Fall 2015

Human Powered Ice Resurfacing Machine

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The purpose of this project was to design and build an ice-resurfacing machine that was entirely human powered so it could be used safely on outdoor rinks and prevent harmful emissions indoors. This required analysis of several different mechanical systems and many different attempts to produce a working prototype. The prototype reduces the amount of water used when compared to a current ice-resurfacing machine by recycling snow from the ice. The sources of risk were determined, analyzed and solved throughout the project.

MEMS 411
Design Report

Human Powered Ice Resurfacer

Nick Furman, Kameryn Truman, Meagan Leonard

Department of Mechanical Engineering and Materials Science
School of Engineering and Applied Science
Washington University in Saint Louis
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1 Introduction

1.1 Project problem statement

The purpose of this project is to design and build an ice-resurfacing machine that is completely human powered. This machine will be used primarily for smaller backyard type ice rinks that will be located outdoors. A local ice arena manager was interviewed to determine the most important design considerations such as rust resistance, maneuverability, and durability. It was also decided to try and improve on current commercial machines by reducing the amount of water used through snow recycling. The budget for the project was $400. The initial prototypes were constructed under that tight budget constraint using the least expensive materials possible. Prototypes of the ice-resurfacer required minimal specialized machining and were relatively straightforward to manufacture.

1.2 List of team members

Nick Furman
Kameryn Truman
Meagan Leonard

Figure 1: Team Members
2 Background Information Study

2.1 Design Brief

The purpose of this project was to design and build an ice-resurfacing machine that is completely human powered to be used on outdoor rinks or to reduce harmful emissions in indoor rinks. The machine should be able to create a level ice layer that provides a safe skating surface. It also needs to be sized appropriately for home use.

2.2 Summary of relevant background information

At a basic level, the process to resurface an ice rink can be broken down into three steps. The ice must be scraped to remove the heavily damaged top layer. The next step requires the snow and ice shavings to be removed from the ice. The final step is to apply a fresh layer of water that will freeze to form the new ice surface\textsuperscript{[1]}. This process has been used since the early 1950’s and has been proven to be effective. The scraping step is necessary to prevent excess ice buildup and to produce the most level ice surface by removing deep cuts in the ice.

The most closely related commercial product to this design brief ice resurfacer is the Zamboni. The company holds three patents on ice resurfacers\textsuperscript{[2]} (2,642,679, 2,763,939 and 3,044,193) and controls the majority of the market share. The Zamboni is impractical for this design problem, however. First, it is very expensive, with costs for a new machine near $100,000. This is not going to be affordable for most small-scale, outdoor “backyard” rinks. The machine is also very heavy, which would make it unsafe for use on outdoor rinks on lakes or ponds with the danger of breaking through the ice. When fully loaded with water, the Zamboni Model 552 weighs 11,350 lbs\textsuperscript{[3]}. Zamboni’s web page is http://www.zamboni.com/.

The only other commercial product that resurfaces ice and is human powered is the NiceIce Resurfacer (http://www.nicerink.com/store/home.php?cat=10). This device is pulled across the rink by hand and only lays down fresh water and does not remove any of the damaged ice surface. The scraping step is necessary because as the gouges and ruts caused by repeated use get larger, adding hot water for resurfacing actually makes them bigger. It also is very slow and requires a hose connection to work, which may not be an option for rinks on lakes and ponds. This product is therefore impractical for this design problem even though it is a human powered ice-resurfacing machine.

In conclusion, there is no current commercial product that meets the stipulations of this design brief. The only human powered option leaves out two of the three steps in the resurfacing process and relies on lengthy hose connections. The motorized options are too heavy and expensive for use on outdoor rinks but provide valuable information on how to produce a machine that creates level ice surfaces.
3  Concept Design and Specification

3.1  User needs, metrics, and quantified needs equations

3.1.1  Record of the user needs interview

<table>
<thead>
<tr>
<th>Customer Data: Human Powered Ice Resurfacer</th>
<th>Date: September 9, 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer: Kevin and Dr. Mark Jakiela</td>
<td></td>
</tr>
<tr>
<td>Address: Webster Groves Ice Arena</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question</th>
<th>Customer Statement</th>
<th>Interpreted Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the primary function of the ice resurfacing machine?</td>
<td>Lay a smooth layer of ice to produce a safe sheet for hockey and figure skating</td>
<td>Removes rough ice</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Produces level ice layer</td>
<td>5</td>
</tr>
<tr>
<td>What should the power source be for the resurfacer?</td>
<td>Human powered with no internal combustion energy</td>
<td>Human powered</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Minimal electric power</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drive mechanism solely human powered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Will the resurfacer be used for indoor or outdoor rinks?</td>
<td>Primarily smaller outdoor rinks</td>
<td>Low enough weight to be held on top of</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Should work on indoor rinks</td>
<td>outdoor ice surface (won’t fall through)</td>
<td></td>
</tr>
<tr>
<td>How large can the resurfacer be while remaining practical?</td>
<td>Must be able to fit in the garage</td>
<td>Small enough size for easy storage</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Smaller than current indoor models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What shape rink will it be used on (rounded corners, rectangular, circular)?</td>
<td>Conventional shaped rinks, straight sides with rounded corners</td>
<td>Resurfacer needs to be maneuverable</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Corner radius varies</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Needs to be able to resurface curved portions of ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How many people should it take to run the resurfacer?</td>
<td>Preferably one</td>
<td>Minimize weight of resurfacer to be</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>powered by one person</td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Indoor Use</td>
<td>Outdoor Use</td>
<td>Rating</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>How often will the resurfacer be used?</td>
<td>For outdoor use only during the winter months, up to a couple times a day.</td>
<td>Resurfacer must be durable and require low maintenance.</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Indoor use 7-8 times a day every day.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How long should an ice make take?</td>
<td>Indoor use – less than 15 minutes.</td>
<td>Minimize weight and maximize traction to increase speed.</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Outdoor use - varies depending on rink size and shape but ideally less than 15 minutes.</td>
<td>Maximize the efficiency of human power transferred to resurfacer motion.</td>
<td>3</td>
</tr>
<tr>
<td>What conditions will the resurfacer be exposed to?</td>
<td>Indoor use- Temperatures between 35-45 degrees F, wet environment.</td>
<td>Materials must be rust resistant.</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Outdoor use- storage in a garage, temperatures varying between -30 and 40 degrees F, wet environment during winter season</td>
<td>Must be able to traverse land without scraping (needs ability to raise the scraping mechanism)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Needs to travel to ice from garage</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>What would you improve about current (indoor) resurfacers?</td>
<td>Minimization of prep time (filling water tanks) and post ice make processing time (snow removal)</td>
<td>Melt snow and recycle for laying ice</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Lower Carbon Monoxide emissions (continued...)</td>
<td>Human Powered</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduce operating costs when compared to indoor resurfacers</td>
<td>Minimal maintenance required (and human powered)</td>
<td></td>
</tr>
</tbody>
</table>


### 3.1.2 List of identified metrics

<table>
<thead>
<tr>
<th>Need Number</th>
<th>Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Resurfacer removes rough ice</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Resurfacer produces level ice</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Resurfacer is human powered</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Resurfacer is light weight</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Resurfacer is compact and easily storable</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Resurfacer is maneuverable</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Resurfacer is powered by one person</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Resurfacer is durable and rust proof</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>Resurfacer can raise blade and traverse over land</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Resurfacer can melt snow and recycle the water</td>
<td>2</td>
</tr>
</tbody>
</table>

### Design Metrics: Ice Resurfacer

<table>
<thead>
<tr>
<th>Metric Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Min Value</th>
<th>Max Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Depth of ice scraped off top of surface</td>
<td>in</td>
<td>1/32</td>
<td>1/8</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Height of layer of water</td>
<td>in</td>
<td>1/32</td>
<td>1/8</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Human Powered</td>
<td>Binary</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>4,6</td>
<td>Weight of system</td>
<td>lb</td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>5</td>
<td>5,6</td>
<td>Height of resurfacer</td>
<td>ft</td>
<td>3.5</td>
<td>5.5</td>
</tr>
<tr>
<td>6</td>
<td>5,6</td>
<td>Length of resurfacer</td>
<td>ft</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5,6</td>
<td>Width of resurfacer</td>
<td>ft</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>Number of operators</td>
<td>Integer</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>Resurfacer is made of rust resistant material</td>
<td>Binary</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>Frame strong enough to hold its own weight</td>
<td>Binary</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>Adjustable blade height</td>
<td>in</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>Can melt shavings</td>
<td>Binary</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>Temperature of water</td>
<td>Deg F</td>
<td>140</td>
<td>160</td>
</tr>
</tbody>
</table>
### 3.1.3 Table/list of quantified needs equations

<table>
<thead>
<tr>
<th>Need#</th>
<th>Need</th>
<th>Depth of ice cut</th>
<th>Ice layer height</th>
<th>Human Powered</th>
<th>Weight</th>
<th>Height</th>
<th>Length</th>
<th>Width</th>
<th>Number of Operators</th>
<th>Rust Resistant?</th>
<th>Structural Integrity</th>
<th>Adjustable blade height</th>
<th>Melt Snow</th>
<th>Temperature of Water</th>
<th>Need Happines</th>
<th>Importance Weight (all entries should add up to 1)</th>
<th>Total Happiness Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Resurfacer removes rough ice</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.33333</td>
<td>0.15</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>Resurfacer produces level ice</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.33333</td>
<td>0.15</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>Resurfacer is human powered</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.15</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Resurfacer is light weight</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.15</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Resurfacer is compact and easily storable</td>
<td></td>
<td>0.33</td>
<td>0.33</td>
<td>0.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.354167</td>
<td>0.1</td>
<td>0.235417</td>
</tr>
<tr>
<td>6</td>
<td>Resurfacer is maneuverable</td>
<td></td>
<td>0.5</td>
<td>0.166</td>
<td>0.167</td>
<td>0.167</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.680167</td>
<td>0.05</td>
<td>0.084008</td>
</tr>
<tr>
<td>7</td>
<td>Resurfacer is powered by one person</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

#### Units

- **in**: Inch
- **lbs**: Pound
- **ft**: Foot
- **deg**: Degree

#### Best Value

- Depth of ice cut: 0.03125
- Ice layer height: 0.03125
- Human Powered: 1
- Weight: 3.5
- Height: 5
- Length: 2
- Number of Operators: 1
- Rust Resistant?: 1
- Structural Integrity: 1
- Adjustable blade height: 1
- Melt Snow: 1
- Temperature of Water: 1
- Total Happiness Value: 0.881925

#### Worst Value

- Depth of ice cut: 0.125
- Ice layer height: 0.125
- Human Powered: 0
- Weight: 500
- Height: 5.5
- Length: 8
- Number of Operators: 5
- Rust Resistant?: 0
- Structural Integrity: 0
- Adjustable blade height: 3
- Melt Snow: 0
- Temperature of Water: 0
- Total Happiness Value: 0

#### Actual Value

- Normalized Metric Happiness: 1.33333, 1.33333
- Total Happiness Value: 0
3.2 Four (4) concept drawings

**ICE RESURFACER CONCEPT 1 - PUSH CART**

Push cart movement is human-powered via hand pump. As cart moves forward, blade drags along and cuts ice is moved towards the large auger. Large auger moves ice upwards, where it is melted by the heating element. Then liquid water fills tank, drains through a water hose to soak a towel which lays down the new layer of ice.

**ICE RESURFACER ISOMETRIC**

1. Wheel and axle
2. Rotating mechanism
3. Frame and lever
4. Blades
5. Auger to lift snow
6. Small auger to move snow towards big auger
7. Snow tank
8. Pipe for melted snow
9. Water tank
10. Base
11. Water hose on back of blade
12. Heating mechanism
13. Towel
14. Battery for heating unit

**ORTHOS OF CUTTING SYSTEM**

**FRONT**

**BACK (WITHOUT TOWEL)**

Figure 2: Concept 1-Push Cart
Figure 3: Concept 2 - Go Kart

Ice Resurfacer Concept 2 - Go Kart

Frame and Ice Cutting System Isometric

1. Steering Wheel
2. Frame
3. Tires and Axle
4. Pedals
5. Back Axle Auger to Collect Snow
6. Seat
7. Snow/Water Tank (tilted)
8. Battery for Heating
9. Towel to Even Water Layers
10. Water Layering System
11. Tube Heating System
12. Auger to Lift Snow to Tank
13. Blade

Ortho of Ice Cutting System

Works like a go-kart. Back axle has an attached auger to collect snow. A blade cuts ice and snow goes through hole in blade to augers. Vertical auger lifts snow to tank with heating unit. Snow is melted and drains to a pipe system that distributes water onto ice. Towel evens out water.
ICE RESURFACER CONCEPT 3 - ICE SUCKER

WORKS LIKE A LEAF-BLOWER, EXCEPT INSTEAD OF EXPELLING AIR, IT TAKES IN CRUSHED ICE. A PUMP AND HEATING ELEMENT MELT THE ICE AND PUSH IT UP TO THE TANK, HOUSED IN THE BACKPACK. ANOTHER HEATING ELEMENT AND PUMP MELT THE FILTERED WATER AND PUSH IT DOWN TO THE TOWEL TO LAY A NEW LAYER OF ICE.

Figure 4: Concept 3 – Ice Sucker
The bike based resurfacer consists of a cutting blade which shaves a thin layer of ice. The shavings are carried up a conveyor belt to the storage tank. An electric heating element melts the snow which is absorbed by a sponge and laid on the ice.

Figure 5: Concept 4 – Bike
### 3.3 Concept Selection Process

#### 3.3.1 Concept scoring (not screening)

<table>
<thead>
<tr>
<th>Ice Resurfacer Concepts 1-4</th>
<th>Depth of ice cut</th>
<th>Ice layer height</th>
<th>Human Powered</th>
<th>Weight</th>
<th>Height</th>
<th>Length</th>
<th>Wetness</th>
<th>Number of Operators</th>
<th>Rust Resistant?</th>
<th>Structural Integrity</th>
<th>Adjustable blade height</th>
<th>Melt Snow</th>
<th>Temperature of Water</th>
<th>Need Happiness</th>
<th>Importance Weight (all entries should add up to 1)</th>
<th>Total Happiness Value</th>
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<tbody>
<tr>
<td>Need#</td>
<td>Need</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>1</td>
<td>Resurfacer removes rough ice</td>
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<td>2</td>
<td>Resurfacer produces level ice</td>
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<td>3</td>
<td>Resurfacer is human powered</td>
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<td>Resurfacer can raise blade and traverse over land</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>160</td>
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</table>

| 1. Pump Cart | Actual Value | 0.125 | 0.0625 | 1 | 500 | 4 | 8 | 5 | 3 | 2 | 1 | 1 | 0 | 1 | 1 | 160 |
| Normalized Metric Happiness | 0 | 0.66667 | 0 | 1 | 0.75 | 1 | 0.66667 | 0.5 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| 2. Go Kart | Actual Value | 0.03125 | 0.03125 | 1 | 200 | 3.5 | 6.5 | 1 | 1 | 1 | 1 | 8 | 1 | 160 |
| Normalized Metric Happiness | 1 | 1 | 1 | 0.6 | 1 | 0.5 | 0.66667 | 1 | 1 | 1 | 0.66667 | 1 | 1 | 1 |
| 3. Ice Sucker | Actual Value | 0.03125 | 0.03125 | 1 | 50 | 5.5 | 7 | 2 | 1 | 1 | 1 | 0 | 1 | 1 | 140 |
| Normalized Metric Happiness | 1 | 1 | 1 | 0.9 | 0 | 0.33333 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| 4. Conveyor Bike | Actual Value | 0.0625 | 0.0625 | 1 | 100 | 4 | 6 | 4 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 160 |
| Normalized Metric Happiness | 0.66667 | 0.66667 | 1 | 0.8 | 0.75 | 0.66667 | 0.33333 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |

| Total Happiness | 0.697658333 |

| Total Happiness | 0.500558333 |

| Total Happiness | 0.881875 |

| Total Happiness | 0.806133333 |

| Total Happiness | 0.697658333 |
3.3.2 Preliminary analysis of each concept’s physical feasibility

**Concept 1: Push Cart**

This design has the most weight of all the concepts. This provides superior traction and easy cutting ability. The main disadvantage from the weight is loss of maneuverability. It may also approach the maximum weight the ice can hold without breaking, creating a safety hazard. This concept can’t turn so it would be difficult to resurface the edges of curved rinks and would have to be manually repositioned after every pass. The propulsion method is reliable but would require two operators at minimum, which is a unique challenge to overcome with this design. The cart would be fairly large and difficult to store. It meets the most essential user needs but doesn’t offer many other advantages. It would require considerable machining to create the thrust mechanism. It would be easy to move forward but the inability to turn is a huge disadvantage. This design would be most useful for large, rectangular rinks, which are rare. The water laying mechanism will provide a smooth layer of ice and a heating system would allow snow to be melted and recycled back on to the ice. Like all concepts it reduces harmful emissions and could be used indoors and outdoors. This design would have to be fabricated from scratch, allowing flexible material choices to reduce the risk of rust and wear and tear. This concept would require minimal maintenance. There are many challenges and disadvantages to overcome with this concept and the potential safety hazard is a very serious concern. Measures would have to be taken to reduce the weight as much as possible. Overall, the concept is feasible but not the most practical.

**Concept 2: Go Kart**

The primary challenge associated with the go kart based design is that it is very back end heavy, which may hamper maneuverability. This system may require additional weight to keep traction, but the weight of the person pedaling should be enough to keep the front wheels on the ice. Another potential solution is more of a trailer based resurfacing system, similar to a tractor based lawn aerator. This issue requires more in-depth analysis. The fabrication of this design also poses issues, due to the large size. It may require welding or other specialized manufacturing techniques to be structurally sound. This concept is one of the heavier designs. This provides additional traction and makes shaving the ice easier but may make it more difficult to pedal. With the verified steering system this concept uses, it would be maneuverable enough to get the rounded corners of the ice rink. One person easily powers it and a simple hydraulic attachment will raise the cutting system off the ice for transport over land. Meeting an important customer need. With a physical size that is already easily storable in a garage this concept is practical for use on outdoor home rinks. Careful material selection will provide rust resistance and minimal maintenance requirements. The electric heating system would save water and significantly reduce the bulk of this concept when comparing it to a commercial ice resurfacer. This reduction in size again promotes home use for ease of storage. This concept will definitely lay a level sheet of ice with the smoothing towel. Overall, this concept is very feasible with challenges that can be addressed with relatively straightforward solutions.

**Concept 3: Ice Sucker**

The main challenge for the ice sucker design is shaving a level layer of rough ice. The cutting mechanism is completely reliant on the operators strength and ability to keep the blade at a constant angle. This concept may require additional arms and weight to ensure the blade remains at
a constant angle and is easy to push through bumps and ruts in the ice. Installing the two pump systems poses several design challenges. First, it would make the backpack based system considerably heavier than the leaf blower concept it is based on. Also the snow would have to be completely melted before it could be pumped up off the ice. This would require significant electrical heating. The backpack based storage tank may not be able to hold enough volume to resurface slightly larger ice surfaces. The backpack system could become heavy very quickly if holding a large amount of water. Water distribution with the low flow may also make laying a smooth layer difficult. The ice laying mechanism would likely need to be rigidly attached to the user to ensure there is a straight path of ice formed. The rate at which the ice can be resurfaced with this concept is much slower than the other concepts; the max velocity of the resurfacer is the operator’s walking speed. This may not be a big issue for small winks. The most obvious advantage with this concept is the maneuverability. It is by far the most maneuverable concept that was generated and would easily resurface all rink shapes. It is the lightest concept as well, which promotes ease of transport. The blade height is not adjustable but could be picked up manually for transport over land. It is the most compact of all designs and would be very easy to store. In conclusion, although very light, maneuverable, and compact, this design may struggle to meet the primary user needs of shaving and laying a level ice layer.

**Concept 4: Bike Based Resurfacer**

The bike based concept presents several challenges that are immediately obvious. Most importantly, it would be difficult to balance the device with the weight heavily on one side. This design would likely require a counter balance system in order to make it easy to ride. The thin tires also pose an issue; they would have to be wide enough to provide traction on the ice surface. Another design challenge would be reverse gearing the conveyor belt because it moves in the opposite direction of the bike. This could likely be overcome but would require considerable gearing. An additional issue with the bike concept is rust and maintenance. It is very evident that bike chains and even the gears and frames rust very easily. Because the device is constantly exposed to water, the development of rust on the bike-based resurfacer will become a major issue and require consistent maintenance. It may be possible to reposition the blade so the bike can travel over land after it leaves the ice but this would likely require a small hydraulic system, which would add bulk to the concept. The main advantage of this design is that it is very maneuverable. This meets one of the most important user needs as it would be able to resurface the rounded corners of the rink. The bike basis and relatively low weight would make the resurfacing process quick. Design concept 4 would successfully shave and resurface the ice, meeting the most important user needs. The balance and maintenance issues, however, are major hurdles for this design to be successful.

**3.3.3 Final summary**

**WINNER: Concept 2 – Go Kart**

Concept 2 is the winner because it meets the most user needs and will always create a level ice surface. The go-kart system has several advantages when compared with the other three designs; it has a reliable steering system to provide good maneuverability, it is heavy enough to make the cutting process easy, but light enough to be easily powered by one person, and the adjustable blade height makes it easy to traverse over land. When compared with concept 1, the lighter weight
eliminates the safety hazard of breaking through the ice on an outdoor rink. Concept 1 is way to heavy to be powered by one person, which is a major drawback. There is no steering system on concept 1 so the go-kart system is much more maneuverable. When compared with concept 3, the ice sucker, the go-kart system provides a better ice resurfacing mechanism. As pointed out in the preliminary analysis, the ice sucker would potentially create variable depth cuts and inconsistent layer height because of the user applying inconsistent forces on the blade. This leads to an uneven ice surface, which doesn’t meet the primary user need of the product. Concept 2 is only slightly less maneuverable than the ice sucker, could cover ground much quicker and the static resurfacing system would provide a level ice surface. The increased speed of resurfacing also helps to create a more level, uniform sheet of ice. Unlike concept 4, the go-kart system’s four wheel stance provides stability and ease of use. It would require less complex gearing and have considerably more traction than the bike based resurfacer. Concept 4 also lacks an adjustable blade height, which would make it a challenge to move over land. It would require the user to carry the bike across land, which is not optimal. In addition to all these advantages when compared with the other designs, concept 2 also had the highest score from the happiness equations. Combining the highest happiness equation score with all the practical advantages makes concept 2, the go-kart based ice resurfacer, the clear winner.

3.4 Proposed performance measures for the design
1. Resurfacer lays an even ice sheet (shaves 1/32” and lays 1/32” of ice)
2. Resurfacer drive mechanism is completely human powered

3.5 Design constraints

3.5.1 Functional
• Overall Geometry (Size) – The ice resurfacer has to be able to be stored in a residential setting so it must be smaller than a car
• Motion of Parts – The ice resurfacer must be only human powered

3.5.2 Safety
• Operational – The ice resurfacer must be light enough so that it does not break through the ice if used on a lake or pond based rink.

3.5.3 Quality
• Quality Control – The blade must be tested individually before it is attached to the machine to ensure that it cuts properly
• Quality Control – The vehicle base must be inspected for rust/prior use damage to unsure stability

3.5.4 Manufacturing
• Production – The design must be producible using standard machining practices that are available in the student machine shop
• Purchase of Components – Supplied parts such as the human powered vehicle must be damage and corrosion free
• Purchase of Components – The storage tank should be clean and free of chemicals so that the water applied to the ice is clean.
• Assembly – This machine is intended for use in “backyard” settings so it assembly should be as simple as possible. The best-case scenario would be no assembly required or minimal assembly required with common tools such as screwdrivers and wrenches.

3.5.5 Timing
• Design and Development Schedule – The short development cycle of this project does not allow much room for testing different blade systems so analysis must be thorough
• Delivery Schedule – Cheap components from overseas will likely not arrive in time to be used on this project.

3.5.6 Economic
• Resources – The main economic constraint is the $400 budget.
• Development Costs – Because the budget is fairly low, there is minimal funds available for testing components of the system. Analysis must be thorough to reduce testing requirements

3.5.7 Ergonomic
• User Needs – Must be human powered, lightweight, and able to be operated by one person.

3.5.8 Ecological
• General Environmental Impact - Must be human powered so there is zero emissions
• Material Selection – Must be rust free to avoid laying rust into the ice, which will affect waterways once the ice has melted.

3.5.9 Aesthetic
• Customer Appeal – The machine should value function over form but it must be compact enough to fit inside a garage.

3.5.10 Life cycle
• Operation – The ice resurfacer should be quiet for use in residential areas
• Maintenance – The ice resurfacer must be durable for repeated use both indoors and out. Parts should be easily sourced and replaced.
• Maintenance – The ice resurfacer will constantly be subjected to wet conditions and cold temperatures so it should be designed accordingly.

3.5.11 Legal
• Intellectual Property – The design needs to account for the Zamboni patents.
4 Embodiment and fabrication plan

4.1 Initial Embodiment drawing

Figure 6 - Initial Embodiment Drawing

Important Note: The Conveyor Belt (21) is wider than shown on this model but was left as is per the request of Dr. Jakiela.

Important Note: There will be a hood around the conveyor belt to ensure snow does not fall off and it will guide snow into the storage drum. This was not modeled per Dr. Malas's request.

Table: Human Powered Ice Resurfacer

<table>
<thead>
<tr>
<th>Contract No.</th>
<th>Nick Furman</th>
<th>Kameryn Truman</th>
<th>Maggan Leonard</th>
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Note: The table includes contact information for Nick Furman, Kameryn Truman, and Maggan Leonard.
## Parts List

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<tr>
<th>Part Number</th>
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**Subtotal $280.05**

### Materials List

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**Subtotal $128.88**

**Total $408.93**
4.3 Draft detail drawings for each manufactured part

Figure 7 - Mounting Plate Part Detail
Figure 8 - Blade Assembly Detail Drawing

All dimensions in inches
All dimensions in inches

Figure 9 - Water Spreader Part Detail
Figure 10 - Water Layer Support Bracket Part Detail

All dimensions in inches
Figure 11 - Top Barrel Bracket Part Detail

All dimensions in inches
4.4 Description of the design rationale for the choice/size/shape of each part

1. Tricycle – The tricycle was chosen because it provides a stable base and structural support for the rest of the machine. It has to be adult sized so it can easily be pedaled. The wide rear wheel stance should provide better traction on the slick ice surface than a two-wheeled vehicle and there were no adult sized pedal carts available.

2. Conveyor Belt Drive Shaft – This size was chosen because it will fit around the rear axle of the tricycle and was the most affordable option.

3. Mounting Plate – The design basis for this part was that it had to be big enough to have the water drum sit on top of it without causing the tricycle to tip over backwards, so it need to be strong but light.

4. Blade Assembly – The blade assembly is designed to provide angled snow push across the ice and to provide frame support for the towel and water laying system.

5. 30 Gallon Drum – The 30 gallon drum was chosen because it is readily available, inexpensive and enough volume to resurface a considerable area of the rink.

6. Bulkhead Adapter – The bulkhead adapter was chosen because it is necessary to punch a hole in the barrel to get water out and a bulkhead fitting creates a seal to prevent water from leaking out of the water storage tank.
7. PVC Pipe – 3/4th inch PVC was chosen because it was the smallest diameter available. The flow of water onto the ice should be minimized so the smaller the pipe diameter the better.
8. PVC Elbow – The PVC elbow changes direction of the water flow and allows it to be applied to the ice in the correct direction.
9. PVC Tee – The PVC tee allows the water to be spread on both sides of the central water distribution pipe.
10. Water Spreader – The water spreader has small holes drilled in PVC and spaced one inch apart because this will generate the best coverage of the ice. The small holes allow more precise water delivery.
11. PVC Cap – The PVC cap fits over the water spreader pipe and prevents excess water from flowing out the side of the spreader.
12. Smoothing towel – The smoothing towel is a generic towel that distributes the water into a smooth layer once it has reached the ice surface.
13. Water Layer Support Bracket – This bracket was designed to cradle the Water Spreader. Its size allows the spreader to be elevated off the ice.
14. Top Barrel Bracket – The top Barrel Bracket has the same diameter as the 30-gallon water storage drum. It provides a base to attach the conveyor system to.
15. Top Barrel Cross Support – The top barrel cross support has a length equal to the diameter of the barrel so that it can span across the top. It is this length so that it can provide a base for the bearings on the conveyor system.
16. Bracket Mounted Bearing – The bracket mounted bearings allow the conveyor system to rotate.
17. The top conveyor drive shaft is sized according to the bend radius of the conveyor belt and allows the conveyor belt to be driven by the conveyor belt drive shaft.
18. Lower conveyor belt bearing – Located near the ice surface, this bearing allows the lower conveyor shaft to rotate.
19. Lower conveyor belt drive Pulley – This pulley is sized according to the conveyor belt and helps drive the conveyor system.
20. Lower Conveyor Belt Drive Shaft – Attached to the pulley and bearing, this shaft rotates at the bottom of the conveyor system and facilitates picking up the shaved ice and snow.
21. Conveyor Belt – The conveyor belt chosen is 6 inches wide and has ridges to pick up the snow.
22. Water Heating Element and 12 Volt Battery – This part has been left out due to not being human powered.
4.5 Gantt chart

Senior Design Project Gantt Chart

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Start</th>
<th>End</th>
<th>Duration (days)</th>
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<tbody>
<tr>
<td>Complete Embodiment Design</td>
<td>9/16/15</td>
<td>9/30/15</td>
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<td>Complete Engineering Analysis</td>
<td>9/21/15</td>
<td>10/9/15</td>
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<tr>
<td>Order Parts</td>
<td>9/16/15</td>
<td>10/30/15</td>
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<td>Build Water Distribution System</td>
<td>10/9/15</td>
<td>10/30/15</td>
<td>21</td>
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<td>Test Water Distribution System</td>
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<td>1</td>
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<td>Build Conveyor System</td>
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<tr>
<td>Test Conveyor System</td>
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<td>Build Blade Assembly</td>
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<td>On Ice Test</td>
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<td>12/1/15</td>
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Table 1 - Gantt Chart Tasks

Figure 13 - Gantt Chart for the Project
5 Engineering analysis

5.1 Engineering analysis proposal

5.1.1 A form, signed by your section instructor

ANALYSIS TASKS AGREEMENT

PROJECT: Ice Resurfacer  NAMES: Kameryn Truman  INSTRUCTOR: Dr. Jakiela

Nick Furman

Meagan Leonard

The following engineering analysis tasks will be performed:

**Before Fabrication Analysis:**

**Statics:**

Ensure that the resurfacer design does not tip over when fully loaded. We performed a basic statics analysis as a part of the embodiment. Full statics analysis will be completed once more materials have been purchased.

**Cutting Force Analysis:**

Preliminary tests were performed using dull knife blade and a standard men's razor blades on ice cubes. A very small vertical force on razor blade easily shaved of layers of ice and produced a smooth surface. This leads to the conclusion that no excessive force is needed beyond the weight of the apparatus. A sample of wood was tested and the results were equated to ice for a basis on the necessary force.

**Tank Sizing:**

Calculations were made to choose a tank size that can hold enough water to cover 5% of a standard ice rink. This percentage was chosen as a margin over the recycled snow shavings. Therefore, as long as less than 5% of the water from the scraping is lost, the resurfacer will be able to resurface the whole ice surface.

**Gearing/Conveyor Belt Speed:**
The driving mechanism is attached to rear axle. The conveyor belt will be driven at same rotational speed as the rear axle. The speed was calculated based on how fast the operator pedaled.

**Thermodynamics:**
Determine the energy required to melt snow inside the storage chamber. This will determine the size and wattage of the heating element and the voltage of the battery.

**After Fabrication Analysis:**
- Cutting Force - Test how much ice is actually shaved by the blade and how different weights and angles affect the cut depth. This will probably require a small subassembly to be fabricated. This analysis will also investigate the angled blade to determine how effective it is at moving the shaved ice.
- Ice layer thickness - Determine amount of water needed to create a layer of ice that has the same thickness as the ice layer that was scraped off. This will meet the primary user need of creating a level ice sheet.
- Slipping/Traction - Determine the modifications necessary to provide the best traction without damaging the ice surface.

The work will be divided among the group members in the following way:

**Analysis Plan:**

- **Nick (NF)** - Thermodynamic analysis and Ice layer thickness analysis check - Static analysis and Cutting Force analysis
- **Kam (KT)** - Statics analysis and Cutting Force analysis check - Gearing analysis and Traction analysis
- **Meagan (ML)** - Gearing analysis and Traction analysis check - Thermodynamic analysis and Ice layer thickness analysis

Instructor signature: ___________________; Print instructor name: ___________________

### 5.2 Engineering analysis results

#### 5.2.1 Motivation.

*Full Calculations in appendix D.* The before analysis is the most important thing to study prior to construction because it identifies key design components that are critical for the success of the machine. This project has a limited budget so the analysis is critical to keep costs low. The most important analysis was the static force balance on the whole system to ensure that when fully loaded the tricycle would not tip backwards. Strength analysis of the frame was also critical to ensure it could support heavy loads applied by a full water tank. These results coupled with other
preliminary analysis were necessary to prove that the fundamental components will be successful. If nothing else the tricycle must remain balanced and be able to hold the weight of the water for resurfacing the ice. This analysis creates the foundation that drives the project forward. It is the basis for the project. Once it is determined that the product will be structurally sound and safe to use all other systems can be developed.

5.2.2 Summary statement of analysis done. Summarize, with some type of readable graphic, the engineering analysis done and the relevant engineering equations

Each individual system was analyzed to ensure it was physically feasible. The design was modular in the sense that most of the systems functioned independently from each other. The analysis shows that the whole system should work. A brief overview of the analysis is shown in table 2.

Table 2 - Engineering Analysis Summary

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<tr>
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<th>System Affected</th>
<th>Key Equations</th>
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<td>Tank Sizing</td>
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<td></td>
<td>$V_{tank} = SA \times \text{Thickness}$</td>
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<td>Thermodynamics</td>
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<td>Layer Thickness</td>
<td>Water Distribution System</td>
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<tr>
<td>Slipping traction</td>
<td>Whole Product</td>
<td>Observed</td>
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5.2.3 Methodology. How, exactly, did you get the analysis done? Was any experimentation required? Did you have to build any type of test rig? Was computation used?

The analysis was completed in two different ways. Most of the analysis was completed by hand. Most calculations were straightforward with minimal computation. The cutting force analysis required some experimentation. Initial testing was completed using a razor blade on an ice cube. Additionally, a razor blade was pushed into a block of wood to test the cutting force necessary. The hardness values of ice and the wood were compared to provide insight into the necessary force. After this we created a test rig for the cutting force by machining a short test blade. The final analysis was completed by observation of the system in use and modifications to get the required values, such as ice layer thickness and traction.

5.2.4 Results. What are the results of your analysis study? Do the results make sense?

The results of the analysis study showed that the initial design was feasible. The static analysis clearly demonstrated that the tricycle would not tip over. The center of mass of the water tank is directly above the rear axle and the weight of the driver easily counteracts the weight of the water, even though the water is much heavier. This was tested prior to building the prototype by having the
group members stand on the rear axle. The frame supported all three team members without flipping. This makes sense and provided the basis for our design.

The cutting force analysis yielded results that the roughly 120 lbf applied by the weight of the water to the blade was sufficient to cut into the ice. There was additional cutting force from the weight of the blade itself, and the sharp edge of the blade concentrated all the force along a single axis. Additionally, the forward momentum of the tricycle was adequate to move the blade forward while cutting. This intuitively makes sense.

The tank sizing calculation determined that this size tank would cover 10% of a standard North American Ice rink. This result does not seem accurate, as a Zamboni uses roughly 70 gallons of water to resurface a rink\(^3\). In testing 20 gallons covered much more than 10% of the ice rink. The tank was not completely full and resurfaced roughly 1/3 of the ice rink. This makes sense when compared to the Zamboni’s tank size. The low approximation of volume allowed the selected tank size of 30 gallons to be more than substantial with the recycled ice.

Analysis of the conveyor speed was based heavily on the assumption that the vehicle could be pedaled at normal biking speed. This assumption yielded that the conveyor system would run at 140 to 240 RPM. This seemed realistic but in testing the conveyor system moved much slower because the pedaling speed was decreased due to several factors. The main issue was the weight of the vehicle when full of water. There was a single gear on the tricycle so it was not possible to adjust RPM speed without changing the speed of the trike. In order to create a level ice layer, the resurfacer was not able to move at high speeds, so again the assumption was too high. Control on the slippery ice surface also played a role, steering became difficult at higher speeds due to slipping. The resurfacer is still able to move at the same speed as a Zamboni.

The results of the thermodynamics analysis showed that with the hot water provided at the ice rink, no heating element was necessary. Due to this analysis the heating element was eliminated from the final prototype. This result seems accurate when considering the water supplied is at least 100°F. Higher temperatures are preferred to create a hard ice layer. The ice resurfacer was not out in the cold temperature of the rink for enough time for heat loss to be a problem. Even if this was the case, insulation could be added.

Layer thickness was observed post construction. It was estimated to be between \(\frac{1}{16}\)th and \(\frac{1}{32}\)nd of an inch thick. Measurements showed that the actual thickness was .021 inch, which is close to that range. This may have been affected by the cut depth, which was difficult to measure. In actual use multiple layers could be applied with the blade raised. Most importantly, although the thickness was slightly outside the range, the surface was still smooth and safe to skate on.

During testing, it was observed that the combined weight of the water and of the operator compressed the trike wheels providing more surface area in contact with the ice and providing enough traction to maneuver the trike. This eliminated the concern of slipping, with the exception of occasionally running over a smoothed patch of ice, which would reduce traction and cause the wheels to spin. Although this was bad for traction, this was a good indicator of the smoothness of the new ice surface. The trike was not tested at lower water levels where the reduced weight could cause problems with traction. Adding weight to the frame or additional devices for traction, such as wires or studs would eliminate this potential issue.
5.2.5 Significance. How will the results influence the final prototype? What dimensions and material choices will be affected? This should be shown with some type of revised embodiment drawing. Ideally, you would show a “before/after” analysis pair of embodiment drawings.

A key change to the final prototype was removal of the heating element. Although this was slightly motivated by budget concerns, the decision to remove it was primarily motivated by the thermodynamic analysis. In addition, small changes were made to the conveyor frame, including an addition of a ‘hood’ at the bottom, which extended the blade and provided a location for the conveyor system to scoop up the snow and ice shavings, as well as a small chute to direct the snow and ice dropped from the conveyor to the water tank. Revised embodiment drawings do not include the heating element, and do not include the hood and chute due to the difficulty in modeling their shape and thinness. Instead, photos showing the hood and chute have been included. See figures 6 and 14 to compare the preliminary embodiment with the final prototype. See figure 18 for the hood and 22 for the snow chute.

5.2.6 Summary of code and standards and their influence. Similarly, summarize the relevant codes and standards identified and how they influence revision of the design.

There are not very many codes and standards that apply to this design. The only relevant code found was ASTM F2442-07, which deals with ice arena layout and construction. This standard covers indoor carbon monoxide monitoring and other rink safety features. Although no codes directly apply to the ice-resurfacing machine, it has caused several rink evacuations in recent years and the emissions from the resurfacer are suspected to be the cause. This design is emission free because it is completely human powered. As such no codes directly affect this design but the emissions problems influenced the decision to make it human powered.

5.3 Risk Assessment

5.3.1 Risk Identification

The first step of any risk analysis is risk identification. In a complicated or multipart system, such as this ice resurfacer, there are many risks. Some risks we initially considered were the blade having enough force to cut without sinking too deeply into the ice, the conveyor system being able to lift and deliver the ice to the tank, the tank staying on the bike and not tipping it over, having enough traction for the trike to move forward, and effects of cold temperatures on the water distribution system.

5.3.2 Risk Impact and Probability

After risk identification is risk impact assessment, or deciding the probability and impact of each risk identified.

The impact of the correct cutting force for the blade was determined for each of the two risks- not cutting enough and cutting too deeply. Not providing adequate cutting force could result in a
rougher starting surface for the new ice to be laid on, and the probability is somewhat high, as our initial embodiment drawings did not have much weight placed directly onto the blade. Providing too much cutting force could cause the blade to take off too much ice or impede forward motion if the trike did not have enough traction to pull the blade forward. It was determined this was a medium probability; although the blade did not have extra weight directly on it, the whole assembly was heavy, and our initial machined steel design for the blade would have been heavy and sharp on its own. As will be discussed later this risk was mitigated by purchasing a snow shovel to use as the blade.

The impact of the conveyor system being able to lift and deliver ice to the tank was a possible buildup of snow and ice shavings at the end of the blade. Although undesired, this would not effect the laying of smooth ice or significantly impact forward motion. This was determined to have a high probability, as the conveyor system was one of the most complicated, and depended on many factor.

The impact of the tank staying on the bike and not tipping over was a malfunction of the entire system; if the bike tipped over or the water tank fell off the ice resurfer would not complete its job of resurfacing ice, and could possibly injure the user. The probability of this happening was determined to be very low, due to the placement of the water tanks, the weight of the user and a full moment analysis (see analysis section for discussion).

The impact of the trike having enough traction to move forward was also a malfunction of the entire system and inability to complete critical function. The probability of this was medium. The trike tires are a somewhat smooth rubber; however the weight of the tank, trike frame, and user was speculated to provide enough force on the smaller surface area of the three wheels to allow for forward motion.

The impact of cold temperatures on the water distribution system was possible freezing in the tank or piping system. Worst-case scenario this could prevent flow of water through the system and not allow new ice to be laid. The probability of this was decided to be low, since the tank and piping system was at approximately 1-1.5 ft from the ice surface, and because heated water could be used to fill the tank.

### 5.3.3 Risk Prioritization

Risk prioritization focused on critical functions, movement and laying smooth ice. As such the high impact risks, including the trike tipping over and the system having enough traction to move were given priority, as well as high probability, medium impact risks, including the blade cutting too deeply. Lower probability and/or lower impact risks were not focused as much on, but were kept in mind during the prototyping, including the conveyor system being able to lift and deliver ice to the tank, the blade not cutting deeply enough, and the effects of the cold temperatures on the water distribution system.

### 5.3.4 Risk Mitigation

Risk mitigation, planning, implementation, and progress monitoring was directly effected by the risk prioritization, and determined how we approached the building of the prototype. Overall it was decided that the best way to focus on critical functions and attempt to mitigate high impact risks, within budget and time constraints, was to prototype, test, and refine each system as we went
along. The project was divided into three systems, the water distribution system, the blade system, and the conveyor system.

Our decision to start with the water distribution system, which incorporated the tank, was focused on addressing the high impact risk of tipping over, as well as ensuring the fundamental function of laying smooth ice worked. The trike and the water tank, as well as the strap system used to secure the tank to the trike were the first items purchased. Initial testing, which involved strapping a full tank of water to in place on the back of the trike and having the user pedal it around, proved successful, alleviating the concern of tipping over. After, the tank was machined and fitted with the water distribution system, including piping, the bulkhead and valve. The test was repeated during the demonstration of initial prototype and showed that the water system distributed water well.

The risk of loss of traction and forward motion was not able to be tested during prototyping as time and budget concerns meant an ice rink to use for testing was unavailable until the final prototype was completed. However, easy to implement ideas, such as adding weight to the system, and adding studs or wrapping the tires in wire were considered options if the trike proved to not have enough traction in testing. Likewise, the effect of cold temperatures was not able to be tested during prototyping, but wrapping the tank and piping in an insulating material or adding a heating element was considered if testing showed it to be a problem.

After building a successful water distribution system, the next system to be built was the blade. Small scale testing with a commercial razor blade and ice cubes demonstrated that with a sharp blade, little force was needed. This was kept in mind when deciding not to fully sharpen the final prototype. Initial testing of a short segment of machined blade proved unsuccessful; the machined chunk of steel was too heavy to easily drag across ice and there were time concerns over the machining. A revised plan included ordering a snow pusher blade and using that instead. The snowpusher blade was attached by bolting some scrap lengths of metal to the bike frame and bolting those to two wood pieces contoured and bolted to the blade. In some initial testing in the hallways, the blade not only picked up material from the floor, but slightly scraped it too, proving promising for further testing on ice.

The conveyor system was developed last, being the least important and most complicated system. A threaded rod was machined to fit the rear wheel axle to provide the driving force for the system. Although a metal frame was initially considered, the prototype was made of wood for concerns that a metal frame would require additional support, which would take additional time and budget. Scrap rollers were attached to the corner of the frame. After examining the ordered treaded belt in person, it was decided to be too stiff and difficult to bend to work. A new belt was made by stapling scrap rubber together and gluing on small lengths of metal to scoop and carry snow shaving. In initial testing the belt picked up bits of plastic from the floor and successfully carried and released them at the top of the frame. In initial testing is was also noted that the belt rotated very slowly, due to the smaller diameter shaft used as well as the fact that the bike had only one gear, and thus pedaling speed, which had to be slow to allow for even laying of ice, could not be adjusted independently.

In final testing, the system performed well. To the team’s relief, the weight of the user and of the water tank proved enough to provide traction. In addition the water system did not freeze, so extra insulation wasn’t necessary. All systems worked extremely well, with the exception of the conveyor system. The conveyor system worked moderately well, being slow as noted before and also having a
tendency to get stuck on the hood added to the blade end to direct the snow and ice shavings close to the conveyor system. The blade successfully scraped the surface without digging in too far, as evidenced by the snow and ice shavings produced. The water distribution system also works extremely well, laying down a very smooth surface of ice and supplying enough water to lay down ice but not enough to flood the rink. The smoothness was verified when the wheels would spin when the ice resurfacer occasionally drove back over a smoothed portion.

6 Working prototype

6.1 A preliminary demonstration of the working prototype
This was completed in recitation on November 3, 2015

6.2 A final demonstration of the working prototype
This was completed in recitation on November 17, 2015

6.3 At least two digital photographs showing the prototype

![Final Prototype Image 1]
6.4 A short video clip that shows the final prototype performing

https://www.youtube.com/watch?v=RZz0H4OGfOk
6.5 At least four (4) additional digital photographs and their explanations

Figure 16 shows the blade system on the ice resurfacer. The blue blade is made of heavy-duty steel and connects to the green angle iron at the top of the image using the wood brackets. On the left side of the image is the hood, where the snow is scooped up by the conveyor system. The blade is at a roughly 30 degree angle to push the snow across the ice to the hood. The blade is filed to a 15 degree angle which was a result of the engineering analysis. Although the analysis showed a 40 inch blade was necessary, the blade was only commercially available in a 30 inch size. This was still adequate for the final prototype demonstration.
Figure 17 also shows the blade system. The green angle iron supports are bolted onto the tricycle frame. The middle support is bolted to each of the side supports. The wood blade attachments are screwed to both the angle iron and the blade. This picture shows how angled the blade is (~30°). The base of the conveyor system is located on the right side and the PVC pipe for the water distribution system rests on the middle cross support. In regards to the analysis, this shows how the blade length calculation was for a best case scenario and the 30 inch blade was still sufficient. The 40 inch blade would required the system to be extended farther behind the wheel base.
Figure 18 shows a close up of the water system. The valve is located close to the tricycle and controls the flow of water out of the water storage tank. The PVC pipe rests on the middle blade support and then branches out to the same width as the tires at the tee intersection. The smoothing towel, the part that creates the smooth ice surface, is attached to the water spreader using zip-ties. It is a microfiber towel.
Figure 19 shows how the water leaves the tank and goes to the ice. The black plastic fitting is the 1” bulkhead fitting that has a rubber washer on the barrel side so that a seal is created. A PVC male adaptor is screwed into the bulkhead fitting and sealed with PTFE tape. The elbow changes the direction of flow and the valve controls the flow to the rest of the system. The thermodynamic analysis showed that the tank will be full of liquid water and it will melt recycled ice fast enough to remain liquid. This will not clog the pipes so we chose the most readily available pipe sizes.
Figure 20 shows the water distribution pipe. The holes are 1/8\textsuperscript{th} inch in diameter and are spaced 1 inch apart. The water is dropped to the ice through these holes and is then smoothed with the towel. The thermodynamic analysis showed that the tank will be full of liquid water and it will melt recycled ice fast enough to remain liquid. This will not clog the pipes so we chose the most readily available pipe sizes. This picture shows the holes used for the water distribution were not clogged.
Figure 21 shows the lower part of the conveyor system. The shaft is made of aluminum and is threaded onto the rear axle of the tricycle. This allows the system to be driven in unison with the driver of the machine pedaling. One of the conveyor rollers is located on the left side of the figure. This roller has a ball bearing built in so it rotates freely, carrying the conveyor belt around its diameter. This picture also shows the cross supports added to the conveyor system to provide extra rigidity. In preliminary analysis for the conveyor system, the pedaling RPM was estimated to be 70-100 RPM and that this would be fast enough to recycle the snow. In actuality this assumption was considerably to high as the pedaling speed had to be slow to lay an even ice layer and maintain control. The tricycle only had one gear, so shifting was not an option.
Figure 22 shows the top of the conveyor system and the water recycling mechanism. The buckets are attached to the conveyor belt with industrial adhesive and are made of thin aluminum sheets. These buckets dump snow into the snow chute which angles down into the water storage tank. The chute is tied to the conveyor system and bolted to the inside of the barrel. The engineering analysis for the conveyor speed led us to space the snow chute appropriately. In reality the speed was much slower so the snow sort of stuck to the buckets. We were able to bend the sheet metal such that it still caught the snow and as it melted it funneled into the water storage drum.
7 Design documentation

7.1 Final Drawings and Documentation

7.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models. Include units on all CAD drawings. See Appendix C for the CAD models.

![Diagram of bicycle with diagram elements labeled from 1 to 22.]

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7.1.2 Sourcing instructions

1. Tricycle – The tricycle is the basis of the design. It is used to move the ice resurfacer around the rink and it drives the conveyor system. A tricycle was chosen because it is a stable human powered vehicle. The wide stance between the rear wheels allows the 30-gallon water tank to be easily attached to the tricycle frame. It was purchased off craigslist but the tricycle is available at target (http://www.target.com/p/schwinn-adult-meridian-26-3-wheel-bike-blue/-/A-10438285?ci_src=17588969&ci_sku=10438285&ref=tgt_adv_XS000000&AFID=google_pla_df&CPNG=PLA_Sports%2BShopping&adgroup=Test&ID=700000001170770pgs&network=g&device=c&location=9030080&gclid=Cj0KEQiA4eqyBRDUh7Omv9Ctso8EiQAqfs8pLMa2p_f4GgNlrzuTPWKTaX_EFTw9kzSvMxS9As-vQaAsV88P8HAQ&gclsrc=aw.ds) for $250.

2. Conveyor Belt Drive Shaft – The conveyor belt drive shaft is threaded onto the rear axle of the tricycle and drives the conveyor system when the driver pedals. It is long enough to support the conveyor frame. It was constructed of scrap aluminum found in the machine shop. A one-inch diameter aluminum bar can be purchased from McMaster Carr (http://www.mcmaster.com/#standard-aluminum-rods/=100ubvs). Model number 8974K13, $7.80/foot.

3. 30 Gallon Drum – The 30 Gallon Drum is used for the water storage system. It provides substantial water to initially cover the ice, and the HDPE material allowed a hole to be cut in the side for snow to be recycled. This was chosen over glass or other tank materials for its durability and ease to work with. This part was purchased off craigslist for $10, and there are many available. Use search terms “30 Gallon Drum” or “30 Gallon Barrel” at craigslist.com.
4. Blade Support Left – The blade support structure is constructed of angle iron found in the machine shop. It attaches the blade to the tricycle. The angle iron provides strength and durability and is also heavy, which increases the cutting force applied to the ice. Angle Iron can be purchased at home depot ([http://www.homedepot.com/p/Everbilt-1-1-2-in-x-14-Gauge-x-72-in-Zinc-Plated-Slotted-Angle-800517/204225758](http://www.homedepot.com/p/Everbilt-1-1-2-in-x-14-Gauge-x-72-in-Zinc-Plated-Slotted-Angle-800517/204225758)), model number 800517, for $2.75/foot.

5. Blade Support Right – The blade support structure is constructed of angle iron found in the machine shop. It attaches the blade to the tricycle. The angle iron provides strength and durability and is also heavy, which increases the cutting force applied to the ice. Angle Iron can be purchased at home depot ([http://www.homedepot.com/p/Everbilt-1-1-2-in-x-14-Gauge-x-72-in-Zinc-Plated-Slotted-Angle-800517/204225758](http://www.homedepot.com/p/Everbilt-1-1-2-in-x-14-Gauge-x-72-in-Zinc-Plated-Slotted-Angle-800517/204225758)), model number 800517, for $2.75/foot.

6. Blade Support Middle – The blade support structure is constructed of angle iron found in the machine shop. It attaches the blade to the tricycle. The middle piece is angled to allow snow to slide across the ice to the conveyor system. The angle iron provides strength and durability and is also heavy, which increases the cutting force applied to the ice. Angle Iron can be purchased at home depot ([http://www.homedepot.com/p/Everbilt-1-1-2-in-x-14-Gauge-x-72-in-Zinc-Plated-Slotted-Angle-800517/204225758](http://www.homedepot.com/p/Everbilt-1-1-2-in-x-14-Gauge-x-72-in-Zinc-Plated-Slotted-Angle-800517/204225758)), model number 800517, for $2.75/foot.

7. Blade Bracket – The blade bracket is a custom made piece of wood that is cut to match the curvature of the blade. It attaches the blade to the blade supports and positions the blade for cutting and scraping the ice. The blade bracket can be made from any piece of scrap wood big enough to meet the dimensions. It must be wide enough to screw the blade supports to the bracket.

8. Plow Blade – The plow blade is used to cut the ice surface and scrape the snow into the conveyor system. It is made by removing the handle and brace from a Garant Yukon Snow Pusher. It can be purchased from amazon ([http://www.amazon.com/Garant-YSP30DU-30-Inch-Pusher-Handle/dp/B003E7URQS/ref=pd_rhf_gw_p_img_8?ie=UTF8&refRID=1PNWRR0M9NYHDWBQ8K16](http://www.amazon.com/Garant-YSP30DU-30-Inch-Pusher-Handle/dp/B003E7URQS/ref=pd_rhf_gw_p_img_8?ie=UTF8&refRID=1PNWRR0M9NYHDWBQ8K16)) for $42 and the model number is YSP30DU.

9. Bulkhead Fitting – The bulkhead fitting connects the piping system to the water storage tank. It creates a seal, preventing the tank from leaking while also creating an opening to allow a pipe to come from the bottom of the tank and distribute water to the ice surface. It can be purchased from amazon ([http://www.amazon.com/Banjo-TF100-Polypropylene-Bulkhead-Fitting/dp/B0079JTX3U/ref=pd_rhf_gw_p_img_11?ie=UTF8&refRID=1WJJHC67F7V8P4HKJKHN](http://www.amazon.com/Banjo-TF100-Polypropylene-Bulkhead-Fitting/dp/B0079JTX3U/ref=pd_rhf_gw_p_img_11?ie=UTF8&refRID=1WJJHC67F7V8P4HKJKHN)) for $6.80 and the model number is TF100.

10. PVC Male Adaptor – The PVC Male Adaptor is a threaded piece of PVC that screws into the bulkhead fitting and allows a piece of 1-inch diameter PVC to be slipped in the other side.
This fitting allows the piping system to connect to the water storage tank. It can be purchased from McMaster Carr (http://www.mcmaster.com/#pvc-pipe-adapters/=100unju) for $1.09 and the model number is 4880K653.

11. PVC Adaptor to elbow – This part is a small piece of 1-inch PVC that allows the Male adaptor to be connected to the PVC elbow. 1-inch PVC pipe can be purchased from Home Depot (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.

12. PVC Elbow – The PVC elbow transitions the water from vertical flow out of the tank to horizontal flow, so the piping system can clear the blade. The PVC elbow can be purchased from McMaster (http://www.mcmaster.com/#standard-plastic-pipe-elbows/=100upte) for $0.61 and the model number is 4880K23.

13. PVC Ball Valve – The ball valve allows the flow to be controlled out of the storage tank. This is a critical component of the water spreading system because it turns the flow on and off. It can be purchased from McMaster (http://www.mcmaster.com/#ball-valves/=100uqru) for $11.13 and the model number is 4876K23.

14. PVC Elbow to Valve – This part is a small piece of 1-inch PVC that allows the PVC elbow to be connected to the ball valve. 1-inch PVC pipe can be purchased from Home Depot (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.

15. PVC Valve to Tee – This part is a small piece of 1-inch PVC that allows the PVC ball valve to be connected to the Tee for the water spreader. 1-inch PVC pipe can be purchased from Home Depot (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.

16. PVC Tee – The PVC Tee diverts the water both directions through the water laying pipes. It can be purchased from McMaster(http://www.mcmaster.com/#standard-pvc-pipe-tees/=100uslj), for $0.81 and the model number is 4880K43.

17. Water Laying Pipe – The water-laying pipe distributes the water from the piping system to the ice. There are 1/8th inch holes spaced 1-inch apart that allow the water to drop to the ice. It is made from 1inch PVC pipe. 1-inch PVC pipe can be purchased from Home Depot (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.

18. PVC Cap – The PVC cap is placed at the end of the water laying pipe and prevents water from coming out the side of the water laying pipe. It keeps the water contained in the system. It can be purchased from McMaster (http://www.mcmaster.com/#pvc-pipe-fitting-caps/=100uuf2), for $0.50 and the model number is 4880K53.
19. Conveyor Bracket – The conveyor bracket provides the structure for the conveyor system. It is made out of wood strips that can be purchased from Home Depot. They are 1”x2”x8’ strips that can be purchased for $0.83 each. (They are not sold online)

20. Roller – The rollers make up the conveyor system. They allow the system to rotate and pick the snow up off the ice. They can be purchased from McMaster (http://www.mcmaster.com/#standard-rollers-for-conveyors/=100uxsa), for $7.29 each and the model number is 5890K301.

21. Snow Chute – The snow chute collects snow from the conveyor system and takes it into the water storage tank for recycling. It is made out of a galvanized steel Round duct pipe that can be purchased at Home Depot (http://www.homedepot.com/p/Master-Flow-6-in-x-5-ft-Round-Metal-Duct-Pipe-CP6X60/100125106), for $8.00 and the model number is CP6X60.

22. Conveyor Belt – The conveyor belt picks up the snow off the ice in custom made buckets and dumps it into the snow chute. The buckets are attached to the conveyor using industrial adhesive. The conveyor belt was found in the machine shop but could be purchased at McMaster (http://www.mcmaster.com/#standard-conveyor-belts/=100v0kd), for $2.52/foot and the model number is 6001K2. The buckets are made of 6 inch aluminum flashing that can be purchased at Home Depot (http://www.homedepot.com/p/Amerimax-Home-Products-6-in-x-10-ft-Aluminum-Valley-Flashing-68306/100038416) for $5.94 and the model number is 68306.

7.2 Final Presentation

7.2.1 A live presentation in front of the entire class and the instructors (this section may be left blank)

7.2.2 A link to a video clip version of 1
https://www.youtube.com/watch?v=XiU8lWaPzkA
7.3 Teardown

TEARDOWN TASKS AGREEMENT

PROJECT: Ice Resurfacer  NAMES: Nick Furman  INSTRUCTOR: Dr. Jakiela
                       Kameryn Truman  \(NF\)  Dr. Malast
                       Meagan Leonard  \(KT\)  

The following teardown/cleanup tasks will be performed:

- Disassemble the blade assembly
- Take apart the conveyor system and recycle parts if able
- Remove the water distribution system from the tricycle frame

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: \(\text{[Signature]}\)  Print instructor name: \(\text{[Name]}\)
Date: 2/1/15

\(NF\  KT'\  ML\)

(Group members should initial near their name above.)

8 Discussion
8.1 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.

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<tr>
<td>11</td>
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<td></td>
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<tr>
<td>12</td>
<td>Need 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>13</td>
<td>Need 13</td>
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</table>

<table>
<thead>
<tr>
<th>Units</th>
<th>in</th>
<th>lb</th>
<th>binary</th>
<th>ft</th>
<th>ft</th>
<th>ft</th>
<th>ft</th>
<th>ft</th>
<th>lb</th>
<th>lb</th>
<th>lb</th>
<th>lb</th>
<th>Total Happiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Value</td>
<td>0.03125</td>
<td>0.03125</td>
<td>1</td>
<td>0</td>
<td>3.5</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>160</td>
</tr>
<tr>
<td>Worst Value</td>
<td>0.125</td>
<td>0.125</td>
<td>0</td>
<td>500</td>
<td>5.5</td>
<td>8</td>
<td>3</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Actual Value</td>
<td>0.0366667</td>
<td>0.0366667</td>
<td>1</td>
<td>300</td>
<td>3.3</td>
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<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>140</td>
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<tr>
<td>Normalized Metric Happiness</td>
<td>1.1666667</td>
<td>1.1093333</td>
<td>1</td>
<td>0.0</td>
<td>0.6666667</td>
<td>0.6666667</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.4166667</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
The above quantified needs results reflect the final performance of the prototype. The overall happiness score of 0.867 reflects that the prototype met the user needs very well. The primary user need was producing a level sheet of ice and that was definitely accomplished. Another important user need was for the device to be completely human powered and it was. There were no external sources of power. Overall the prototype performed very well and met nearly all the user needs. The blade could’ve been more adjustable but it still accomplished the purpose.

8.2 Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects?

The main issue that we had with part sourcing was finding a blade or enough metal to make a blade. At first, we wanted to manufacture a blade from steel scrounged from the machine shop. However, after much consideration we found that it was best to use a snow pusher blade and sharpen the bottom of it to a point. This eliminated extra weight on the project and unnecessary machining time.

We were able to scrounge parts for the drive shaft, the belt, screws and wires, and parts of the frame that held the blade. The drive shaft was a piece of metal found in the machine shop. It was chosen because the threading on the inside of the shaft already fit the threading on the tricycle axle. This made for an easy and cheap drive shaft. The belt was made from sheets of rubber in the machine shop. The sheets were cut into 5” wide sheets and stapled together to make a long belt. Originally, we bought a different belt to use and the one made in the machine shop was made just to test the conveyor system. However, the purchased belt had a larger curve radius when it curved around the drive shaft and there was not enough contact between the shaft and the belt and the system would not rotate. This caused us to continue using the belt made from the machine shop scraps. Obviously, there is a need for screws, wires and other connective materials that are easily found in the machine shop. Also, using metal and wood from the machine shop to make the support system for the blade was the best option because there was not a real need for these parts to weigh a certain amount or be made of particular material. We had no parts with unreasonably long delivery time as the majority of our parts were found on amazon, craigslist, or at a local hardware store.

Our recommendation for future projects would be to order their parts in the same way that we did. First, identify your few most important parts of your project and purchase those right away. Second, identify the parts that do not affect other parts of your project
and find those while you wait for the first parts to come in. Last, find all parts that were dependent on the other parts that you bought.

8.3 Discuss the overall experience:

8.3.1 Was the project more of less difficult than you had expected?
The project was more difficult than expected. At first we expected to be able to build each system (water, blade, and conveyor) separately and then attach all three to the tricycle and have it work. However, there were a few instances that the systems would run into each other or they were too far apart for the system to function and at those points we had to trouble shoot a lot.

8.3.2 Does your final project result align with the project description?
Our final project result does align with the project description. The system scraps the ice, lays a layer of water on the ice, and lifts the shaved ice and dumps it back into the bucket. The only misalignment between the original project description and our project was that we originally wanted the system to scrape and lay 1/16” of ice and water but by the end of the project we decided that 1/32” was sufficient.

8.3.3 Did your team function well as a group?
Our team functioned very well as a group. We all took the time to do our parts of the project and did our best to make it to as much of the manufacturing time as possible. Obviously, there were times that not everyone could make it or could get their part done but overall we worked well together.

8.3.4 Were your team member’s skills complementary?
Our group had a lot of complimentary skills. Nick took the lead on the majority of sketching and manufacturing. He made sure that everyone in the group had a job to do and that they were getting it done. When things went wrong Meagan was the one, a lot of times, that was able to identify where the root of the issue was. For instance if the conveyor stopped working she would be the one to find the source of this problem. Kameryn was very good at coming up with a creative solution to the problems that arose with the resources that were available.

8.3.5 Did your team share the workload equally?
For the most part, work was shared evenly. As stated in the previous section there were many times that Nick took the lead in coordinating and manufacturing for the group but all group members were expected to do their fair share of the work.

8.3.6 Was any needed skill missing from the group?
There was no major skill that we felt was missing for the group; however, there were times that only two people were working on the project at a time and in those scenarios we could feel an absence of some skills.
8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

We consulted the manager at the ice rink throughout our design process but we still stuck to the original design brief. The rink manager more taught us about their Zamboni and how ice resurfacing works.

8.3.8 Did the design brief (as provided by the customer) seem to change during the process?

The design brief did not change through the process.

8.3.9 Has the project enhanced your design skills?

We feel that this project has enhanced our design skills and problem solving skills as there were many times throughout the project where small changes needed to be made in order to reach the end goal.

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

We would feel more comfortable accepting design project assignments now as we feel that our problem solving skills have become more refined.

8.3.11 Are there projects that you would attempt now that you would not attempt before?

There is a project that we have all discussed moving forward with now that this project is up and working and we have learned more about ice resurfacing.
9 Appendix A - Parts List

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QTY</th>
<th>PART NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Tricycle(flat)</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Conveyor Belt Drive Shaft</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>35 Gallon Drum</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Blade Support Left</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Blade Support Right</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Blade Support Middle</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>Blade Bracket</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>Plow Blade</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>Bulkhead Fitting</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>PVC Male Adaptor</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>PVC Adapter To Elbow</td>
</tr>
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<td>12</td>
<td>1</td>
<td>PVC Elbow</td>
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<td>1</td>
<td>PVC Ball Valve</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>PVC Elbow To Valve</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>PVC Valve to Tee</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>PVC Tee</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>Water Laying Pipe</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
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</tr>
<tr>
<td>19</td>
<td>2</td>
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</tr>
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<td>21</td>
<td>1</td>
<td>Snow Chute</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>Conveyor Belt</td>
</tr>
</tbody>
</table>

Figure 23: Parts List

10 Appendix B - Bill of Materials

1. Tricycle – (http://www.target.com/p/schwinn-adult-meridian-26-3-wheel-bike-blue/-/A-10438285?ci_src=17588969&ci_sku=10438285&ref=tgt_adv_X5000000&AFID=google_pla_df&CPNG=PLA_Sports%2BSHopping&adgroup=Test&UID=700000001170770pgs&network=g&device=c&location=9030080&gclid=Cj0KEQiA4eqyBRDUh7Om9vCtsoBEiQApsfs8pLMA2p_f4GgNrzruTPWKTaX_EFtw9kzSvMxS9As-vQaAsV88P8HAQ&gclsrc=aw.ds) for $250.


3. 30 Gallon Drum – craigslist for $10, and there are many available. Use search terms “30 Gallon Drum” or “30 Gallon Barrel” at craigslist.com


7. Blade Bracket – The blade bracket is a custom made piece of wood that is cut to match the curvature of the blade. It attaches the blade to the blade supports and positions the blade for cutting and scraping the ice. The blade bracket can be made from any piece of scrap wood big enough to meet the dimensions. It must be wide enough to screw the blade supports to the bracket.

8. Plow Blade – (http://www.amazon.com/Garant-YSP30DU-30-Inch-Pusher-Handle/dp/B003E7URQS/ref=pd_rhf_gw_p_img_8?ie=UTF8&refRID=1PNWRR0M9NYHDWBQ8K16) for $42 and the model number is YSP30DU.


10. PVC Male Adaptor -- (http://www.mcmaster.com/#pvc-pipe-adapters/=100unju) for $1.09 and the model number is 4880K653.

11. PVC Adaptor to elbow – (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.

12. PVC Elbow – (http://www.mcmaster.com/#standard-plastic-pipe-elbows/=100upte) for $0.61 and the model number is 4880K23.

13. PVC Ball Valve – (http://www.mcmaster.com/#ball-valves/=100ugru) for $11.13 and the model number is 4876K23.

14. PVC Elbow to Valve – (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.

15. PVC Valve to Tee – (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.

16. PVC Tee – (http://www.mcmaster.com/#standard-pvc-pipe-tees/=100uslg), for $0.81 and the model number is 4880K43.

17. Water Laying Pipe – (http://www.homedepot.com/p/Unbranded-1-in-x-10-ft-PVC-Schedule-40-Plain-End-Pipe-531194/202280936) for $0.29/foot and the model number is 531194.
18. PVC Cap – (http://www.mcmaster.com/#pvc-pipe-fitting-caps/=100uuf2), for $0.50 and the model number is 4880K53.

19. Conveyor Bracket –They are 1”x2”x8’ strips that can be purchased for $0.83 each. (They are not sold online)

20. Roller – (http://www.mcmaster.com/#standard-rollers-for-conveyors/=100uxsa), for $7.29 each and the model number is 5890K301.

21. Snow Chute – (http://www.homedepot.com/p/Master-Flow-6-in-x-5-ft-Round-Metal-Duct-Pipe-CP6X60/100125106), for $8.00 and the model number is CP6X60.

22. Conveyor Belt – (http://www.mcmaster.com/#standard-conveyor-belts/=100v0kd), for $2.52/foot and the model number is 6001K2. (http://www.homedepot.com/p/Amerimax-Home-Products-6-in-x-10-ft-Aluminum-Valley-Flashing-68306/100038416) for $5.94 and the model number is 68306.

11 Appendix C - CAD Models
CAD models uploaded to blackboard group per Dr. Malast. See section 6 for drawings.

12 Appendix D - Engineering Analysis Calculations
Embodiment Assignment – Analysis for Ice Resurfacer

Nick Furman, Kam Truman, Meagan Leonard

Tank Sizing:
Known:
1/16” shaved off ice surface
200 ft *85 ft = Surface Area of ice rink
35 gallon tank

Find:
How much of a rink could this hold?

Solution:
231 in^3/gal x 35 gal = 8085 in^3 amount of storage in a tank
200 ft x 12in/ft = 2400 in length of ice rink
85 ft x 12 in/ft = 1020 in  width of ice rink

2400 in x 1020 in x 1/16 in = 153000 in^3  volume of ice shaved in 1 resurfacing

100% x 8085 in^3/153000 in^3 = 5.3%

Therefore, since we have a recirculating snow to water system, a 35 gallon tank will work as long as we don’t lose more than 5% of the shaven snow.

**Blade Angle:**

According to the university of Iowa the “maximum cutting angle with the minimal force” for cutting solid ice is 15° (Tested on snow plows, which are similar to ice-resurfacer).

**Source:** “Measurement of Ice Scraping Forces on Snow-Plow Underbody Blades” Iowa Department of Transportation Project HR 371

![Image of a 15° angle](image.png)

**Blade Length:**

Blade must be angled so that snow will collect on one side of the resurfacer and can then be lifted into the tank (via conveyor belt).

\[
\cos(45^\circ) = \frac{28.5}{\text{Hypotenuse}} = \frac{28.5}{L}
\]

\[
28.5 \times \sqrt{2} = 40.30 \text{ in} = L
\]

**Conveyor Belt Speed:**

Driving mechanism is attached to rear axle. Conveyor belt will be driven at same rotational speed as the rear axle.

\[
S_1 = \text{front gear rotational speed}
\]
\[
T_1 = \text{number of teeth in front gear}
\]
\[
S_2 = \text{back gear (rear axle) rotational speed}
\]
\[
T_2 = \text{number of teeth in back gear}
\]

\[
S_1 \times T_1 = S_2 \times T_2
\]

\[
S_1 = 70 \text{ rpm} – 100 \text{ rpm}
\]

\[
T_1 = 40
\]
T2 = 20

At 70 rpm,
70 x 40 / 20 = 140 rpm = minimum

At 100 rpm
100 x 40 / 20 = 200 rpm = maximum

Therefore it will be fast enough rotation to move the 6” conveyor belt system.

Static Analysis:

Mass of barrel = 35 gallons (8.3454 lbf/gal) = 292.089 lbf

FBD:

\[
\sum M_x = F_{Driver} \times R_{Driver} - F_{Barrel} \times R_{Barrel}
\]

\[
\sum M_x = 160 \text{lbf} \times 1 \text{foot} - 292.089 \times 0.5 \text{foot} = 160 - 146.05 = 13.95 \text{ft \cdot lbf}
\]

This shows the weight of the barrel will not cause the ice resurfacer to tip over.

Cutting Force Analysis:

Tests performed. No excessive force needed beyond the weight of the apparatus. Also, 15 deg angle works well.

Thermodynamics:

\[
Q = mc\Delta T
\]

\[
Q = (113.49 \text{kg}) \left( \frac{2090 \text{J}}{\text{kg} \cdot \text{°C}} \right) (-15 \text{°C} - 0 \text{°C}) = 3557598 \text{J}
\]
This is how much energy it would take to melt the entire barrel full of snow at one time. This is not the case because the snow is slowly dumped into the barrel full of water and therefore only small amounts of snow would have to melt at one time.

13 Annotated Bibliography (limited to 150 words per entry)


How to complete a risk assessment

by Bernie Eccles and Professor Ian Bruce
Cass Business School Centre for Charity Effectiveness, 2010
How to complete a risk assessment

Bernie Eccles and Professor Ian Bruce OBE

1 A note about the design of this publication

KnowHow NonProfit has designed this publication to be accessible for people using screen readers. The source file for this PDF has been edited in the Royal National Institute for the Blind (RNIB) Word template. As such, we have deliberately chosen to prioritise an accessible structure over eye-catching design. We believe this makes our PDFs easier to read for everyone.
2 Introduction

There are four stages involved in preparing a risk assessment for a project, organisation or set of operating processes. These are:

- risk identification: identifying the main risks
- risk assessment: assessing the likelihood of each risk occurring and the consequences for the organisation
- risk mitigation: identifying the most appropriate actions to reduce or eliminate the risk
- contingency assessment: identifying the contingencies that need to be put in place following the risk assessment.

Risk management is an ongoing process and should be fully integrated into project management and review processes.

3 Risk identification

The first step in completing a risk assessment is to identify the risks associated with the management and operational processes for the organisation or project. A good way to do this is to hold a brainstorming session. The aim should be to identify risks, without going on to debate or assess them at this stage.

A typical local voluntary organisation should think about potential risks within each of the following areas:

- trustees
- organisation
- funding
- paid staff
- volunteer staff
- health and safety
- client service levels
- IT · premises
- finance.

Each area may have several risks associated with it. The funding area, for example, may contain risks involving loss of core funding, loss of a significant grant or contract, or late payments.
Once you have identified all of the risks for your organisation or project, you can review the list to remove any overlaps and to make sure it covers all of the important risk areas.

4 Risk assessment

Risk assessment involves rating each risk against two dimensions: probability and impact.

4.1 Probability

The ‘probability’ aspect of risk assessment involves deciding how likely it is that the risk will occur. Each risk should fall into one of three categories:

- high probability: the risk might occur once every one to two years
- medium probability: the risk might occur once every three to five years
- low probability: the risk might occur less frequently than once in five years.

4.2 Impact

The ‘impact’ aspect of risk assessment involves considering what the potential impact of the risk would be on the organisation, client or project. Each risk should fall into one of three categories:

- high impact: the organisation might be forced to terminate activities as a result of a catastrophic failure or occurrence defined by the risk
- medium impact: the organisation would continue but the risk will have significantly effected its performance, timescales or costs
- low impact: the impact would be small and easily managed at a relatively routine level within the organisation.

4.3 Risk classifications

Once you have decided the probability and impact of each risk, you can plot them on a risk classification chart like the one below.
4.3.1 Critical risks

- major risks with high probability and high impact
- require explicit management to keep them under control
- example: late payment of a grant that causes the charity to become insolvent.

4.3.2 Difficult/insurance risks

- risks which are unlikely to occur but which would have severe consequences if they did occur
- difficult to manage
- example: a catastrophic power failure in the organisation’s operational headquarters, causing all computers and systems to fail.

4.3.3 Routine risks

- commonly occurring risks which have only a minor impact on the organisation
- as they occur frequently, action to mitigate the risk should be built into a routine process
- example: minor human errors in delivery processes or procedures.

4.3.4 Low importance risks

The four quadrants on the chart define different categories of risk which require different management approaches. These are described below.
• risks which have both low likelihood and low impact
• responsibility for these risks might be delegated to lower levels in the organisation
• these risks may be monitored to see if they develop into more important risks.

5 Risk mitigation

The next step is to decide how to manage the higher importance risks. In some cases the only action might be to monitor the risk and see if it becomes more significant.

Risk mitigation actions might include:

• define actions which would eliminate the risk or reduce it to an acceptable level. For example, in the event of a late grant or contract payment, the organisation could seek to generate or borrow a contingency fund of one to three months’ revenue.
• insure against unlikely but high impact risks. For example, to mitigate against a power failure, the organisation could pay for a back-up computer server housed offsite, with systems and processes automatically transferred to the back-up server.
• redefine or redesign the activity generating the risk to be lower risk. For example, to reduce routine human errors, manual activities could be transferred to computer-based processes with operator prompts and support.
• monitor the risk to see if it develops into a higher category risk. For example, monitoring the reliability of key office equipment to ensure that items can be replaced cost-effectively and in good time.

Once you have defined the actions for each risk, you will need to estimate the resources, workload and costs for each action. You can then assess the resources and costs against the risks to decide whether they are sensible and in proportion. It is very easy to generate a large list of actions which require a significant amount of budget and resources. It is often necessary to review and revise the list to achieve an appropriate set of risk mitigation actions.

Risk mitigation actions should be reviewed regularly, as risks and the appropriate responses can change over time. The risks for projects and mature operational processes should reduce substantially over time as understanding and experience grow. For projects close to completion, the total risk should fall to almost zero.

6 Contingency assessment
The last stage in the risk assessment process is to decide what contingencies should be put in place to assure management that projects and operational performance are secure.

There are four aspects to consider when assessing contingency:

• performance
• funding · timescale
• cost.

6.1 Performance
This is the standard of client performance or service that has been promised to a grant provider or advertised externally. In general, an organization will promise around five to ten per cent less than the standard they believe they can achieve on a routine basis.

6.2 Funding
This area of contingency covers the amount and timing of the funds or income that needs to be raised. Most organizations would not want to assume that the funding they have been promised will come into the organization in full and on time, so will try to commit resources only when the funding is assured. Some organizations align core funding areas with more certain sources of income and other services or resources with smaller, less certain funding sources. It can also be sensible to hold an appropriate level of funding in reserve.

6.3 Timescale
This contingency relates to the completion date of a project or the date at which a certain level of performance is achieved. The typical contingency is to quote a later completion date than is necessary, to allow for things that might go wrong.

6.4 Cost
Project costs or ongoing operational costs, including inflation, should be a major area of contingency. The management team might decide to forecast a somewhat higher cost than they believe they can achieve, to allow for additional costs and resources that would be required if things go wrong or the project runs for longer than planned.
## 7 Risk assessment matrix

A risk assessment matrix collates information on risks, probabilities, impacts and mitigating actions. The example below shows some of the risks that might apply to a medium to large-sized local voluntary organisation delivering funded services.

<table>
<thead>
<tr>
<th>Risk area</th>
<th>Risk description</th>
<th>Probability</th>
<th>Impact</th>
<th>Mitigating actions</th>
<th>Responsibility</th>
</tr>
</thead>
</table>
| Funding         | Loss / reduction of core funding         | Low         | High   | • document in detail how the organization helps core funders to meet their key objectives  
                        |                           |             |                                                 | Chair and chief executive      |
|                 |                                         |             |        | • quantify in numerical terms the volume and quality of outcomes achieved by the organization  
<p>| | | | |
|                           |             |                                                 |                              |
|                 |                                         |             |        | • communicate regularly with core funders.                                            |                              |</p>
<table>
<thead>
<tr>
<th>Risk area</th>
<th>Risk description</th>
<th>Probability</th>
<th>Impact</th>
<th>Mitigating actions</th>
<th>Responsibility</th>
</tr>
</thead>
</table>
| Trustees  | Inadequate trustee coverage resulting in failure to address key areas of governance | Low         | Medium | • target recruitment of suitable volunteers through networks, volunteering websites and local publications  
• identify back-up trustees to share/overlap responsibilities  
• identify professional experts to provide support/advice  
• organise subcommittees in appropriate areas to ensure trustees are kept informed effectively  
• trustees to attend staff meetings where appropriate. | Chief executive                                      |
| Paid staff| Loss of key permanent staff | Medium      | High   | • identify ‘shadows’ or deputies for all key staff and provide training  
• identify recruitment agencies and interim managers in advance of losses. | Chief executive and key staff           |
| Health and safety | Significant accident or incident | Low | Medium | • define appropriate health and safety policies and audit them regularly  
• undertake a separate health and safety risk assessment  
• record and report all accidents/incidents and ensure lessons are learnt. | Chief executive / safety officer |
|------------------|-------------------------------|-----|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| IT               | Complete loss of IT services due to computer or power failure | Low | High   | • ensure all equipment has automatic local back-up  
• ensure all data is regularly backed-up and filed by each operator  
• explore the cost-effectiveness of computer back-up at a separate site. | IT manager |
| Client service levels | Target service levels not met by a significant margin | Low – medium | High | • monitor service levels on a monthly basis  
• define and monitor targets for staff numbers and productivity levels  
• identify specific actions needed to address reduced service levels and report on actions monthly. | Chief executive and key staff |
<table>
<thead>
<tr>
<th>Risk area</th>
<th>Risk description</th>
<th>Probability</th>
<th>Impact</th>
<th>Mitigating actions</th>
<th>Responsibility</th>
</tr>
</thead>
</table>
| Finance   | Major fraud or error | Low         | High   | • define and audit all financial processes  
• second review of all significant payments, with two signatures on cheques  
• two-person review of all financial transactions. | Finance director and chief executive |
KnowHow NonProfit is part of the Cass Business School Centre for Charity Effectiveness and is currently funded by a Big Lottery Fund grant to the City Centre for Charity Effectiveness Trust Ltd (registered charity no. 1101084).