org/ethics/eh1-code.asp

Acknowledgements

We would like to thank mechanical engineer Luis E. Angeles, of Pratt and Whitney, for his priceless advice and support.