RETROFIT SCAFFOLDING LEVELER

A thesis submitted to the
Faculty of the Mechanical Engineering Technology Program
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by

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ABSTRACT

Scaffolding needs a new leveling concept. The current scaffolding levelers, stems and screw jacks, are both ergonomically unfriendly. The stems are fast to assemble but can’t be adjusted to be level on odd slopes. And the screw jacks can be adjusted to be level but take time to do so; screw jacks also will become hard to adjust over time. The new design is driven by customer’s surveys to ensure improvement from the other concepts. The product objectives are determined and the design process begins. Beginning with three new concepts, a weighing decision matrix is completed to determine proper concept. Using experience, the proper calculations are completed to ensure the systems credibility. During the design process, changes are made to the product objectives because of problems that occurred during the calculations. After the proper calculations are finished, the proper components are selected determining the bill of material and budget for the project. Then the project is assembled; issues are resolved when they happen. The proposed budget and schedule are compared to the actual, and a finish date is proposed.
INTRODUCTION

PROBLEM STATEMENT

A recent OSHA study showed that 20 percent of construction deaths were due to falls from scaffolding or elevated work platforms. (1) The Retrofit Scaffolding Leveler will improve one cause of the instability of current scaffolding systems, the adjustable feet (base plates).

The current scaffolding levelers, stems and screw jacks, are both ergonomically unfriendly. The stems are fast to assemble but can’t be adjusted to be level on odd slopes. And the screw jacks can be adjusted to be level but take time to do so; screw jacks also will become hard to adjust over time.

The focus of this design project will be to design a new scaffolding leveling system that will be ergonomically friendly, fast to level and assemble, and will be capable of being adjusted level. The feet of the system will be designed to prevent sinking into different ground materials as well. By eliminating the current levelers, the overall stability of a scaffolding system will be improved greatly reducing the current injury and fatality rate.
CURRENT SCAFFOLD LEVELING SYSTEMS

**Basic Scaffolding System**
Basic Scaffolding shown in Figure 1 (2) is made four legs that are stabilized with a horizontal diagonal gooser, two cross brace, and feet or casters attached to stems that are all secured with locking pins. If a screw jack is used, the inside bottom of the legs will have female threading for the jacks to screw into.

![Basic Scaffolding System](image)

**Stems and Feet**
Figure 2 (3) on page 3 shows the base plates that are used to secure accessories to. The most common accessory attached to the base plates are caster (shown above in Figure 1). When accessories are not attached, they are simple used as feet. All adjustment devices can easily be attached to the base plates.

The stems are used to adjust height in current systems. They slide into the leg and a gravity pin is used to slide through the scaffolding’s frame and the chosen height’s hole to keep the stem extended at that height. Once one leg is complete, the other three legs are adjusted. If the ground is level, they are done by counting the amount of holes from the bottom or top of the stem to secure them at an even height.

The biggest issue for the stems is if the scaffolding is needs to be adjusted level on a sloped surface. The adjustable stem’s notches are usually spaced an inch apart. This creates an error of levelness capability.
Screw Jacks

Figure 3 (3) shows two types of screw jacks. The jack on the left has a base plate attached to it. Unlike the stems, the jack will slide into the base leg of the scaffolding but will not use a gravity pin to secure. The screw jacks will use gravity instead; the weight of the system will secure the system on top of the screw jack. By twisting the adjuster clockwise or counterclockwise will raise or lower the scaffolding system. Again all four screw jacks will have to be adjusted separately.

The screw jack shown to the right in Figure 3 has the same concept but has a socket on the bottom end. This is also used for casters; the socket is used for Stem Swivel Casters and the base plate is used to attach Rigid Caster. The difference between the two is the Swivel Casters will roll in any direction and a Rigid Casters will only roll forward and backward.

Corrosion will begin to affect the screw jacks over time. The jacks will become harder to adjust the more corroded they get. This will lead to the user buying a new set.
OTHER LEVELING SYSTEMS

The choice of the other systems were based on the weight support and securing a specific height for long periods of time.

MANUAL LEVELING SYSTEM

Figure 4 (4) shows a RV (recreational vehicle) mechanical jack. They are used on the on the front of a recreational vehicles for leveling the vehicle after being detached from the vehicle transporting it. This helps RV users to gain a level living area without any fluctuation due to the transporting vehicle’s shocks.

The RV mechanical works by using set of manually rotated gears. As the user rotates the lever clockwise or counterclockwise, the gears will rotate raising or lowering the foot leveling the RV. It is more ergonomically friendly than the two current systems because the lever is at the top of the jack.

HYDRAULIC SYSTEMS

The Bigfoot EZE leveling system shown in Figure 5 (5) on page 5 is a hydraulic system designed for Class C motor homes but is not limited to that type. It works by using a powerful single pump to operate four jacks. What makes this system unique compared to the following hydraulic system is this system allows fluid to flow to two jacks when operated. This will eliminate the problem of frame twisting over time.

It is controlled by a single controller shown in the center of Figure 5. All the user must do is plug the wires in and run a battery cable. The feet of the system are 10” x 10” to prevent the feet from sinking into the ground.
The Dual Lift in Figure 6 (6) uses two hydraulic cylinders to lift one system. This concept is a built in system. The dual lift is put in put into the ground; it is secured in place with concrete. It is a low pressure and maintenance free system that can lift heavy loads.

The most important part of this concept that pertains to my project is the vertical hydraulic cylinder used. Unlike the previous, this system raises the platform up instead of pushing the down.

**MECHANICAL SYSTEM**

The system in Figure 7 (7) is a pure mechanical system. It uses a 2 horse power motor that will rotate the spiral mechanism to raise and lower the platform. The scissor stiffeners are used to minimize the deflection to 0.06” accuracy. It can collapse as low as the height of the motor box. The spiral mechanism is made up of interlocked horizontal rings and vertical bands. The spiral mechanism will collapse within itself. The only thing needed to secure the unit in place is four anchors.

All the leveling systems mentioned above are shown in Appendix A and are not feasible solutions for a retrofit scaffolding system. Using the knowledge attained from the research, a proper system will be designed.
SURVEY

CUSTOMER SELECTION
Customers for the leveler system was decided by choosing users of scaffolding. The most common users of scaffold system are home remodelers and painters. The nine surveys returned for the evaluation were the surveys that were completed in person. With the surveys returned the averages were concluded and are shown in Table 1 and 2. The actual survey sent out can be found in Appendix B.

<table>
<thead>
<tr>
<th>Importance of customer requirements</th>
<th>Most important to least</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>Name</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Weather resistance</td>
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</tr>
<tr>
<td>2</td>
<td>Repeatability</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Compatibility</td>
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</tr>
<tr>
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<tr>
<td>5</td>
<td>Ease of storage</td>
<td>4.89</td>
</tr>
<tr>
<td>6</td>
<td>Durability</td>
<td>4.89</td>
</tr>
<tr>
<td>7</td>
<td>Ease of operating</td>
<td>4.89</td>
</tr>
<tr>
<td>8</td>
<td>Reliability</td>
<td>4.88</td>
</tr>
<tr>
<td>9</td>
<td>Safety</td>
<td>4.78</td>
</tr>
<tr>
<td>10</td>
<td>Affordability</td>
<td>4.67</td>
</tr>
<tr>
<td>11</td>
<td>One person operated</td>
<td>4.44</td>
</tr>
</tbody>
</table>

Table 1 – Customer Importance

<table>
<thead>
<tr>
<th>Current System Satisfaction of customer requirements</th>
<th>Most important to least</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>Name</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Compatibility</td>
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<tr>
<td>2</td>
<td>Ease of storage</td>
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</tr>
<tr>
<td>3</td>
<td>Affordability</td>
<td>4.89</td>
</tr>
<tr>
<td>4</td>
<td>Repeatability</td>
<td>4.88</td>
</tr>
<tr>
<td>5</td>
<td>Reliability</td>
<td>4.78</td>
</tr>
<tr>
<td>6</td>
<td>Weather resistance</td>
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</tr>
<tr>
<td>7</td>
<td>Safety</td>
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</tr>
<tr>
<td>8</td>
<td>Durability</td>
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</tr>
<tr>
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<td>One person operated</td>
<td>3.78</td>
</tr>
<tr>
<td>11</td>
<td>Ease of operating</td>
<td>3.33</td>
</tr>
</tbody>
</table>

Table 2 – Customer Current Satisfaction

IMPORTANT CUSTOMER REQUIREMENTS
In an interview with a long time home remodeler named Gary Forsythe (8), he stated that the repeatability of the two existing systems were good. But also said the ease of operating the levelers became more difficult over time. This was due to corrosion of the levelers. As the system became more corroded the friction increased for the screw jacks and the stems adjustment; causing the user to purchase new levelers. He also described if scaffolding was up for a long period of time, it would become unlevel. This was likely because of the base plate design. With the current levelers having sharp edges, the vibrations of work being done on the scaffolding would cause the feet to dig into the ground.

The survey’s results concluded that the customer’s most important requirements were the repeatability and weather resistance of the leveler. Because this system will primarily be used outdoors, the weather resistance is most important of the two; with the average price of $250 for the system. If this objective were not met, there would be failures to many other objectives including repeatability. If the system became corroded on any surface of the leveler, it would cause weaknesses on the assembly. This would be a major safety issue. The system is meant to support people and the equipment needed to complete a job. The leveler would likely fail with those loading conditions applied to the rusted area. The compatibility of the leveler would be harmed if the corrosion were to occur at the securing area. If the system were not sealed properly, the systems electrical parts would likely fail.
CURRENT CUSTOMER SATISFACTION
The existing levelers, stems and the screws jacks, current satisfaction, shown in Table 2, averages were not as high as the customers wanted importance of a leveler system. The most satisfied feature was the compatibility of the levelers. This is because the levelers snap into the base frame of the scaffolding or use a simple gravity pit to secure. This is something that should not be exacerbated in the new design. The least satisfied feature with the current levelers is the ease of operation. Again, this is because of the corrosion over time making it harder to adjust.

PLANNED SATISFACTION
Comparing the customer importance and the current satisfaction from the survey directs the design into planned satisfactions. Shown in Table 3 are the decided planned satisfactions compared to the customer importance and current satisfaction averages. The customer importance for design is created using the planned satisfactions. The design focus is based on the time needed to spend on a customer requirement to achieve the planned satisfaction from the customer importance.

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Importance Average</th>
<th>Current Satisfaction Average</th>
<th>Planned Satisfaction Average</th>
<th>Satisfaction Diff.</th>
<th>Relative Weight</th>
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</thead>
<tbody>
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<td>Ease of operation</td>
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<td>Ease of Assembly</td>
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<tr>
<td>3</td>
<td>Safety</td>
<td>4.78</td>
<td>4.56</td>
<td>4.6</td>
<td>1</td>
<td>9</td>
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<tr>
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<td>4.5</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>Reliability</td>
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<tr>
<td>6</td>
<td>Repeatability</td>
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<td>0</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>Compatibility</td>
<td>4.89</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>Weather resistant</td>
<td>5</td>
<td>4.67</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>Durability</td>
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<td>4.22</td>
<td>4.25</td>
<td>1</td>
<td>9</td>
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<tr>
<td>10</td>
<td>Affordability</td>
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<td>4.89</td>
<td>4.89</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>Ease of storage</td>
<td>4.89</td>
<td>4.89</td>
<td>4.5</td>
<td>-8</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 3 – Importance for Design

After the relative weight of each customer requirement is found, the design focuses are Ease of Operation and the Ease of Assembly of the system.
PRODUCT OBJECTIVES

The product objectives of the system are used as guidelines throughout the design process. Each customer requirement has ways to achieve that requirement and is shown below each one in the design specifications. When designing a system it’s important to design toward the specifications of the system.

DESIGN SPECIFICATIONS

The levelers design will focus on scaffolding frame tubing no larger than 2” OD. The leveler can be used on any kind of surface such as pavement, gravel, dry grass, and dry dirt. The leveling system is meant for scaffolding stacked no higher than an average two story home. The customer requirements are put in order from most important to least and have specifications for each. The product objectives can also be found in Appendix D.

Ease of operation (12%):
1. Will have an umbilical controller to ensure no bending over for adjusting
2. No more than two operations to level each leveler.
3. Orientation of the controller’s controls will be intuitive; up will raise the scaffolding, down will lower the scaffolding, and lock will lock the leveler in place.

Ease of Assembly (10%):
1. Assembly will take no longer than a current leveling system.
2. No more than two parts (per leveler) for the operator to put together.
3. Parts will lock in place; no tools required

Safety (9%):
1. Capacity will be 4 times the intended load + scaffolding weight.
2. With maximum load, will not sink into any material listed above when placed on them.
3. The base will lock in place once leveled.
4. Total weight of each leveler will weigh no more than the max recommended lifting weight for a woman with an occasionally lifted load according to the International Labour Organization.

One person operated (9%):
1. Can be assembled by one person
2. Weight of parts will not be heavier than the recommended lifting load according to the International Labour Organization.

Reliability (9%):
1. Is able to lift the weight of the scaffolding’s frame base
2. Electrical components and gears will be within an enclosure to ensure that no outside contaminants will cause failure.
3. Materials chosen will not fail with the maximum intended design load.
4. All mechanical parts within the enclosure will be secured with Loctite so they will not come loose.
5. The leveling system will be level with and without load.

Repeatability (9%):
1. Materials chosen will be coated with Teflon or Xylan.

Compatibility (9%):
1. Will retrofit to any scaffolding frame tubing below 2” OD.
2. Feet will secure to any type of pavement, gravel, grass, and dirt.

**Weather resistant (9%)**:  
1. All sensitive parts will be within a corrosion resistant enclosure and sealed with gaskets or silicone to ensure that no outside contaminants will cause failure.  
2. All exposed parts will be corrosive resistant.

**Durability (9%)**:  
1. Exposed materials chosen will be corrosion resistant or painted.  
2. All enclosure seams will be sealed.  
3. Electrical components will be soldered and covered with heat wrapped.  
4. Loctite will be used on all bolts, nuts and screws.

**Affordability (8%)**:  
1. Will cost no more than a hydraulic leveling jack for a trailer.

**Ease of storage (8%)**:  
1. Will have a handle for easy carrying.  
2. Will have flat sides so motion is more challenging during storage.  
3. No bigger than a hydraulic leveling jack for a trailer.
ENGINEERING FOCUS

A tool for planning and problem-solving was used to help the focus of the design shown in Appendix C. By using the product objectives for each customer requirement the technical measures are created. These technical measures are the features of the design that have been identified as the means to satisfy the customer requirements.

CUSTOMER REQUIREMENT’S TECHNICAL MEASURES

The engineering characteristics that were chosen effected each customer requirement. The following are the required characteristics; size/shape, reduced number of components, weight of leveler, enclosure material, feet footprint, feet construction, feet lock type, manufacturability, actuation method, controller type, controller intuitiveness, steps to complete leveling, gear coating/material, attachment construction, handle for carrying. The order at which they effect the customer requirements is shown in Table 4 below.

<table>
<thead>
<tr>
<th>Engineering Characteristic Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
</tr>
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</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>15</td>
</tr>
</tbody>
</table>

Table 4 – EC Importance

The three most important engineering characteristics are the attachment construction, actuation method, and the lock type. These affect the most customer requirements. For example (shown in Appendix C), the attachment construction doesn’t affect the ease of operation only. And for the actuation method, it only doesn’t affect the ease of assembly and ease of storage.
DESIGN

DESIGN ALTERNATIVES AND SELECTION
After researching many current leveling systems, three concepts were determined before designing how it would be assembled. When conceiving the three concepts, the largest concern was ensuring that the leveler would lift the dead load of the scaffolding base of the system. The three concepts conceived were two mechanical lifts and a hydraulic lift shown below.

Figure 8 shows the motor concept. The concept uses a motor attached to the enclosure to do the lifting. The shaft of the motor would be forcing a rack and pinion to lift the system. The foreseen problems with this concept are the weight of the motor. This is supposed to be a light weight system; the motor will add weight to the assembly and create an offset to the weight distribution. Also, the motor would need a power source. This would create a constraint to the usability of the system.
Figure 9 shows the hydraulic concept. It uses a cylinder and a hydraulic pump to lift the scaffolding. Very few parts would be needed for this concept because it consists of a hydraulic cylinder, pump, foot, and a neck to retrofit to the scaffolding. The foreseen problem with this system is it would compromise the product objective to make the system light weight. The lifting weight recommended for women by the International Labour Organization is only 35 lbs. (9). The pump would weigh around 30 lbs. already putting the concept close to the maximum weight allowed. The safety of the system would be more severe because of the increase in components to lift the system.
Figure 10 shows the Cordless Drill Concept. This concept uses a rack and pinion to lift the system. Unlike the motor concept, this concept lifts with the use of the cordless drill. The leg would lock at a chosen height using a detent pin. This makes this the most flexible concept in concerns to where it is being used. The only problem with this concept is the use of a cordless drill. Cordless drills, compared to a motor and cord drills, has a smaller amount of torque. A mediocre priced 18 volt drill from Home Depot has approximately 0.5 HP and 1700 RPM. That is equivalent to 8.5 in-lbs of torque at maximum charge.

To choose which concept is used for the new design, a weighted decision matrix was used shown below in table 5. The full weighted decision matrix can be seen in Appendix G. The 5 design criterions to secure the cordless drill concept to score the highest was ease of operating, safety, one person operating, ease of assembly, and ease of storage.

<table>
<thead>
<tr>
<th>Design Criterion</th>
<th>Motor</th>
<th>Score</th>
<th>Rating</th>
<th>Hydraulic Lift</th>
<th>Score</th>
<th>Rating</th>
<th>Cordless Drill</th>
<th>Score</th>
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<td>0.63</td>
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Table 5-Weighted Decision Matrix

The reasoning why the cordless drill concept scored the highest in the criterions was decided with experience in manual labor. The ease of operating the cordless drill concept was highest because it was the only concept that didn’t have a need for an outlet power source. For the hydraulic pump and motor an outlet power source would be needed near the operation of the leveler. The cordless drill concept was also ranked the highest in safety. This was because the other two concepts were ergonomically unsafe; they either had an offset weight or a heavy pump required to set up the system. The cordless drill concept also would be the easiest to operate with one person. The motor concept’s offset weight would create problems when connecting the lift to the scaffolding base’s leg. And the hydraulic lift would require running the pump while leveling the scaffolding base. Because of the other systems need for an outlet power source, the cordless drill concept would be the easiest to assemble on site. The cordless drill concept is the lightest and it also would be the easiest to store.
LOADING CONDITIONS AND ANALYSIS

Before doing any calculations and design of the cordless drill concept, it is important to understand the process of its use:

1) Put the scaffolding base together
2) Connect all four scaffolding levelers to scaffolding base legs
3) Use cordless drill to lift first leg to desired height
4) Lock leg
5) Repeat steps 3 and 4 to the other three legs
6) Begin applying additional loads to system

The system has two major differences concerning the “forces applied”:

1) Lifting the system with only the scaffolding base weight.
2) Maintaining height with additional forces applied

When designing for the lifting of the scaffolding base weight only, constraints need to be creating. Nothing is known at this point. The three things needed is the maximum weight of a scaffolding base that the leveler would lift, the cordless drill that would be used, and the pinion specifications that would be forced to lift the system. The largest scaffolding base chosen was a standard 5 ft. x 5 ft. x 7 ft. long which is 112 lbs. For calculation purposes, 150 lbs. would be used as a design factor. The drill that will be used is an 18 volt cordless Dewalt drill with a specification, at max charge, of 0.55 HP and 1,700 RPM. The pinion is a 3 in. dia., 1 in. wide, 36 teeth, 20° pressure angled spur gear.

Once the constraints were created, the design was created by using stock items. The reasons stock items were chosen was because of lead time and budget. In order to make the leveler cheaper than a current hydraulic jack for a trailer that was proposed in the product objectives, stock components are needed. Shown in figure 11 on page 15 is the design of the retrofit scaffolding leveler.

The first calculation needed is the amount of torque required to lift the system. This will prove that an 18 volt Dewalt drill is capable of lifting the system. If this can’t be done by the drill, then this concept will not work. Shown in figure 12 on page 15 is the direction of torque required to lift the system and the forces applied. The Ft is 150 lbs. and the Vt (linear speed) is 120 ft/min. A Vt of 120 ft/min (2ft/s) is chosen because it is a more reasonable speed when adjusting the height less than a foot.

\[
\text{Power} = \text{Ft} \times \text{Vt} = 150\text{lbs} \times 120 \frac{\text{ft}}{\text{min}} = 18,000 \frac{\text{ft-lb}}{\text{min}} \times \frac{1\text{hp}}{33,000\text{ft-lb/min}} = 0.55\text{ HP}
\]

The drill at max charge has 0.55 HP. This shows that the cordless drill is capable of lifting the system. If the drill is not fully charged, it will raise the system more slowly.
Figure 11-Retrofit Scaffolding Leveler

Figure 13-Forces applied during lifting
The next calculation is to determine the stress of the gear teeth. This is determined by using the Lewis formula (10).

\[ \sigma_t = \frac{F_t \times P_d}{W \times J} \]

\[ F_t = 150 \text{ lbs.} \]
\[ P_d = 12 \]
\[ W = 1 \text{ in.} \]
\[ J = 0.42 \]

\[ \sigma_t = \frac{150 \times 12}{1 \times 0.42} = 4,286 \text{ psi} \]

Shown in figure 13 are the countersink holes drill through the rack and the linear actuator to secure the rack. Parts of the teeth will be missing where the countersink holes are drilled out. Another calculation needs to be done. The new length of the tooth is found by using SolidWorks to measure.

\[ \sigma_t = \frac{150 \times 12}{0.45 \times 0.42} = 9,524 \text{ psi} \]

The material of the gear chosen is not specific. The specification of the gear's material is steel. Using the recommended stress for steel of 30,000 psi, it is safe to say the gear will not fail while lifting.
The drive shaft chosen for the system is a 0.75 in. diameter shaft. Shown in figure 14 is the shaft being used. The end will be machined to a standard 9/32 square socket size. This is the end of the shaft that will be driven by the cordless drill. A calculation to ensure the square end will not shear off needs to be completed. Using the torsional shear max formula (10) the max stress of the square end is found.

\[
\tau = \frac{T}{Q}
\]

\[
T = \frac{P}{\omega} = \frac{18,000 \text{ ft}-\text{lb/min}}{(850 \text{ rev/min} \times 2\pi)} = 3.37 \text{ ft-lb or } 40.44 \text{ in-lb}
\]

\[
Q = 0.208 L^3 = 0.208 \times 0.28125^3 = 0.004 \text{ in}^3
\]

\[
T = \frac{40.44}{0.004} = 8,791 \text{ psi}
\]

The shaft's material specification is steel again. The recommended shear stress for steel is 15,000 psi. This is a 1.71 design factor for the square end of the shaft.

Shown in figure 14, there are 4 retaining ring slots. The torsional shear needs to be calculated for the retaining ring slots. The retaining ring slots will be in torsion when the gear is lifting the system.

\[
\tau = \frac{Tc}{J} \times kt
\]

\[
T = 40.44 \text{ in-lb}
\]

\[
C = D/2 = 0.75/2 = 0.375 \text{ in}
\]

\[
J = \frac{\pi x D^4}{32} = \frac{\pi x 0.75^4}{32} = 0.031 \text{ in}^4
\]

\[
kt = 2.5 \text{ for retaining ring}
\]

\[
\tau = \frac{40.44 \times 0.375}{0.031} \times 2.5 = 1,223 \text{ psi}
\]

The next calculation will be done to ensure that the bending stress applied to the drive shaft. Figure 15 on page 18 shows the shear and bending diagram created for the drive shaft. The Fr is used for this equation instead of Ft. Using the values found by using the diagram and the stress due to bending the stress can be calculated.

\[
Fr = Ft \tan (\theta) = 150 \text{ lb. tan (20°) = 55 lb.}
\]

\[
\sigma = \frac{Mc}{I}
\]
M = 470.25 lb-in

\[ c = 0.375 \text{ in.} \]

\[ I = \frac{\pi b^4}{64} = \frac{\pi \times 0.75^4}{64} = 0.016 \text{ in.}^4 \]

\[ \sigma = \frac{470.25 \times 0.375}{0.016} = 1,102 \text{ psi} \]

This is all the calculation needed for the drive shafts credibility. A figure of the components are shown in Appendix H. The bearings chosen were selected by using the shaft diameter and the Fr applied. A set of two grease bearings were selected. The gears selected are non-coated. This was due to the small stress applied. The gear is held in place by two set screws 90° from each other. The grommet for the end of the shaft is used to prevent the shaft from rubbing against the enclosure wall when spinning.

The next set of calculations deal with the leveling system maintaining the height with additional forces applied. The detent pins strength will determine the max load that can be applied to the leveling system. Figure 16 on page 19 are show the forces applied to the detent pin.
After the detent pin is locked in place, additional forces are then able to be applied to the scaffolding. The major force of concern for the detent pin is the shearing force applied. First a shear and bending moment diagram need to be completed and is shown in figure 17.
Using the values obtained from the diagrams and the shear stress formula, I can confirm if the 0.5 in. detent pin is suitable for this application.

\[ \tau = \frac{F}{A} \]

\[ F = 489.5 \text{ lb} \]
\[ A = \pi r^2 = \pi 0.25^2 = 0.196 \text{ in.}^2 \]

\[ \tau = \frac{489.5}{0.196} = 2,497 \text{ psi} \]

The detent pins specification for material is steel. With the detent pin having a half inch diameter, the design factor for the pin is 6. The recommended design factor for a shock load is 5 (10). The maximum load before the system fails can be determined by using a shear formula.

\[ \tau = \frac{15,000}{5} = 3,000 \text{ psi} \]
\[ A = 0.196 \text{ in.}^2 \]

\[ 3,000 = \frac{F}{0.196} = 588 \text{ lb. (per leg)} = 2352 \text{ lb. (scaffolding, if evenly distributed)} \]

The final shown calculation for the system is to determine the minimum step height between detent pin holes. If the holes are too close to each other, the pin will shear through to the next step below it. Figure 18 on page 21 shows the detent pin’s area in between the steps. This is done by using the shear stress formula.

\[ \sigma_s = \frac{F_{\text{max}}}{A} \]

\[ \sigma_s = 15,000 \text{ psi} \]
\[ F_{\text{max}} = 588 \text{ lb.} \]
\[ A = L x W = 1 x W \]

\[ 15,000 = \frac{588}{(1 x W)} \]
\[ W = 0.0392 \text{ in.} \]

This value is extremely small and can’t be used. The leveling system will have 0.5 in steps; this is still an improvement compared to the currently used stems. Stems can only be adjusted every two inches.
These are all the hand calculations completed for the linear actuation shaft. A figure of the components can be found in Appendix H. The linear actuation shaft should be the number one concern. The machining on the shaft will to be very intricate. The linear support was added to prevent the shaft from rubbing against the inside of the scaffolding base leg. The U-bolts were added to prevent the actuation shaft from sliding out when the system was transported. And the bumper was added to the top of the rack to prevent the leveler from getting damaged because the gears are in free motion when adjusting.

All other calculations done for the design of the system were done in SolidWorks using a program called cosmos. The diagrams and charts for the linear actuation shaft, vertical supports, and the connector base plate can be found in Appendix I.

The enclosure was designed with galvanized steel plates on the top and bottom for weather resistance. Figure 19 shown below shows the two weldments needed. The sides will be made from blue tinted plastic to decrease the total weight of the system. Major components of the enclosure are the two welded components.
The foot design is similar to the current feet used. It’s 5 in. x 5 in. x 1/8 thick galvanized steel. The tube that the linear actuation shaft will sit in is ¼ in thick with a 1 in. inner diameter. The tube and the foot plate are continuously welded together.

The connector design is shown below in figure 20. The retrofit coupling is made from polycarbonate plastic which has high impact strength and is weather resistance. Different retrofit couplers will be used for different sized outer diameter scaffolding base legs. There is no clamping involved with this design. The coupling will slide into the tube on top of the enclosure. After the coupler is secure, the scaffolding can slide into the coupler. The more force applied to the system, the tighter the coupler clamp onto the scaffolding base legs. Different size scaffolding outer diameters will use a different colored coupler. This will make the retrofit couplers easier to find.

Figure 20- Retro fit Coupler
The overall size of the system is shown below in figure 21. Using SolidWorks weight analysis and selecting all the correct materials for the components, the total weight of the system 24 pounds.

Figure 21- Overall Dimensions
FABRICATION AND ASSEMBLY

The fabrication process includes creating the shop drawings, fabricating, and assembly. All shop drawings can be found in Appendix J. Once the drawings were complete the fabrication could begin. The order of the fabrication was determined by the complexity of the components.

1) Fabricate all parts for weldments
2) Fabricate linear shaft
3) Weld Components
4) Fabricate drive shaft
5) Fabricate retrofit coupler
6) Fabricate plastic sides

The picture shown below in Figure 21 are photos taken during the fabrication of the lift. The tooling needed to fabricate the scaffolding lift included:

- Drill Press
- Lathe
- Mill
- Grinder Wheel
- Abrasive Saw
- Press
- Band Saw
- Chop Saw
- Belt Sander
- TIG Weld
- MIG Weld
- Plasma Cutter

Figure 22- Fabrication Pictures
**ISSUES DURING FABRICATION**

During the fabrication only two parts had issues. The linear shaft shown below in Figure 23 had issues with all the holes needed to be made. The material selected for the linear shaft was 5166 case hardened steel; the machinability of the steel after being case hardening is very poor. The machine shop didn’t have a drill bit capable of drilling the holes needed for the detent pin. This shaft should have been machined before the case hardening. Once the issue was observed another shaft was purchased and machined before it was case hardened.

![Figure 23 – Linear Shaft](image)

The rack shown on page 26 in Figure 23 originally had holes drilled through the teeth for a bolt to slide through and fasten to the shaft shown above. The machinability of the gear teeth was very poor. The holes were removed from the design of the rack. The rack was secured to the shaft with welds.
Figure 24 - Rack

Figure 24 shown below is the finished linear shaft assembly. This one component of the lift extended the fabrication time by two weeks. These changes would be implemented the same way for future fabrication of the linear shaft assembly.
**FINISHED RETROFIT SCAFFOLD LIFT**

After all parts were fabricated, welded, and the issues resolved; the next step was the assembly. The assembly was designed with common threading, 10-32 and 6-32. Thirty-two of the holes in the design have PEM nuts to prevent the assembler from handling nuts. Figure 25 shows the finished retrofit scaffold lift. The lifts overall weight was 25.8 lbs. after completed.

![Figure 25 – Finished Retrofit Scaffold Lift](image)

**Figure 25 – Finished Retrofit Scaffold Lift**

![Figure 26 – Retrofit Scaffold Lift](image)

**Figure 26 – Retrofit Scaffold Lift**
TESTING AND PROOF OF DESIGN

TESTING METHODS AND RESULTS

In the loading condition analysis it was established that the two major forces to be tested are:

1) Lifting the system with only the scaffolding base weight.
2) Maintaining height with additional forces applied

The testing procedure includes 5’ x 5’ x 7’ rented scaffolding from a local hardware store with three acme screw jacks. The screw jacks are used instead of the base plate stems to ensure equal levelness with the new scaffold lift. The forces of the two listed above are being tested. The scaffold system must lift the scaffold weight. Once level and the detent pin is inserted, additional weight will be applied. Shown below in Figure 27 is the testing set-up.

A cordless drill was used to test the lift with no load, half load, and full load. The results were the lift system worked at no load and half load. At full load the pinion would make it half way up the rack then the gear teeth would bind up. The reasons for the issue were two things; the drive shaft was not perpendicular to the rack and the rack was not secured in the horizontal orientation.

Due to time constraints these issues were not resolved. The next stage in the prototype process would have been correcting the issued using simple methods. Securing the rack horizontally could have been resolved by using two simple pieces of coated square tubing along the flat sides of the rack. The coating would need to be used because of the metal to
metal contact along the flats of the rack. The drive shaft could have been solved by mounted
the bearings on a metal block. After the welding was complete, the block could have been
machined exactly perpendicular to the rack.

Testing for additional loading was the next step in the testing procedure. The additional
force applied to the lift was 400 lbs. The max shear force the detent pin could handle is 588
lbs determined in the loading conditions. The weight was applied by two 190-200 lb. males
jumping up and down on the scaffolding lift’s corner. The result of the test determined the
scaffold lift could stay at a desired level with 400 lbs. of force applied in shock.

Video footage was taken of all testing and is documented with the electronic copy of the
report.
The budget shown in Table 6 shows the forecasted and actual amount of the leveler’s design. The total is $870 dollars for the forecasted and $718 dollars for the actual. Some major components were removed from the initial design budget. There is no motor or pump in the new system. Before designing the system, a controller was planned to lift and lower the system. Also, because the gearing is lifting a light load, no gear coating is necessary. The two most expensive components are the vertical supports square tubing and the linear support.

### Table 6-Budget

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NEW

OLD
SCHEDULING

Table 7 is a schedule of major parts of the project. The dates that are highlighted are the weeks of the school break. The yellow (lighter) blocks highlighted show the planned weeks to finish. The red (darker) blocks highlighted show the actual week those tasks were finished. The full schedule is shown in Appendix F.

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Table 7- Schedule
CONCLUSION

It is important to understand the problems with the current scaffolding leveling systems. They either take too long to set up or it can’t be set level on odd slopes. The new retrofit scaffolding leveler is designed using customer surveys to improve on those bad qualities. Changes occurred from the product objectives, but by using the engineering design process, the minimum changes were needed. Redesigning the drive shaft mounting and the linear shaft would improve this new design in the next prototype step.
BIBLIOGRAPHY
APPENDIX A - RESEARCH

Interview with customer, Sep. 29, 2010
Gary Forsythe, Home Remodeler, (Called for interview)
Uses scaffolding occasionally for high up jobs (gutters, painting, siding, repairs, etc…)
Easy to adjust when brand new
Difficult to adjust level of screw jack if older
Adjusting hurts hands
Once scaffolding is adjusted correctly and up, Gary keeps it up until job is complete
Scaffolding needs to stay stable; scaffolding tends to slowly become unlevel when used for a while

Screws jacks have corrosion resistance and easy clip in design. The screw jack w/ socket can easily have a caster clipped into its socket. Coupling pins are needed to accomplish this improvement.

- Up to 24” of adjustment
- Accessories can be added if coupling pins are bought
Screw jacks have corrosion resistance and easy clip in design.

- Up to 24” of adjustment
- Bolt on Bracket and Hardware Included

Spiral scissors lifts offer a dependable and unique mechanical lifting solution to raising a load to any elevation from beneath with a continuous, stacked spiral column of interlocked horizontal rings and vertical bands. This proprietary spiral design provides a high degree of precision and repeatability, and can be used in single or multiple columns depending on the load capacity.

- Lubricated-for-life composite bearings on all pivot points
- Solid one-piece steel legs with stiffener bars
- Adjustment created to customer request

Sinks in soft ground (heavy)
Corrosion resistant
Easy to assemble and maintain
Ergonomically friendly
Repeatability
Position will not drift or deflect (.06” accuracy)
Autoquip Dual Ram Lifts can efficiently raise loads to 200,000 pounds and have platforms to 16' by 40' with high axle loading over the sides, and travels to 28'. The Dual Vertical Rams are equalized by cables and sheaves, rack and pinion, or structurally equalized.

- One moving part
- Wear proof bearing lengths of 24" to 36" or more
- Low pressure systems
- Maintenance free

This system utilizes a powerful single pump to operate four jacks. A unique new manifold design allows fluid to flow to two jacks when operated. This design provides for a true bi-axes leveling system that eliminates the problem of frame twisting. Up to 24" of adjustment

- NO SPRING or HINGES to rust and break
- 10" x 10" foot pad, supporting the object from sinking
- Transferable-ability to install on your next unit
- 12-17,000 lb. capacity per leg
They include large heat treated gears, four bearings, and heavy walled tubing. It also includes a handle that is easily removed but will not slip off during operation. Each jack features a full 36” lift and a large foot pad for added stability. Includes standard corner brackets and hardware.

- Bolt on Bracket and Hardware Included
- 2000 lb. capacity per jack
- full 36” lift
- Gears: large, heat-treated tungsten-steel, full 18 tooth gears for added strength and durability
- Bearings: three bearings plus one master thrust bearing
- Handle won’t slip off when in use, but is easily removed

<table>
<thead>
<tr>
<th>Sinks in soft ground</th>
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</thead>
<tbody>
<tr>
<td>Corrosion resistant</td>
</tr>
<tr>
<td>Easy to assemble</td>
</tr>
<tr>
<td>Not powered</td>
</tr>
<tr>
<td>Ergonomically unfriendly because of how low it is</td>
</tr>
<tr>
<td>Can’t get exactly level</td>
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</table>

Appendix A4
This is a very basic metal home scaffolding diagram showing all the basic components for scaffolding. This is from affordablescaffolding.com

- Accessories can be added

Corrosion resistant
Easy to assemble
Not powered
Ergonomically unfriendly because of how low it is
# Appendix B – Survey and Results

## Retrofit Scaffolding Leveler Customer Survey

I'm conducting a survey for my senior project to uncover what features are most important to you, as a potential customer, about your current scaffolding leveling system. This survey will help me create a better scaffolding leveling system for your future purchases.

### How important is each feature to you for the design of a new leveling system?

<table>
<thead>
<tr>
<th>Feature</th>
<th>1=low importance</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5= high importance</th>
<th>Avg.</th>
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<tbody>
<tr>
<td>Safety</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>(2)4</td>
<td>(7)5</td>
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<tr>
<td>Affordability</td>
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<td>2</td>
<td>3</td>
<td>(3)4</td>
<td>(6)5</td>
<td>N/A</td>
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<tr>
<td>Ease of operating</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>(1)4</td>
<td>(8)5</td>
<td>N/A</td>
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<tr>
<td>One person operated</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>(5)4</td>
<td>(4)5</td>
<td>N/A</td>
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<tr>
<td>Reliability</td>
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<td>2</td>
<td>3</td>
<td>(1)4</td>
<td>(8)5</td>
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<tr>
<td>Repeatability</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>(9)5</td>
<td>N/A</td>
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<tr>
<td>Compatibility</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>(1)4</td>
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<td>N/A</td>
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<tr>
<td>Easy to assemble</td>
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<tr>
<td>Weather resistance</td>
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<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Ease of storage</td>
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<td>2</td>
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<td>(1)4</td>
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<tr>
<td>Durability</td>
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<td>2</td>
<td>3</td>
<td>(1)4</td>
<td>(8)5</td>
<td>N/A</td>
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</tbody>
</table>

### How satisfied are you with the current leveling system?

| Feature                          | 1=low importance | 2 | 3 | (4)4               | (5)5 | N/A  | 4.56 |
|----------------------------------|-------------------|---|---|--------------------|------|------|
| Safety                           | 1                 | 2 | 3 | (1)4               | (8)5 | N/A  | 4.89 |
| Affordability                    | 1                 | (1)2 | (5)3 | (2)4               | (1)5 | N/A  | 3.33 |
| Ease of operating                | 1                 | 2 | (3)3 | (5)4               | (1)5 | N/A  | 3.78 |
| One person operated              | 1                 | 2 | 3 | (2)4               | (7)5 | N/A  | 4.78 |
| Reliability                      | 1                 | 2 | 3 | 4                  | (9)5 | N/A  | 5    |
| Repeatability                    | 1                 | 2 | 3 | (1)4               | (8)5 | N/A  | 4.88 |
| Compatibility                    | 1                 | 2 | 3 | 4                  | (9)5 | N/A  | 5    |
| Easy to assemble                 | 1                 | 2 | (2)3 | (6)4               | (1)5 | N/A  | 3.89 |
| Weather resistance               | 1                 | 2 | 3 | (3)4               | (6)5 | N/A  | 4.67 |
| Ease of storage                  | 1                 | 2 | 3 | (1)4               | (8)5 | N/A  | 4.89 |
| Durability                       | 1                 | 2 | (2)3 | (3)4               | (4)5 | N/A  | 4.22 |

### How much would you be willing to pay for this kit?

- $25-$50(2), $50-$100(1), $100-$200(2), $200-$400(4)
- $400-$700, $700-$1000, $1000-$2000

### Thank you for your time

Avg. Cost 244.44
### APPENDIX C - QFD

| Size/Shape                      | Reduced number of components | Weight of leveler | Enclosure material | Feet footprint | Feet lock type | Manufacturability | Actuation method | Controller type | Controller Intuitiveness | Reduced number of steps to complete leveling | Gear Coating/Material | Attachment Construction | Handle for carrying | Customer importance | Current Satisfaction | Planned Satisfaction | Improvement ratio | Modified Importance | Relative weight | Relative weight % |
|--------------------------------|------------------------------|-------------------|-------------------|------------------|----------------|------------------|------------------|-----------------|------------------------|---------------------------------------------|------------------------|--------------------------|-------------------|-------------------|---------------------|---------------------|-------------------|-----------------|------------------|
| Safety                         | 9                            | 3                 | 9                 | 1                | 9              | 9                | 3                | 3              | 3                     | 3                             | 3                      | 9                        | 1                | 4.78             | 4.56               | 4.60              | 1.01             | 4.82              | 0.09            | 9%               |
| Affordability                  | 3                            | 9                 | 3                 | 9                | 9              | 9                | 9                | 3              | 9                     | 9                             | 9                      | 1                        | 4.67             | 4.89             | 4.90               | 1.00              | 4.68             | 0.08              | 8%               |
| Ease of operation              | 9                            | 3                 | 9                 | 3                | 9              | 9                | 9                | 9              | 1                     | 9                             | 9                      | 1                        | 4.89             | 3.78             | 4.50               | 1.19              | 5.29             | 0.09              | 9%               |
| One person operated            | 9                            | 3                 | 9                 | 3                | 9              | 9                | 9                | 3              | 1                     | 9                             | 9                      | 3                        | 4.44             | 3.78             | 4.50               | 1.19              | 5.29             | 0.09              | 9%               |
| Reliability                    | 3                            | 9                 | 9                 | 3                | 9              | 9                | 9                | 3              | 1                     | 9                             | 9                      | 1                        | 4.88             | 4.78             | 4.75               | 0.99              | 4.85             | 0.09              | 9%               |
| Repeatability                  | 1                            | 9                 | 9                 | 3                | 9              | 9                | 9                | 1              | 9                     | 9                             | 9                      | 5.00                      | 4.89             | 4.88             | 4.88               | 1.00              | 5.00             | 0.09              | 9%               |
| Compatibility                  | 3                            | 1                 | 3                 | 3                | 9              | 3                | 9                | 1              | 9                     | 9                             | 9                      | 1                        | 4.89             | 5.00             | 5.00               | 1.00              | 4.89             | 0.09              | 9%               |
| Ease to assembly               | 9                            | 9                 | 9                 | 3                | 1              | 9                | 9                | 3              | 9                     | 9                             | 9                      | 4.89                      | 3.89             | 4.50             | 1.16              | 5.66              | 0.10             | 10%               |
| Weather resistant              | 9                            | 3                 | 9                 | 9                | 3              | 9                | 9                | 9              | 3                     | 9                             | 9                      | 5.00                      | 4.67             | 5.00             | 4.95               | 1.07              | 5.35             | 0.09              | 9%               |
| Ease of storage                | 9                            | 9                 | 9                 | 3                | 3              | 1                | 9                | 9              | 3                     | 9                             | 9                      | 4.89                      | 4.22             | 4.25             | 4.25               | 1.01              | 4.92             | 0.09              | 9%               |
| Durability                     | 1                            | 1                 | 9                 | 9                | 9              | 9                | 1                | 9              | 9                     | 9                             | 9                      | 4.89                      | 4.22             | 4.25             | 4.25               | 1.01              | 4.92             | 0.09              | 9%               |

| Abs. importance | 3.82 3.42 3.73 3.95 1.43 4.54 6.33 1.00 6.87 4.78 1.92 3.18 3.86 7.95 2.15 | 58.9 | 56.6 | 1.00 |
| Rel. importance  | 0.06 0.06 0.06 0.07 0.11 0.12 0.08 0.08 0.03 0.03 0.07 0.13 0.04 0.04 0.04 | 1.00 |

David Overwine
Retrofit Scaffolding Leveler

9 = Strong
3 = Moderate
1 = Weak

Appendix C1
APPENDIX D – PRODUCT OBJECTIVES

The following is a list of product objectives and how they will be obtained or measured to ensure that the goal of the project was met. The product objectives will focus on scaffolding frame tubing no larger than 2” OD. The leveler can be used on any kind of surface such as pavement, gravel, dry grass, and dry dirt. The leveling system is meant for scaffolding stacked no higher than an average two story home.

Ease of operation (12%):
4. Will have an umbilical controller to ensure no bending over for adjusting
5. No more than two operations to level each leveler.
6. Orientation of the controller’s controls will be intuitive; up will raise the scaffolding, down will lower the scaffolding, and lock will lock the leveler in place.

Ease of Assembly (10%):
4. Assembly will take no longer than a current leveling system.
5. No more than two parts (per leveler) for the operator to put together.
6. Parts will lock in place; no tools required

Safety (9%):
5. Capacity will be 4 times the intended load + scaffolding weight.
6. With maximum load, will not sink into any material listed above when placed on them.
7. The base will lock in place once leveled.
8. Total weight of each leveler will weigh no more than the max recommended lifting weight for a woman with an occasionally lifted load according to the International Labour Organization.

One person operated (9%):
3. Can be assembled by one person
4. Weight of parts will not be heavier than the recommended lifting load according to the International Labour Organization.

Reliability (9%):
6. Is able to lift the weight of the scaffolding’s frame base
7. Electrical components and gears will be within an enclosure to ensure that no outside contaminants will cause failure.
8. Materials chosen will not fail with the maximum intended design load.
9. All mechanical parts within the enclosure will be secured with Loctite so they will not come loose.
10. The leveling system will be level with and without load.

Repeatability (9%):
2. Materials chosen will be coated with Teflon or Xylan.

Compatibility (9%):
3. Will retrofit to any scaffolding frame tubing below 2” OD.
4. Feet will secure to any type of pavement, gravel, grass, and dirt.

Weather resistant (9%):
3. All sensitive parts will be within a corrosion resistant enclosure and sealed with gaskets or silicone to ensure that no outside contaminants will cause failure.
4. All exposed parts will be corrosive resistant.
Durability (9%):
5. Exposed materials chosen will be corrosion resistant or painted.
6. All enclosure seams will be sealed.
7. Electrical components will be soldered and covered with heat wrapped.
8. Loctite will be used on all bolts, nuts and screws.

Affordability (8%):
2. Will cost no more than a hydraulic leveling jack for a trailer.

Ease of storage (8%):
4. Will have a handle for easy carrying.
5. Will have flat sides so motion is more challenging during storage.
6. No bigger than a hydraulic leveling jack for a trailer.
## APPENDIX E – BUDGET

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<th>Actual Amount</th>
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<td>Motor</td>
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<td>Controller/ Switches</td>
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<td><strong>Total</strong></td>
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## APPENDIX F – SCHEDULE

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### APPENDIX G – WEIGHTED DECISION MATRIX

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APPENDIX H –COMPONENTS

All the Components that were assembled in SolidWorks

Drive Shaft Components
Linear Actuation Components

Weldments

Bumper and Grommet
APPENDIX I – COSMOS DATA

The linear actuation shaft was calculated using a SolidWorks program for stress analysis. The force of concern was the notched out section for the rack to be mounted to. The chart in the middle shown below shows the color scheme for different stresses. Before running the program a material is selected. After running the program, there are no major stresses with the force applied.

The vertical supports shown below were analyzed using SolidWorks as well. These beams are meant to support the force from the detent pin.
The connector base plate shown below was analyzed using SolidWorks. The plate was tested to ensure that it wouldn’t fold in half when the force is to it.