Wheelchair Tip Prevention Prototype

A Baccalaureate thesis submitted to the
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College of Engineering and Applied Science
University of Cincinnati

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requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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ACKNOWLEDGEMENTS

I would like to thank the IMS team, consisting of Michael Lyons, Patrick Brown, and David Siegel for all their help and funding on my project.

I want to thank Patricia Clark for giving me the opportunity to work with her company, Beechwood Home, on this project.

I also want to thank my advisor, Amir Salehpour, for all his help and support on this project.
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ABSTRACT

The purpose of this project was to find a way to stop wheelchairs from tipping to their sides. From this thought process a device was created to stop this tipping. It would be attached to the back of a wheelchair on the support wheels. The device has two positions, non-deployed and deployed. In the non-deployed position the legs, that would hold the chair up if tipped, are crossed behind the chair, out of the way. In the deployed position the legs are positioned downward at the ground so when tipping happens the legs are there to help stop the falling and keep the chair upright.

The parts that were manufactured were made of A36 steel. They were custom made so the price for the parts was quite high. This would not be viable for mass production so the parts would have to be made into dies so they could be made easier and faster.

The legs are deployed with the help of a torsional spring attached to the hinge that the legs are on. This helps the legs begin deployment and once the legs get past a certain point gravity helps finish the deployment at a greater speed.

Once the manufactured parts were received they were worked on further to make sure the moving parts would function properly. Cutting and grinding of some parts were done to accomplish this.

After this was done the entire device was assembled and attached to the chair. The device fit as expected and ran through its operations. It was able to be deployed without any problems, and can be locked in place when in the non-deployed position as well as the deployed position. From the information gained in the project it is found that this system could be possible. More work will have to be done to see what other material could be used besides the one used for the manufactured parts. Also a different deployment method could be researched to see if instead of a swing out deployment it could be a telescopic deployment. This would be a more effective way to get the legs out to the point needed and would produce a safer device. This means that it will get to the deployment point faster and would have a lower potential to hit objects or people around the device that is on the chair.
INTRODUCTION
The Beechwood Home is a not-for-profit long term care nursing facility. Most of their patients are in wheelchairs that stay at the facility for the rest of their lives. The patients are able to roam anywhere in and around the facility; because of this they encounter uneven ground or objects. This can cause the patient to fall over in their wheelchair and hurt themselves. With these problems Beechwood wants a way to keep their patients safe without taking away the freedom they have. Beechwood has said that this has happened 3 times in the beginning of the Fall season alone.

Beechwood wants to prevent tipping when a motorized wheelchair tips over on its side. They say that this is the main problem they run into with their patients and want an effective way to stop it from happening. Therefore a design will be developed to detect when the wheelchair is about to tip over so it can deploy a tip prevention system. With this system installed patients that are at risk of tipping over in their chair will be safe and able to travel around without worry of being hurt from falling over.

RESEARCH
INTERVIEWS
Michael Lyons
Michael Lyons is the Program Coordinator for the Intelligent Maintenance Systems (IMS) center at the University of Cincinnati. The project is funded through IMS and their team will be assisting on the project as needed. Michael discussed the project and would be needed to design and build a device to stop a wheelchair from tipping sideways. He described what the situation was at Beechwood Homes and how the situation could be approached. He said that the Beechwood patients were able to go wherever they wanted to so they were running into some issues with patients tipping over. (1)

Patricia Clark
Patricia Clark is the Chief Executive Officer at The Beechwood Homes in Cincinnati, Ohio. She discussed further what exactly they wanted out of the project and showed the facility to see what would be the best way to deal with the problem. Patricia expressed that she wanted her patients to be safe but to still have the freedom they have now. So being able to keep the patients independent is a big thing for them. The facility has a large interior with multiple floors and many rooms for the patients to do whatever they want in. Outside there is lots of space for the patients to move around and enjoy the outdoors. This is where the problem comes in of wheelchairs tipping over.

In the tour she described many different patients with a wide variety of different syndromes or diseases. Patricia explained that they have many different cases.
in their facility and that a lot of them have slow reaction time. So even if they see that they will run into something or be in danger of tipping over they can’t react fast enough to stop it. Therefore they want something that can be deployed automatically so the operator doesn’t have to be worrying about activating the device. (2) Figure 1 depicts a powered wheelchair in use at The Beechwood Homes.

**EXISTING PRODUCT ANALYSIS**

**AMG Anti-tip device**

Designed specifically for the AMG line of wheelchairs, these anti-tip devices snap into the rear tubing using a push button mechanism. Slightly angled and equipped with a rubber stopper, this serves to prevent the chair from tipping over.

It is a very simple design but very effective. It has rubber or plastic ends to prevent scratching and also to grip the ground when it comes into contact. The device is low to the ground so if the wheelchair begins to tip backwards the device catches the wheelchair before it goes too far. Figure 2 and 3 depict the anti-tip device. The device is small and out of the way, is easy to install, and comes at a low cost. (3)

![Figure 2 - AMG Anti-tip device on wheelchair](image)

![Figure 3 - AMG Anti-tip device](image)

**Comfy Wheelchair Anti-Tip Device**

The **Comfy™ Anti-tip Device** is height adjustable to provide the exact angle needed for stability. No tools are necessary for installing the **Comfy™ Wheelchair Anti-Tip Device.** (4)

It attaches to the lower back portion of the wheelchair to prevent backward tipping. On this model the device that hits the ground is metal instead of plastic. This could cause unwanted scraping on the ground. This model is also adjustable so it can be higher or lower to the ground depending on what is needed for the situation. It is also has a spring mechanism on the device for easy removal when not needed. Figure 4 depicts the Comfy wheelchair anti-tip device. (4)

![Figure 4 - Comfy Wheelchair anti-tip device](image)
Adjustable Universal Wheelchair Anti Tipper with Wheels – STD807
The Adjustable, Universal Rear Anti Tippers with Wheels in black by Drive Medical can be used on most leading manufacturer’s wheelchairs. The unique, spring loaded, flip lock mechanism easily flips up and down for traversing curbs safely and securely. A universal spacing sleeve can be added or removed to accommodate a secure fit with Drive Medical Viper Plus Wheelchair. (5)

This device can be paired with the other backwards tip prevention devices for manual wheelchairs. This is a little different because unlike the other ones this device has wheels, where the other ones do not. This allows the wheelchair to go backwards as it starts to tip and this device catches it. The other two anti-tip devices listed both stop the movement of the wheelchair as well as stop it from tipping. This device lets the wheelchair continue to move backward rather than stop it, because of the wheels on this anti-tip device. Figure 5 depicts the Adjustable Universal Wheelchair anti tipper as it would be seen on a wheelchair. (5)

Sun Mountain Three 5 Stand Bag
Built to carry, the Sun Mountain Three 5 Stand Bag is lightweight and uses the E-Z Fit dual strap system and a state-of-the-art roller bottom leg mechanism. The E-Z Fit straps are easy to adjust and contoured for comfort, and the Three 5 also offers several cart-friendly features such as a leg-lock system and cart-friendly bottom. (6)

The stand legs are activated by a button on the bottom of the bag and when the bag is leaned forward pressure is applied to the button, deploying the legs. This holds the bag up so clubs from inside the bag can be easily accessed. A similar idea could be implemented onto to sides of a powered wheelchair to provide support if the chair were to ever tip over. The legs would have to be very strong to support the heavy weight of the powered chair and there would have to be some sort of deploying system. Figure 6 depicts the golf bag with the stand legs deployed. (6)
**PRODUCT RESEARCH SUMMARY**
Positive and negative aspects of each of the products detailed above were taken into account with respect to information gained through interviews, and a list of design characteristics. These characteristics were put into categories and filtered. The product features determined for this product would be:

- Reliable
- Safe
- Have a good range of operation
- Affordable
- Easy to maintain
- Compact

**CUSTOMER FEEDBACK, FEATURES AND OBJECTIVES**

**SURVEY ANALYSIS**
A customer survey was created to collect feedback on the product features, and to see how they liked the current anti-tip devices they had installed on the manual chairs. The customer survey was distributed to a handful of employees at Beechwood Homes to get their opinion on the matter, since the device is being made for their facility and they work with the patients and wheelchairs first hand. A 1 to 5 rating system was used to gather data from the customers, 1 being the lowest and 5 being the highest. The customer survey with complete results can be found in Appendix B.

In designing a product compromises must be made for various reasons such as time, budget, or customer feedback. A relative weight was calculated for each of the product features to assist in picking these features. Customer importance and current satisfaction were adjusted by planned satisfaction improvement ratios and designers multipliers to determine the relative weights of each Product Feature, all of which can be found in Table 1.

**Table 1 - Customer Survey Results Analysis**

<table>
<thead>
<tr>
<th>Product Features</th>
<th>Customer importance</th>
<th>Designer’s Multiplier</th>
<th>Current Satisfaction</th>
<th>Planned Satisfaction</th>
<th>Improvement ratio</th>
<th>Modified Importance</th>
<th>Relative weight</th>
<th>Relative weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>5</td>
<td>1.1</td>
<td>3.2</td>
<td>5</td>
<td>1.6</td>
<td>8.6</td>
<td>0.21</td>
<td>21%</td>
</tr>
<tr>
<td>Safety</td>
<td>5</td>
<td>1.1</td>
<td>3.2</td>
<td>5</td>
<td>1.6</td>
<td>8.6</td>
<td>0.21</td>
<td>21%</td>
</tr>
<tr>
<td>Range of Operation</td>
<td>3.8</td>
<td>0.9</td>
<td>1.4</td>
<td>3.5</td>
<td>2.5</td>
<td>8.6</td>
<td>0.21</td>
<td>21%</td>
</tr>
<tr>
<td>Price</td>
<td>3.2</td>
<td>1.0</td>
<td>1.4</td>
<td>3</td>
<td>2.1</td>
<td>6.9</td>
<td>0.17</td>
<td>17%</td>
</tr>
<tr>
<td>Ease of Maintenance</td>
<td>4.2</td>
<td>1.0</td>
<td>3.4</td>
<td>4</td>
<td>1.2</td>
<td>4.9</td>
<td>0.12</td>
<td>12%</td>
</tr>
<tr>
<td>Size</td>
<td>3</td>
<td>0.9</td>
<td>2.8</td>
<td>3</td>
<td>1.1</td>
<td>2.9</td>
<td>0.07</td>
<td>7%</td>
</tr>
</tbody>
</table>
Customer Importance
The customer importance level for each feature was calculated to determine which features were most important to the customer, in this case Beechwood Homes. This was done by averaging the selected importance for each feature from the surveys collected. The most important features were reliability and safety, the least important was size. With the results gathered reliability and safety were the most important, and size was the least important.

Designer’s Multiplier
The designer’s multiplier allows for additional importance to be placed on certain aspects of the design as seen fit by the person making the device. On this product I chose to focus more on reliability and safety, and less on range of operation and size. Beechwood Homes is very concerned with their patient’s wellbeing so emphasizing that in the building of the anti-tip device is important.

Current Satisfaction
The current satisfaction for each feature was calculated by taking the average of the survey results in regards to the current anti-tip devices they have in use at Beechwood right now. Beechwood Homes are most satisfied with ease of maintenance and least satisfied with price and range of operation.

Planned Satisfaction
Planned satisfaction is the target customer satisfaction that the designer will try to reach to achieve with the product. The device must be reliable and safe enough for the patient so that the wheelchair can be operated and be able to stop any tipping that may occur. These two stats are the most important because they directly correlate with the main objective of the project, to keep the patients safe by preventing wheelchair tipping. The intended result is that the planned satisfaction is higher than the current satisfaction which is shown in Table 1.

Product Price
The last part of the customer survey was for the price range. Beechwood Homes was given a range of price options that they would be willing to pay for the new product. Results can be found in Table 2.

<table>
<thead>
<tr>
<th>Price Range</th>
<th>Customer Population Selection Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>$50 - $75</td>
<td>0%</td>
</tr>
<tr>
<td>$75 - $100</td>
<td>66%</td>
</tr>
<tr>
<td>$100 - $150</td>
<td>0%</td>
</tr>
<tr>
<td>$150 - $250</td>
<td>33%</td>
</tr>
</tbody>
</table>

It was determined that the target price range would be between $75 and $250. Assuming that if the higher range is chosen the 66% that chose the $75-$100 range would not be satisfied, but the 33% will be satisfied.
Customer Survey Summary
In summary, the analysis performed on the customer survey resulted in customer features that have a certain priority on them which helps the designer determine where more or less work should be focused. For this product size and ease of maintenance can be sacrificed for more work in safety, reliability and range of operation.

PRODUCT FEATURES AND OBJECTIVES
The product features were then analyzed to determine the engineering characteristics. These engineering characteristics, the product objectives, can be found in Table 3 along with the product features and their relative weights as calculated in the customer survey. The complete Analysis of the product objectives can be found in Appendix C.

Table 3 - Product Features and Product Objectives

<table>
<thead>
<tr>
<th>Product Feature</th>
<th>Relative Weight</th>
<th>Product Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>21%</td>
<td>Anti-tip device will be able to withstand force of the wheelchair and patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Device will last an extended period of time before needing to be replaced</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensor will be able to operate for as long as the wheelchair has charge to run</td>
</tr>
<tr>
<td>Safety</td>
<td>21%</td>
<td>Device will be out of the way to prevent anyone else from running into it</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Will prevent the wheelchair from tipping over from the sides</td>
</tr>
<tr>
<td>Range of Operation</td>
<td>21%</td>
<td>Can stop tipping from many different angles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can be changed to different heights and angles depending on the terrain being</td>
</tr>
<tr>
<td></td>
<td></td>
<td>encountered</td>
</tr>
<tr>
<td>Price</td>
<td>17%</td>
<td>Built using standard parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Build the device in the most cost effective way possible</td>
</tr>
<tr>
<td>Ease of Maintenance</td>
<td>12%</td>
<td>Can use simple tools to work on the device as needed</td>
</tr>
<tr>
<td>Size</td>
<td>7%</td>
<td>Device will be a manageable size so it is out of the way for others around wheelchair</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Device will not interfere with anything on the wheelchair itself</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Won’t make a weight difference in operation the wheelchair</td>
</tr>
</tbody>
</table>
QUALITY FUNCTION DEPLOYMENT ANALYSIS
The quality function deployment (QFD) was developed to bring personal interface to modern manufacturing and business. The QFD links the needs of the customer with design, development, engineering, manufacturing and service functions. (7) The customer satisfaction component of the QFD was presented in Table 1.

The rest of the QFD focuses on the correlation between product features and product objectives. The QFD used the designer defined correlation factors and the relative weight of each product feature to determine the relative importance of the engineering characteristics. From the QFD it is found that the sensor for the device is the most important at 28%. The sensor is an important part of the design because it will alert the device when to deploy to stop the wheelchair from tipping over. If something were to happen to this part of the product it would jeopardize the safety of the patient. This table shows which characteristics should be focused on the most when in the designing phases of the product. The higher percent the more important and more focus should be put into that aspect of the design.

Table 4 shows the prioritized list of engineering characteristics and their relative importance. The complete QFD is shown in Appendix D.

<table>
<thead>
<tr>
<th>Engineering Characteristics</th>
<th>Relative Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor for device deployment</td>
<td>28%</td>
</tr>
<tr>
<td>Standard components</td>
<td>19%</td>
</tr>
<tr>
<td>Adjustable</td>
<td>16%</td>
</tr>
<tr>
<td>Force applied on part</td>
<td>14%</td>
</tr>
<tr>
<td>Device out of the way</td>
<td>11%</td>
</tr>
<tr>
<td>Disassembled using simple parts</td>
<td>7%</td>
</tr>
<tr>
<td>Weight</td>
<td>4%</td>
</tr>
</tbody>
</table>

SCHEDULE AND BUDGET
SCHEDULE
The schedule for the design of the product is put forth by the designer to follow so that they have set goals to reach. Checkpoints must be reached and completed before the next can be started as the process builds on top of itself. Time has been allotted for the time off during Christmas and Spring break, but work can be done during these times as needed. The project is on track with the schedule as it stands and should keep a similar pace into the final report due in April. The dark blue sections are the time period each task is worked on. The red sections show the breaks in the calendar for Christmas and Spring break. The complete schedule can be found in Appendix E.
Table 5 - Comprehensive Wheelchair Tip Prevention Overview

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<tbody>
<tr>
<td>Proof of Design Agreement and Concept Selection</td>
<td>5</td>
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<td>3D Model Development</td>
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<td>Finalize Design and Associated Documentation</td>
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<tr>
<td>Ordering, Fabrication and Assembly of Parts</td>
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<tr>
<td>Oral Report and Presentations</td>
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<tr>
<td>Product Testing and Design Modification</td>
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<tr>
<td>Design Expo</td>
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<tr>
<td>Finalize Library Report and Submit to Blackboard</td>
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**BUDGET**

The project budget is an estimate of what the product will cost to make. Each component is listed and priced individually. The budget will have the real values entered once the design is finalized and parts are bought. The Budget is shown in Appendix F.

Table 6 - Comprehensive Wheelchair Tip Prevention Budget

<table>
<thead>
<tr>
<th>Materials/Components of Labor</th>
<th>Forecasted Cost</th>
<th>Actual Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame</td>
<td>$60</td>
<td>$3200</td>
</tr>
<tr>
<td>Wiring</td>
<td>$15</td>
<td></td>
</tr>
<tr>
<td>Battery</td>
<td>$15</td>
<td></td>
</tr>
<tr>
<td>Sensor</td>
<td>$40</td>
<td></td>
</tr>
<tr>
<td>Misc.</td>
<td>$20</td>
<td>$150</td>
</tr>
<tr>
<td>Total</td>
<td>$150</td>
<td>$3350</td>
</tr>
</tbody>
</table>
DESIGN ANALYSIS PROCESS

BRAINSTORMING

Current motorized wheelchairs do not have any kind of tip prevention system passed the wheels that come installed on the chair. Also there are no parts or devices you can buy to attach to them to stop tipping. There are only anti-tip devices for Manuel chairs and even those are only for forward and backward tipping. Beechwoods patients encounter many kinds of uneven ground and need to be able to stop side tipping from occurring. A few issues need to be addressed in order to solve the problem Beechwood is having. One if that the motorized wheelchairs are very heavy, weighing 300 pounds or more. With this kind of weight whatever is designed needs to be strong enough to hold against the chair and the patient. The second is where and how the device will be applied to the chair. The chair is covered in lots of parts that can’t be interfered with, so a way to place the device on the chair while still keeping it function is a must.

In the section below there is a list of brainstorming ideas in conceptual form.

CONCEPT SKETCHES

Cell design concept #1
This concept would catch the wheelchair using extendable rods on either side that deploy once the chair detects tipping. Device uses telescopic deployment. Tipping could be detected using an actuator.

Pro’s
- Can catch wheelchair from any side angle
- Placed close to ground to stop tipping as soon as possible
- Low to ground

Con’s
- Needs to support a lot of weight
- Not a lot of room to place device

Figure 7 - Cell Design Concept #1
**Cell design concept #2**

This design is similar to the first but instead a kind of telescope deployment the rods flip out to deploy. They would be placed on the wheelchair so that they are at an angle with the ground attached to one of the supports on the chair.

**Pro’s**
- Rigid system that doesn’t need to move
- Can be attached to the support wheels of wheelchair

**Con’s**
- Would have to be held by gears or pins that would have to handle a large load
- The flip system would need to deploy soon enough to snap into place, or the device won’t deploy properly

---

**Cell design concept #3**

This design is meant to have some device attach to the motorized wheels. When tipping is detected the device will extend of the wheel to stop the tipping that is happening.

**Pro’s**
- Easy to attach to wheel
- Low to ground

**Con’s**
- Won’t stop all side tipping
- Could damage motorized wheel it is attached to
- Needs to be small enough to fit through a doorway
Cell design concept #4
This design would have either 1 or 2 rods per side of the wheelchair. The rods would act like legs that would deploy down to stop tipping when it occurred. Similar to how the legs of a golf bag work.

Pro’s
- Could easily stop tipping
- Might be able to get away with one set of legs rather than two
- Not many moving parts

Con’s
- Legs could have a higher chance to snap with the amount of force they encounter
- May be difficult to find a place to put legs higher on wheelchair

Cell design concept #5
This design is similar to the flip out system where it will flip out from the wheelchair. But this design will come out closer and horizontal to the ground.

Pro’s
- Easily stop tipping
- Low to ground

Con’s
- Hard to find a spot on the wheelchair that it can deploy
- Needs 2 rods per side
Cell design concept #6
This design is made to attach to the bottom of the wheelchair. It is a plate that could have wheels on it so that when it is deployed it won’t scratch and wear it or the ground. When the wheelchair detects tipping the plate pushes down on the ground. Therefore when one side is closer to the ground the plate will push up off the ground evening out the chair and preventing tipping.

Pro’s
- Doesn’t require anything to deploy outside the area of the wheelchair
- Out of the way from patient and surroundings

Con’s
- Would need much more force to be applied
- Not much space under wheelchair to work with

Cell design concept #7
This design completely replaces the support wheels in the front and back of the motorized wheelchair. In their place new wheels will take their place that will be able to move to prevent tipping. Once tipping is detected the wheels will move accordingly to prevent that falling motion.

Pro’s
- Would be very strong
- Wouldn’t have to add extra parts onto chair, only replace existing ones

Con’s
- Hard to install/replace wheels
- May not be able to deploy far enough to stop all tipping
CONCEPT DESIGN

EVALUATION

Evaluating all the concepts using pros & cons to weigh the differences and using the customer feedback from the survey a weighted evaluation was made on customer requirements. Only a few of the most promising options for the wheelchairs are showed in the table below. A rated score is given to show the best design concept for the problem.

Table 7 - Tip Prevention Analysis

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Concept 1, Telescopic Deployment</th>
<th>Concept 2, Flipout Deployment</th>
<th>Concept 4, Kickstand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance Factor</td>
<td>Rating</td>
<td>Weighted Rating</td>
<td>Rating</td>
</tr>
<tr>
<td>Reliability</td>
<td>21%</td>
<td>3</td>
<td>0.63</td>
</tr>
<tr>
<td>Safety</td>
<td>21%</td>
<td>3</td>
<td>0.63</td>
</tr>
<tr>
<td>Range of Operation</td>
<td>21%</td>
<td>3</td>
<td>0.63</td>
</tr>
<tr>
<td>Price</td>
<td>17%</td>
<td>2</td>
<td>0.34</td>
</tr>
<tr>
<td>Ease of Maintenance</td>
<td>12%</td>
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<td>0.36</td>
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<tr>
<td>Size</td>
<td>7%</td>
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<td>0.14</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>-</td>
<td>2.73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rating value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsatisfactory</td>
</tr>
<tr>
<td>Tolerable</td>
</tr>
<tr>
<td>Adequate</td>
</tr>
<tr>
<td>Good</td>
</tr>
<tr>
<td>Excellent</td>
</tr>
</tbody>
</table>

SELECTION OF PREFERRED DESIGN

The best concept for this process will be Concept 2, using the flip out deployment. This device allows us to attach it to the lower portion of the wheelchair so that when it deploys it stops tipping early. Not only that, but it will also be out of the way, compact and easy to maintain.

Below is a further concept of what the flipout deployment device could look like when completed. It will attach to the back support wheels. The legs that flip out will be stored
behind the chair and when tipping is detected the legs can be deployed as shown below. The legs will be attached to a bracket that is locked in place on the back supports of the wheels. This design will provide a sturdy area for the legs to be deployed and hold the weight of the chair if it should tip to its side.

Wheels will be added to the ends of the legs so that if the wheelchair tips over the legs will hit the ground and slide. This helps so the legs don’t have to support a lot of weight over an extended period of time. The wheels allow the wheelchair to slide if it does tip so it has a chance to go back into its upright position.

Figure 14 – Device deployed
REFINEMENT

DESIGN ANALYSIS

Material Properties

The material used in the design is ASTM A36 Steel (8). This material will be used for the bracket, legs, support wall and hinge that will have to be manufactured. Most if not all of the other parts in the device will be bought and incorporated into the design.

Selection of Components

In the device the following components will be used:

- Caster wheels
- Springs
- Safety locking mechanism
- Clamps
- Pins
- Screws

Caster Wheels

The caster wheels will be attached to the ends of the legs. This is so when the legs are deployed they slide on the ground. This allows the wheelchair to slide on the leg if it tips which could put the chair back in its upright position. Below is the Heavy Duty Threaded Stem Caster (9) that will be attached to the end of each leg.

Figure 15 – Caster Wheels
Springs

The hinges used in the device will be how the legs deploy with the help of a torsional spring. The legs will rotate around these hinges after being activated. The hinges being used are going to be manufactured and put together once received. The hinge will also be made of A36 steel. A spring and a pin will be bought and attached to the hinge.

Here is the design for the hinge to be used for the device. It will be attached to the bracket and the leg.

The spring that will be used to make the hinge deploy is called a Music Wire Torsion Spring. (10)

The pin that will be used in the hinge is called an Alloy Steel Dowel Pin. (11) The pin is rated to take a load of 65,000 lbs so it will not break in the application it will be used in.

Safety Locking Mechanism

The safety locking mechanism will lock the legs in place before deployment. This device is simulating what will hold the legs in place before deployment happens. If this device were attached to a sensor it could actuate this device to tell it to release and then the legs would then move into their deployed position. The mechanism that will be used is called a Push/Pull Action toggle Clamp. (12). Here is a picture of what the device looks like.
Clamps

The clamp will be the connection between the chair and the support wall. It will be tightened to these two objects to provide support for the device when it is deployed. Here is a picture of the type of clamp that will be used for the design. It is called a Medium Pressure Single Hole Repair Clamp. (13)

Screws

The main parts: base, bracket and hinge are attached to each other with the use of screws. This allows the device to be assembled or disassembled easily for any number of purposes. The pin is also held in place by set screws that go through the hinge to stop the pin from falling out of it. Once the base is secured to the wheelchair with the clamp and tubing, the screws hold the rest of the device together.

Stress Analysis

Angle of Tipping and Area Calculation

Stress analysis was done on the legs to determine how much force would be applied when the legs contacted the ground.

\[ \phi_{tip} = \arcsin\left(\frac{h_{tip}}{2A}\right) \]

This equation was used to find the tipping angle of the wheelchair. “A” represents the distance from the CG of the wheelchair to the outside. \(h_{tip}\) stands for the height under the highest tipped wheel.

\[ \phi_{tip} = \arcsin\left(\frac{7.5}{2(9.5)}\right) \]

\[ \phi_{tip} = 23.24^\circ \]

This is the angle the chair will fall at when tipped to the side. The device should be deployed before the chair gets to this angle. With this in mind the device will deploy

Figure 18 - Clamp

Figure 19 – Equation Pictorial
when the chair tips 15 degrees. The leg is already at 35 degrees so the total angle for when the chair contacts the ground is 58.24 degrees.

From this angle the force can be found. The weight of the chair is given to be 488 lbs, and the assumed weight of the person in the chair is 200 lbs. These combined convert to 312.06 kg.

\[ F = mg \cos \theta \]
\[ F = (321.06)(9.81)(\cos 58.24) \]
\[ F = 1657.83 \text{ N} \]
\[ F = 372.695 \text{ lbs} \]

This is the force that the legs will have to withstand they that they don’t fail. To make sure the legs will be able to withstand the force the surface area of the legs will be calculated. The area is found with the following equation. Yield stress is found to be 250 MPa from the MatWeb properties page (8).

\[ \text{Area} > \frac{(F)(\text{Safety Factor})}{\text{Yield Stress}} \]
\[ \text{Area} > \frac{1657.83(3)}{250 \times 10^6} \]
\[ \text{Area} > 19.894 \text{ mm}^2 \]

Therefor each leg needs to have a minimum of 19.894 mm\(^2\) surface area so they don’t break including a safety factor of 3. Going beyond this value would be better so that any additional weight can be accounted for. The legs have a surface area of 1290.32 mm\(^2\) so it is well above the minimum required.

Bending and Shear Stress

Bending and shearing needs to be accounted for in the legs to make sure that they will not break under load. The 1657.83 N(372.695 lbs) can be used as a starting point for these calculations.

Shear Stress

\[ T = \frac{F \ast (\text{Safety Factor})}{A} \]
\[ T = \frac{372.695 \text{ lbs} \ast 3}{1 \text{ in} \ast 2 \text{ in}} \]
\[ T = 559.0425 \text{ psi} \]
The A36 steel material has a shearing modulus of 11500 ksi. The found shear stress applied to the leg is far below that of the material. Therefore no shearing will occur.

Bending Stress

\[ \text{Moment} = F \times \text{Length} \]

\[ \text{Moment} = 372.695 \text{lfs} \times 13.25 \text{in} \]

\[ \sigma = \frac{6 \times M \times (\text{Factor Safety})}{b \times h^2} \]

\[ \sigma = \frac{6 \times 4938.2 (\text{lfs} - \text{in}) \times 3}{13.25 \text{in} \times 2 \text{in}^2} \]

\[ \sigma = 1677.1245 \text{ psi} \]

Yield stress is 250 MPA, converting this to psi becomes 36259.425 psi. The bending stress found is far below the materials so therefore bending will not occur.

Spring Forces

For the leg to be able to deploy it needs to have a strong enough spring to push it out in that direction. The time it takes to deploy the leg needs to be found.

Spring constant

\[ k = \frac{P}{\text{angle}} \]

\[ k = \frac{P28 \text{ lbf} - \text{in}}{180 \text{ deg}} \]

\[ k = 0.15556 \frac{\text{lbf} - \text{in}}{\text{deg}} \]

Converted to rads

\[ k_{\text{rad}} = \frac{k \times 360}{2 \times \pi} \]
Mass of leg obtained from the volume of the leg and the density of the A36 steel material.

\[ \text{Mass} = V \times \rho \]

\[ \text{Mass} = 26.5 \text{in}^3 \times 0.284 \frac{\text{lb}}{\text{in}^3} \]

\[ \text{Mass} = 7.526 \text{ lbs} \]

Take this mass and add it to the mass of the caster wheels that will be attached to them. The caster wheels are 1.4 lbs so the new mass becomes 8.926 lbs.

Moment of Inertia

The given moment of inertia from the solid works model of the leg is 183 psi. Using this number with another equation gives us the moment of inertia. In the equation below r is the distance from the pivot point to the center of mass.

\[ I = mr^2 \]

\[ I = 8.926 \text{lbs} \times 6.625 \text{in}^2 \]

\[ I = 391.76 \text{ lbs} - \text{in}^2 \]

Add this value to the original 183 the final moment of inertia is 574.76 \text{ lbs} - \text{in}^2.

Convert this to \text{slugs} - \text{ft}^2 to get 0.1239 \text{slugs} - \text{ft}^2

Time to reach final angular position

\[ \text{time} = \sqrt{\frac{I \left(\text{in slugs} - \text{ft}^2\right)}{k} \times \cos^{-1} \left(\frac{\text{final spring angle}}{\text{initial angle}}\right)} \]
From this equation it is found that the leg will deploy from its upright position to its deployed position in 0.64 seconds. This is an adequate amount of time to allow the leg to get into position to stop the wheelchair from tipping over.

**MODELING**

The following are concepts of what the device could look like when finished.

![Figure 20 – Device in deployed position](image-url)
Figure 21 – Device in upright position

Figure 22 – Top view of device
The base is what the bracket is mounted to. This connects the wheelchair and the device together.

Figure 23 – Base

Figure 24 - Bracket
The Bracket is used to help reinforce the leg when it is deployed. The hinge connects the bracket and leg together.

![Figure 25 - Leg](image)

The leg is what contacts the ground when tipping occurs and stops the chair from tipping. A caster wheel will be attached to the end of each leg to help the chair get back to its upright position when tipped.

**IMPLEMENTATION**

**FABRICATION**

As said previously the legs, bracket, support wall and hinge will be made out of the ASTM A36 Steel. These will be special ordered for this device from Stewart Assembly and Machining. The rest of the components being used will be bought separately and built onto the device.

Once the parts were received from the manufacturer they were assembled and checked for interference and friction. Once problems in these areas were found they were fixed through cutting of the material and filling down certain areas that were creating friction. These processes were continued until the device was operating in a satisfactory condition. Once this was complete the device was able to deploy with the help of the spring on the hinge of the leg. Once the spring pushed the leg past a certain point gravity would help push it the rest of the way, accelerating the leg to its final deployed position.
ASSEMBLY

Once the parts were corrected for problems the device was assembled. The entire device is attached to the base that is placed on the support of the wheels on the wheelchair. The base is connected by a half tube to the chair. A clamp was then placed on these tubes to hold the device in place on the chair. The bracket is then attached to the base. The hinges are then attached to the bracket and the pin and leg is attached to the hinge mechanism. Once all parts are assembled it looks like what is shown below.

![Figure 26 – Fully Assembled Device](image)

![Figure 27 – Hinge Assembly](image)
CONCLUSION

After assembly and testing of the anti-tip device it is found to work. The device that has been made is a prototype and should not be used in the field yet. If this idea were to be worked on in the future I would recommend researching to find a more lightweight material and hollow out parts of the device you can. Also instead of the leg swinging out to deploy a telescopic deployment action could be researched. I believe if successfully done this kind of deployment would be more effective and safer to implement. If this device were to be taken to the market the price for the device can go down because the parts can be made out of dies which would bring the cost down.

Overall I think that this solution is viable and I believe that it could be worked on further to become a useful device that can help those that are in wheelchairs.
WORKS CITED
APPENDIX A - RESEARCH

Interview with Program Coordinator: Michael Lyons, University of Cincinnati/IMS Center. Rhodes Hall 503, 513-556-4650

We met to talk about the project and what would be requested to be done in it. He described that patients at Beechwood are allowed to roam around the facility as they choose therefore patients run into uneven ground and have potential to fall over. He said in the last month 3 patients have fallen over and have been unable to get up. He wants me to design a device that will detect if the wheelchair is tipping over and then it will deploy a device to stop the wheelchair from tipping. All of the patients at Beechwood are in wheelchairs so they really want something that can serve this purpose. Something that can be integrated easily to the wheelchair without hindering the patient or the wheelchair.

Important features to include: Sensing system to detect tipping. Device to deploy to prevent tipping

Interview with Chief Executive Officer: Patricia Clark, 2140 Pogue Avenue. Cincinnati, Ohio 45208. 513-321-9294 pclark@beechwoodhome.com

I met with Patricia and the IMS group that would be funding my project to talk more in detail what would be done. She explained to us what kind of problems they have been having with wheelchairs tipping over and what they were after. I then discussed with the IMS group what kind of plans we had to move forward with. We then got a tour of the facility to look at some of the wheelchairs that the patients used. We got an idea what we would be building for as some of their patients use motorized wheelchairs. So I will have to design some device that will work on both.

Important features to include: Tip prevention from all sides, supports the weight of the wheelchair plus patient
### Anti-tip Device
These anti-tip devices snap into the rear tubing using a push button mechanism. Slightly angled and equipped with a rubber stopper, this serves to prevent the chair from tipping over.

<table>
<thead>
<tr>
<th>Prevents chair from tipping over backwards.</th>
<th>Prevents chair from tipping over backwards.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will not help stop tipping from multiple directions</td>
<td>Cost effective</td>
</tr>
<tr>
<td>Small and out of the way</td>
<td>Easy fix to falling backwards</td>
</tr>
<tr>
<td>May not stop all falls backwards depending on how much force is applied</td>
<td></td>
</tr>
</tbody>
</table>

[http://www.amgmedical.com/site/our_products_results.asp?trouv1=701-165](http://www.amgmedical.com/site/our_products_results.asp?trouv1=701-165)  
10/13/2013
<table>
<thead>
<tr>
<th><strong>Comfy™ Wheelchair Anti-Tip Device</strong></th>
<th>Prevents chair from tipping over backwards. Will not help stop tipping from multiple directions. Small and out of the way Easy fix to falling backwards Adjustable for different angles and heights May not stop all falls depending on the angle of fall potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>When attached to the bottom of a wheelchair, these easy-to-install anti-tip devices provide stability and security to the wheelchair when patients are placed in a reclining position. Spring mechanism allows for easy release of the device when not in use. The <strong>Comfy™ Anti-tip Device</strong> is height adjustable to provide the exact angle needed for stability. No tools are necessary for installing the <strong>Comfy™ Wheelchair Anti-Tip Device</strong>.</td>
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<td><img src="image" alt="Height-adjustable tips provide the exact angle needed for stability." /></td>
<td><a href="https://www.ncmedical.com/item_202.html">https://www.ncmedical.com/item_202.html 10/13/2013</a></td>
</tr>
<tr>
<td><strong>Adjustable Universal Wheelchair Anti Tipper with Wheels - stds807</strong></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td></td>
</tr>
<tr>
<td>The Adjustable, Universal Rear Anti Tippers with Wheels in black by Drive Medical can be used on most leading manufacturer’s wheelchairs. The unique, spring loaded, flip lock mechanism easily flips up and down for traversing curbs safely and securely. A universal spacing sleeve can be added or removed to accommodate a secure fit with Drive Medical Viper Plus Wheelchair.</td>
<td></td>
</tr>
<tr>
<td>Prevents chair from tipping over backwards. Will not help stop tipping from multiple directions. Cost effective Easy fix to falling forwards Adjustable for different angles and heights May not stop all falls depending on the angle of fall potential</td>
<td></td>
</tr>
<tr>
<td>10/13/2013</td>
<td></td>
</tr>
</tbody>
</table>
Sun Mountain Three 5 Stand Bag

The stand on golf bags can be found on various models and is good for keeping your golf bag standing while not holding it. It is deployed by placing it on an angle on the ground and a button on the bottom is pushed forcing the legs outward for the golf bag to lean on. Once the legs are extended outward the bag looks like it does in the picture below. This is a type of support device and a similar process could be followed for wheelchair tip prevention.


10/15/2013

Easy to use
Easy to understand
Cheap
Has to be deployed by person, won’t really happen on its own
Sturdy enough to hold what is in the bag
If something similar was made for a wheelchair it would have to be very strong so it could support the weight of the chair plus the person in it
APPENDIX B – SURVEY

WHEELCHAIR TIP PREVENTION CUSTOMER SURVEY

The Wheelchair tip prevention will be used to help make the wheelchairs at The Beechwood Homes safer for its patients. Patients run into uneven and angled ground which can be difficult to overcome. Because of this they want to have some device that will prevent their wheelchairs from falling over, saving their patients from the potential harm that could be caused by this.

How important is each feature to you for the design of a new wheelchair tip prevention device?
Please circle the appropriate answer.  
1 = low importance  
5 = high importance  

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5(5)</th>
<th>N/A</th>
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</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5(5)</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5(5)</td>
<td>N/A</td>
<td>5</td>
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<tr>
<td>Range of Operation</td>
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<td>4</td>
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<td>3</td>
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<tr>
<td>Ease of Maintenance</td>
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<td>4(2)</td>
<td>5(2)</td>
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<td>4.2</td>
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<tr>
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<td>2</td>
<td>3(1)</td>
<td>4(2)</td>
<td>5(1)</td>
<td>N/A</td>
<td>4</td>
</tr>
</tbody>
</table>

How satisfied are you with the current tip prevention device on wheelchairs that you have?
Please circle the appropriate answer.  
1 = low importance  
5 = high importance  

<table>
<thead>
<tr>
<th>Feature</th>
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<th>2(1)</th>
<th>3(3)</th>
<th>4</th>
<th>5(1)</th>
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<td>Reliability</td>
<td>1</td>
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<td>3(3)</td>
<td>4</td>
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<td>Safety</td>
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<tr>
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How much would you be willing to spend?

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<tbody>
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<td>$50–$75</td>
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<tr>
<td>$75–$100</td>
<td>2</td>
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<tr>
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Avg= $125

Thank you for your time.
APPENDIX C – PRODUCT OBJECTIVES

OBJECTIVES
Based on the survey, the product objectives are the list of features that are taken into consideration. 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.

Reliability 21%
- Anti-tip device will be able to withstand the force of the wheelchair plus patient
- Will last a long time
- If sensor is used it will be able to operate for an extended period of time before needing to be replaced

Safety 21%
- Device will be out of the way to prevent anyone else running into device attached to wheelchair
- Will help keep the patient in the wheelchair safe from tipping over

Range of operation 21%
- Will be able to stop tips from many directions
- Can be changed to different heights/angles depending on the terrain being encountered

Price 17%
- Built using standard parts
- Build the device in the most cost effective way possible

Ease of maintenance 12%
- Anti-tip device will be made with standard parts
- Can be disassembled easily when needed using simple tools

Size 7%
- Device will be a manageable size so it is out of the way of others around the wheelchair
- Device will also be out of the way for the patient on the wheelchair so it doesn’t interfere with anything else on the wheelchair
- Small enough so it doesn’t make a weight difference for the patient
## APPENDIX D – (QFD) QUALITY FUNCTION DEPLOYMENT

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<th>3 = Moderate</th>
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## APPENDIX E - SCHEDULE

Lucas Tamowski  
Wheelchair tip prevention

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## APPENDIX F – BUDGET

Wheelchair tip prevention

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