Roof Mounted Assisting Bicycle Rack

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TABLE OF CONTENTS
ROOF MOUNTED ASSISTING BICYCLE RACK ................................................................. I
ACKNOWLEDGEMENTS ................................................................................................. II
TABLE OF CONTENTS .................................................................................................. II
LIST OF TABLES ........................................................................................................... III
ABSTRACT ..................................................................................................................... IV
INTRODUCTION ............................................................................................................. 1
  BACKGROUND .......................................................................................................... 1
RESEARCH OF EXISTING BIKE RACK DESIGNS .................................................. 2  
  YAKIMA HIGHROLLER BIKE MOUNT ................................................................. 3
  YAKIMA SPROCKETROCKET ROOF MOUNT .......................................................... 3
  VEHICLE BICYCLE RACK EXTENSION ................................................................. 4
  SUMMARY .............................................................................................................. 4
CUSTOMER FEEDBACK, FEATURES, AND OBJECTIVES .................................... 5
  SURVEY ANALYSIS ............................................................................................... 5
  PRODUCT FEATURES AND OBJECTIVES ........................................................... 8
DESIGN ....................................................................................................................... 9
  DESIGN ALTERNATIVES ....................................................................................... 9
  FINAL SELECTION ............................................................................................... 12
  PRODUCT DESIGN ............................................................................................ 13
  LOADING CONDITIONS ...................................................................................... 15
  DESIGN ANALYSIS ............................................................................................ 15
  FACTORS OF SAFETY OF CONCERN ............................................................... 18
  MATERIAL AND COMPONENT SELECTION ................................................. 19
  FABRICATION AND ASSEMBLY DRAWINGS ............................................... 19
  BILL OF MATERIALS ......................................................................................... 19
FABRICATION AND ASSEMBLY ........................................................................ 20
  FABRICATION OF COMPONENTS .................................................................... 20
  ASSEMBLY .......................................................................................................... 22
  TESTING ............................................................................................................. 23
  RECOMMENDATIONS ...................................................................................... 25
PROJECT MANAGEMENT ..................................................................................... 26
  SCHEDULE ......................................................................................................... 26
  BUDGET ............................................................................................................ 27
CONCLUSION ......................................................................................................... 28
REFERENCES ....................................................................................................... 29
APPENDIX A - RESEARCH .................................................................................. A1
APPENDIX B – CUSTOMER SURVEY AND RESULTS .............................................. B1
APPENDIX C – QUALITY FUNCTION DEPLOYMENT .............................................. C1
APPENDIX D – SCHEDULE ................................................................................... D1
APPENDIX E – BUDGET ......................................................................................... E1
APPENDIX F – DESIGN ALTERNATIVES .............................................................. F1
APPENDIX G – WEIGHTED DECISION MATRIX .................................................. G1
APPENDIX H – CALCULATIONS .......................................................................... H1
APPENDIX I – FABRICATION AND ASSEMBLY DRAWINGS ............................... I1
APPENDIX J – BILL OF MATERIALS ...................................................................... J1
APPENDIX K – CUSTOMER TESTING SURVEY AND RESULTS ............................ K1

LIST OF FIGURES
Figure 1 Mega Joe Trunk Bike Rack ........................................................................ 2
Figure 2 HighRoller Bike Mount ............................................................................. 3
Figure 3 Yakima Sprocket Rocket Roof Mount ...................................................... 4
Figure 4 Vehicle Bike Extension Rack .................................................................... 4
Figure 5 Pivot Arm Design ..................................................................................... 9
Figure 6 Telescoping- Pivot Base Design ............................................................... 10
Figure 7 Sliding Base Design ............................................................................... 11
Figure 8 Pivoting Motion ...................................................................................... 13
Figure 9 Clamp Assembly .................................................................................... 13
Figure 10 Design Adjustability ............................................................................. 14
Figure 11 Load from Hanging Bike ....................................................................... 16
Figure 12 Shear on Pivot Pin ................................................................................. 17
Figure 13 Free Body Diagram with Rubber Stop .................................................. 17
Figure 14 Vertical Bandsaw ................................................................................... 20
Figure 15 Vertical Milling Machine ....................................................................... 20
Figure 16 MIG Welding Aluminum ...................................................................... 21
Figure 17 Completed Bike Rack Assembly ........................................................... 22
Figure 18 Testing - Mountain bike ........................................................................ 23
Figure 19 Testing - Road Bike ............................................................................... 23
Figure 20 Schedule of project milestones ............................................................. 26

LIST OF TABLES
Table 1 Average survey results ........................................................................... 1
Table 2 Development of Improvement Ratio ......................................................... 6
Table 3 Importance of Engineering Characteristics ............................................. 1
Table 4 Sorted Customer Features ....................................................................... 1
Table 5 Weighted Decision Matrix ....................................................................... 1
Table 6 Customer Testing Survey Results ............................................................ 1
Table 7 Final Budget Costs .................................................................................. 1
ABSTRACT

Cyclists use roof racks as a way to transport their bicycles on vacations and different riding location. There are currently no bike racks that help and assist the consumer in raising and lowering a bike from the top of the car. There is potential for injury and damage caused to the rider, bike, or vehicle when loading a bike onto a roof rack. With vehicles getting taller and larger, the potential for injury increases.

By utilizing customer feedback, various concepts were created and evaluated. The new design focused on assisting the customer in raising and lowering the bike to a safer mounting position, the side of the car. The prototype was designed, fabricated, and tested in the following project. The testing results prove that the design assisted the user in mounting a bike to a roof rack system in a safer, more ergonomic approach.
INTRODUCTION

BACKGROUND

Bicycles have been a form of transportation for a very long time. Technology has evolved and so has the bicycle. There are different types of road bike and mountain bikes, all available in different sizes, shapes, and material. People take their bikes with them on vacations, using different variations of bike racks. People also tend to drive larger cars, vans, and sport utility vehicles (SUV). This has presented a problem when loading a bike on the roof rack of a tall vehicle. It is awkward and unsafe to try and balance while holding your heavy bike with one hand over your car. One can easily drop the bike, damaging the car, the bike, or even hurting themselves.

The design of a roof mounted assisting bicycle rack would eliminate this problem. Manufacturers have yet to produce a roof mounted bike rack that lowers to the side of the vehicle for easy loading and unloading of your bicycle. This design project is to develop, fabricate, and assemble a roof mounted assisting bicycle rack. The bike rack will lower the bicycle to the side of the car at a safe and easy height to load and unload the bicycle without removing the front tire. It will then assist the operator in raising the bicycle to a secure position on the roof of the car. This bicycle rack will eliminate the chance of dropping a bike while raising it to your roof, and allow you to safely, securely attach the bicycle to the bike rack.
RESEARCH OF EXISTING BIKE RACK DESIGNS

Research on existing roof mounted bicycle racks was conducted using an interview, a previous senior design project, and internet sources. This was conducted to gain an understanding of the current roof mounted bicycle rack design. The objective was to find the current flaws or areas of improvement for the current designs used in the market.

An interview was conducted with a Chris Douglas, a cycling enthusiast and racer, that has had experience using roof mounted bike racks on various vehicles, including SUV’s, and small sedans. The purpose of the interview was to find current issues with roof racks Chris had used. Many of the problems were related to the ease of use, and design. The operator had difficulty mounting the bike to the roof rack while using the taller SUV. The operator had to stretch to an uncomfortable and awkward position to reach the roof of the car, while trying to balance the bike and secure the lock with each hand. Chris also did not like having to remove the front wheel from the bicycle before mounting it to the bike rack. This created an inconvenience and took too much time. While discussing the new design idea, durability, adjustability, and cost were all mentioned as important factors when looking for a roof mounted bicycle rack (1).

YAKIMA MEGA JOE TRUNK BIKE RACK

Yakima specializes in the manufacturing of roof, trunk, and hitch mounted bicycle racks. One very common style of bicycle rack is the trunk mounted design. Yakima has created many different styles of trunk rack, with a very popular one being shown in Figure 1, the Mega Joe Trunk Bike Rack. It is designed for simplicity and value. The bike rack is made of high quality steel that will allow for a durable design. The steel tubing has pads mounted to it to prevent any damage to the cars paint or surface finish. This design can carry three bicycles, fitting a wide variety of road and mountain bikes while only costing $89 (2).

The simplicity and low cost of this design make this a great bike rack but it does have issues. The bike rack is mounted to the trunk of the car, making it impossible to gain access to this storage space while the bike rack is being used. The other issue with this design is a lack of security. The bikes mount securely to the rack with ratchet straps, but there is no way to lock them to the car. This leaves the bicycles vulnerable to theft while the owner is not at the car.

Figure 1 Mega Joe Trunk Bike Rack
**Yakima HighRoller Bike Mount**

The Yakima HighRoller Bike Mount shown in Figure 2 is the best roof mounted bike rack Yakima offers. The bike rack mounts to roof rails on the top of your car, truck, or SUV. The advantages of this bike rack are its versatility and security. The bike mounts securely to the roof rack without removal of the front wheel. The mounting arms that hold the front wheel and the ratchet strap for the rear wheel provide secure and stable mounting points for the bike. This bike is mounted using the wheels so there is no chance to damage the frame. It can be adjusted to carry all sizes of road and mountain bikes (3).

![Figure 2 HighRoller Bike Mount](image)

This bike rack is one of the best roof rack designs offered, yet still does not help our current problem. The bike rack is mounted statically to the roof of the car. This still causes a problem when lifting the bike up to a taller roof. The user may struggle to safely and securely mount the bike to the rack.

**Yakima SprocketRocket Roof Mount**

Yakima also makes another high quality roof mounted bike rack called the SprocketRocket. This roof mounted bike rack uses a fork mounting design, reducing the number of parts, while increasing simplicity. As shown in Figure 3, the SprocketRocket uses a very slim and aerodynamic design. The bike rack has superior bike security with the fork mount design, and an integrated lock system. The fork mount design uses a quick release skewer to clamp to the lower flanges on a bicycle fork, while using a ratchet strap to secure the back wheel. The SprocketRocket fits all bikes, allowing superior versatility (4).

The SprocketRocket’s design makes it very aesthetically pleasing to the user, and provides great bike security. One issue with this bike mount is the fork mounting design. This means the operator must remove the front wheel of the bike before mounting it to the roof rack. The other issue with the SprocketRocket is the inability to lower the bike mount to the side of the car. It is statically mounted to the roof rails on the car, making it difficult for the operator to mount the bicycle on the rack with a taller car.
VEHICLE BICYCLE RACK EXTENSION

A senior design project was previously done on the same topic in 1995 by Sam Yorgovan. The main objectives were to create a bicycle rack that extended from the roof of the car or van, simplifying the process of loading and unloading a bike. It concentrated on making sure the user did not have to reach over their head or to the top of the car to perform this task. This design used a spring actuated mechanism to help lift the bike, making it seem as if the bike was 50% lighter than its actual weight. The bike rack extends far enough to prevent any damage to the car surface finish and paint. The bike rack is capable of carrying up to 70 pounds, and four bicycles (5). One disadvantage of this bike rack is the fork mounting design. The user must remove the front wheel to load the bicycle onto the rack. The bike rack itself is also very tall. This will create wind noise while traveling, and can be a nuisance to the driver.

SUMMARY

The preceding research shows the room for improvement with a roof mounted bike rack. Using materials and technology from today should allow for an ergonomic design more suited for the taller vehicles people drive. This will allow for a practical design that will assist the user in loading and unloading a bicycle from a roof rack mount on a vehicle.
CUSTOMER FEEDBACK, FEATURES, AND OBJECTIVES

Survey Analysis

To gain valuable information this survey was passed out to various cycling enthusiasts and shops around the Cincinnati, OH area. Only five of those twenty were completed and returned at the time this report was being completed. Many store owners were unwilling to fill out the survey because the product was not something they sold at their location. Extensive research and the returned surveys provided a general understanding of what the customer’s feel is necessary for this bike rack.

The basis of this survey was focused on customer features that were determined through the research and interviews conducted earlier, and included the new designs compatibility with current bike and roof rack systems, the bike racks ease of operation, and durability. The first part of the survey asked customers to rank the features importance for the new design (See Appendix B for full survey results). The importance was rated on a scale of 1-5, with 5 having the highest importance. Table 1 shows the average customer rating for each feature, sorted by importance.

<table>
<thead>
<tr>
<th>Question Surveyed</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatible with road and mountain bikes</td>
<td>5.0</td>
</tr>
<tr>
<td>Easy to operate by one person</td>
<td>4.8</td>
</tr>
<tr>
<td>Easy to maintain</td>
<td>4.8</td>
</tr>
<tr>
<td>Compatible with existing roof rack systems</td>
<td>4.6</td>
</tr>
<tr>
<td>Provides bike security</td>
<td>4.6</td>
</tr>
<tr>
<td>Easy to access from side of car</td>
<td>4.4</td>
</tr>
<tr>
<td>Durable</td>
<td>4.4</td>
</tr>
<tr>
<td>Resistant to outdoor environment</td>
<td>4.4</td>
</tr>
<tr>
<td>Affordable</td>
<td>4.0</td>
</tr>
</tbody>
</table>
For the second part of the survey, the customer was asked to rate the satisfaction of a current bike rack design used. Again using a scale from 1-5, with 5 being very satisfied. Table 2 shows the participant’s average satisfaction with a current roof rack product. The results show that customers are currently least satisfied with affordability, and ease of accessibility from the side of the car. Customers were also unsatisfied with bike security, durability, and ease of operation. Bike compatibility and ease of maintenance were the ranked with the highest satisfaction for a current design. The new design will immensely improve the satisfaction of these features.

After analyzing both sets of results from the survey, a planned satisfaction was determined for each customer feature. Shown in Table 2 are the average results desired after the customer uses the new bike rack. These values show improvement in both customer importance and satisfaction.

After determining the average planned satisfaction, an improvement ratio was calculated and shown in Table 2. The ratio was the planned satisfaction versus the current satisfaction, and helped to show the necessary increase in improvement for each feature. Easy access from the side of the car requires a 147% increase in customer satisfaction to reach the planned satisfaction goal that has been set. These values are then used to modify the customer’s importance average. The importance average is then used to determine the importance of each customer feature.

<table>
<thead>
<tr>
<th>Question Surveyed</th>
<th>Current Satisfaction</th>
<th>Planned Satisfaction</th>
<th>Improvement Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to access from side of car</td>
<td>3.4</td>
<td>5.0</td>
<td>1.47</td>
</tr>
<tr>
<td>Easy to operate by one person</td>
<td>3.8</td>
<td>5.0</td>
<td>1.32</td>
</tr>
<tr>
<td>Compatible with existing roof rack systems</td>
<td>4.0</td>
<td>5.0</td>
<td>1.25</td>
</tr>
<tr>
<td>Affordable</td>
<td>3.2</td>
<td>4.0</td>
<td>1.25</td>
</tr>
<tr>
<td>Provides bike security</td>
<td>3.6</td>
<td>4.0</td>
<td>1.11</td>
</tr>
<tr>
<td>Resistant to outdoor environment</td>
<td>3.6</td>
<td>4.0</td>
<td>1.11</td>
</tr>
<tr>
<td>Compatible with road and mountain bikes</td>
<td>4.8</td>
<td>5.0</td>
<td>1.04</td>
</tr>
<tr>
<td>Durable</td>
<td>4.0</td>
<td>4.0</td>
<td>1.00</td>
</tr>
<tr>
<td>Easy to maintain</td>
<td>4.4</td>
<td>4.0</td>
<td>0.91</td>
</tr>
</tbody>
</table>
The modified importance values are then used to find the final relative importance of each feature. This is done by normalizing the values to a total of one, and then converting them to a percentage. Table 3 shows the features sorted in descending order from most important to least important, based on the calculated relative importance.

<table>
<thead>
<tr>
<th>Question Surveyed</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to access from side of car</td>
<td>14%</td>
</tr>
<tr>
<td>Easy to operate by one person</td>
<td>13%</td>
</tr>
<tr>
<td>Compatible with existing roof rack systems</td>
<td>12%</td>
</tr>
<tr>
<td>Compatible with road and mountain bikes</td>
<td>11%</td>
</tr>
<tr>
<td>Provides bike security</td>
<td>11%</td>
</tr>
<tr>
<td>Affordable</td>
<td>11%</td>
</tr>
<tr>
<td>Resistant to outdoor environment</td>
<td>10%</td>
</tr>
<tr>
<td>Durable</td>
<td>9%</td>
</tr>
<tr>
<td>Easy to maintain</td>
<td>9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engineering Characteristic</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic and aluminum materials</td>
<td>16%</td>
</tr>
<tr>
<td>Assists user to lift bike</td>
<td>13%</td>
</tr>
<tr>
<td>Wheel mounting system</td>
<td>11%</td>
</tr>
<tr>
<td>Lowers bike to side of car</td>
<td>10%</td>
</tr>
<tr>
<td>Adapters for different crossbars</td>
<td>9%</td>
</tr>
<tr>
<td>Bike rail adjusts for different bike sizes</td>
<td>8%</td>
</tr>
<tr>
<td>Bike locks to rack</td>
<td>8%</td>
</tr>
<tr>
<td>Costs less than $300</td>
<td>8%</td>
</tr>
<tr>
<td>Number of components</td>
<td>7%</td>
</tr>
<tr>
<td>Load capacity of 60 lbs</td>
<td>6%</td>
</tr>
<tr>
<td>Adjustable clamping pressure to hold bike</td>
<td>3%</td>
</tr>
<tr>
<td>Components painted</td>
<td>2%</td>
</tr>
</tbody>
</table>

The engineering characteristics were directly related to the customer features found in the research and survey. A Quality Function Deployment was created from the survey results, and can be seen in Appendix C. The QFD was used to show how each engineering characteristic related to the customer features based on a strong to weak correlation. The engineering characteristics shown in Table 4, shows the relative importance determined by the summation of their correlation value and the relative weight of the customer feature. In Table 4, the characteristics are sorted in descending order or relative importance as found in the QFD.
PRODUCT FEATURES AND OBJECTIVES

The following is a list of product objectives and how they will be obtained or measured to ensure that the goal of the project was met. The product objectives will focus on a roof mounted assisting bicycle rack used for a car, van, or SUV. The bicycle rack will be used with current roof racks and can work with all types of bikes.

Easy to access from side of car (14%):
1.) The bike rack will lower bike to the side of the car without damaging painted surfaces on the car and bike rack.
2.) Bike rack will reduce the height needed to lift bike by 50%.

Easy to operate by one person (13%):
1.) The bike rack will use a type of spring or motor to assist the user in lifting the bike to the roof of the car.
2.) Sizing adjustments will have clear markings for different bikes.
3.) Operator will not need to remove wheels from bike to place on roof rack.

Compatible with existing roof rack systems (12%):
1.) User will be able to use their existing base bars with the new bike rack attachment.
2.) The bike rack will have different adapters for common roof rack including slotted, round, and square bars.

Compatible with road and mountain bikes (11%):
1.) Bike rail will be wide enough to accommodate road and mountain bike tires.
2.) Bike rack will be adjustable for different size wheels ranging from 26”-29”.
3.) Bike rack will be capable to hold up to 60 lbs.

Provides bike security (11%):
1.) Bike rack will hold bikes in place using a wheel mounting system.
2.) User will be able to add lock to bike rack to prevent bike from being stolen while mounted on roof.

Affordable (11%):
1.) The bike rack attachment will cost less than $300.

Resistant to outdoor environment (10%):
1.) All materials will be painted or rust resistant.

Durable (9%):
1.) Bike rack will be made of materials such as plastic and aluminum.
2.) Bike rack will be designed with factor of safety to improve strength and eliminate premature failure.
3.) The design life for this roof rack will be 10 years.

Easy to maintain (9%):
1.) Bike rack will require no maintenance once mounted to base bars.
2.) Number of components will be less than current designs.
DESIGN

DESIGN ALTERNATIVES

The first design alternative that was created was the Pivot Arm. This design utilizes a single pivot that rotates from 0° to 90° to the side of the car. This design also uses a rotating clamp assembly that will attach to the top tube of the bike. The bike would also be attached to the wheel tray with two ratchet straps that lock the wheels to the wheel tray. The ratchet straps would be adjustable for different wheelbases. It will keep the bike in an upright position at all times. The initial design was to have the bike fold flat to the roof while not in use. The main arm assembly would telescope for height adjustment. The design would also attach to all existing roof racks with adjustable mounts on the wheel tray.

There are many advantages to this design. The bike is mounted securely by the frame and mounted to a solid wheel tray with two ratchet straps. This provides a very stable and secure mounting position. The single pivot is a very simple design that will be very sturdy, while providing easy access to the bike from the side of the car. This design can be adjusted very easily in many different ways. The height will be easily adjustable due to the telescoping arm. Grooves in the wheel tray will allow the ratchet straps to be positioned for varying wheelbases. The wheel tray will also have brackets that attach easily to the base bars of many different cars.

There are a few disadvantages to this design. It has a very complex clamp design that will attach at the top tube of the bike. It will contain parts that need to rotate freely to achieve the desired operation. The other disadvantage to this design also has to do with the clamp. It will be attaching straight to the frame of the bike, so the material must not damage the finish or integrity of the frame.

Figure 5 Pivot Arm Design
The second design alternative that was created was the Telescoping-Pivot Base. This design utilized a pivoting base that rotated up, with arms that telescoped out to the side of the car. The design was meant to be low profile and take up very little space. The bike rack utilizes brackets that surround and clamp down on the front wheel and tire, similar to other roof rack options available. They are adjustable for different size wheels, and fold flat when not in use. There is also a ratchet strap at the rear of the wheel tray that will hold the rear wheel down. This tray will also be able to mount to different base bars for different cars.

The advantages to this design are the ability to mount to the front wheel, and its low profile design. The wheel brackets are very user friendly and are easily adjustable. They also clamp to the wheels, preventing any chance to damage the frame. The design is also small and has a low profile when not in use. It would reduce wind noise and be more aesthetically pleasing to the customer.

There are many disadvantages to this design. The ability to clamp to the front wheel eliminates the chance to damage the frame, but also reduces bike security. The bike will not be as stable when mounted to the tires of the bike. The telescoping design is also very complex. It requires the use of a pivoting base with many joints in the extensions. The design would make it difficult to prevent damage being done to the side of the car when lowering the bike. It may also be difficult to have the system lower the bike to a suitable height for the user. This design will also require a lot of material, increasing the weight of the bike rack. Overall, this is a very complex design and may not be very user friendly to operate.
The third design alternative is the Sliding Base design. It utilizes a guide rail that will slide over the back of the car. The wheel tray would use some type of ball bearings to easily slide to the rear of the car. It would then pivot towards the ground lowering the bike to a reasonable level for the operator. This bike rack would clamp directly to the top of both tires, securely holding the bike in place. The wheel clamps would be adjustable for different size wheels, as well as slide along the wheel tray to accompany different wheelbases for a range of bikes.

There are a few advantages to this design. The ball bearings and guide rail would make it very easy for the operator to slide the bike on and off of the roof of the car. The wheel mounts are also an advantage. The clamping arms would securely hold the bike in position. Because they are only touching the tires, there is no chance of damaging the frame or bike.

The disadvantages of this design deal with ease of operation. When the bike would be lowered off of the rear of the car, the orientation of the bike to the user would be very awkward. The operator may struggle to load and unload the bike due to balancing issues. This design may not work well with taller vehicles either. The bike may not be lowered to a reasonable height and therefore cause more inconvenience to the operator. Because this design lowers the bike over the rear of the car, access to the trunk is lost. The last disadvantage to this design has to do with the wheel clamps. The clamping arms would stand very tall from the roof of the car when not in use, potentially causing unwanted wind noise. The ball bearings would also need regular maintenance to maintain their optimum performance.

Figure 7 Sliding Base Design
**Final Selection**

After analyzing the three design alternatives, a weighted decision matrix, as seen in Table 5, was created and used for selecting a final design. The matrix utilizes the product features and their relative weights, along with the advantages and disadvantages of each design alternative. The scores were rated from 1-3, on that designs ability to fulfill the product features, with 3 being the best score. The Pivoting Arm design was selected for having a highest total of 2.67. This matrix shows that the main advantages to this design are the ease of access from the side of the car, as ease of operation by one user. These are the two most important product features based on the relative weights from the QFD. This design only fell short to the two others in compatibility with different bikes. This is due to the clamping design utilizing a direct frame clamp. Some high-end racing bikes are constructed with carbon fiber, a material that can be damaged if not handled carefully. With this weighted decision matrix and discussion, the Pivoting Arm design was selected as the preferred design.

<table>
<thead>
<tr>
<th>Table 5 Weighted Decision Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Criterion</td>
</tr>
<tr>
<td>Easy to access from side of the car</td>
</tr>
<tr>
<td>Easy to operate by one person</td>
</tr>
<tr>
<td>Compatible with existing roof racks</td>
</tr>
<tr>
<td>Compatible with road/mountain bikes</td>
</tr>
<tr>
<td>Provides bike security</td>
</tr>
<tr>
<td>Affordable</td>
</tr>
<tr>
<td>Resistant to outdoor environment</td>
</tr>
<tr>
<td>Durable</td>
</tr>
<tr>
<td>Easy to maintain</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
**PRODUCT DESIGN**

This design was selected for many reasons, ease of access from the side of the car being one of them. Figure 8 shows how this assembly allows for the user to easily raise and lower the bike to the side of the car. The arm rotates around the single pivot, stopping at 0° and 90°. The main bracket uses a spring pin that will lock the bike rack at both positions, providing stability when the bike is being loaded and on top of the car. Rubber stops are used to support the weight of the bike and arm and prevent damage or failure to the pin.

![Figure 8 Pivoting Motion](image)

This design also provides a very secure and adjustable clamping mechanism, as shown in Figure 9. The entire clamp assembly rotates about the mounting bolt. This allows the user to adjust the clamp to different top tube angles on bikes. This design also keeps the bike standing perpendicular to the ground. It does this with the channels in the clamp. Foam bushings are secured to the inside of the channels, allowing the bike to rotate freely when clamped in place. Velcro straps are mounted to the clamp and close the clamp securely around the bike.

![Figure 9 Clamp Assembly](image)
The adjustability of this design is great for different size bikes, as well as different base bar configurations on cars. As shown in Figure 10, the height is adjustable from 20-36”. This encompasses almost all bikes on the market. A slot in the lower member guides a bolt with a wing nut on it. It can be loosened and will slide to the desired position, then tightened for use. Polyurethane bushings allow the upper member to slide easily without much effort. The wheel tray utilizes channels for adjustability. There are two channels, one on each side, that house the ratchet straps for the wheels. The straps can slide the whole length of the bike tray, making it possible to adjust for different bike’s wheelbases. The mounting system utilizes a groove in the bottom of the bike tray so the rear base bar clamp can be adjusted for different base bar configuration vehicles.

![Figure 10 Design Adjustability](image)

The Pivoting Arm really focuses on the features necessary for this product. The system lowers the bike to the side of the car with a simple design that will be durable and easy to use. The adjustability of the clamp system and wheel tray allow for different size road and mountain bikes to be securely mounted to the roof of the car.
**LOADING CONDITIONS**

Due to the how this product will be used, there are many different loading conditions that were analyzed to ensure a strong and safe design. The first condition that was analyzed was when the bike would be hanging on the side of the car during loading and unloading. The bikes weight creates a number of conditions on the arm, pivot bolt, main bracket, and wheel tray. These include bending stress, shear stress, torsional stress, and deflection. These all had to be calculated for the load created by the bike hanging on the side of the car. The next loading condition is due to wind load. The bike rack is mounted to the roof of a car, meaning the operator will be driving. The condition analyzed was for highway driving. This created a bending stress on the arm, as well as shear and torsional stresses on the main bracket. Another condition that was analyzed was due to centripetal force applied while a car was turning. The worst case was assumed to be a car driving on and off of an exit ramp on the highway. Here, a shear stress was calculated on the pin that holds the bike at 0° when mounted to the roof of the car. All calculations are shown in Appendix H.

**DESIGN ANALYSIS**

The loading conditions all start with an initial load being applied to the bike rack while hanging from the side of the car. The arm utilizes 2.5” square tubing as well as 2” square tubing, both with a wall thickness of 0.125”. All calculations were done using the 2” square tubing, because worst case would have the load all applied to the smallest sized material. The first step to the design analysis was calculating the moment of inertia for the aluminum tubing that would be used. The moment of inertia was found to be 0.5518 in⁴.

\[
I = \frac{(b \cdot h^3) - (0 \cdot h^2)}{12}
\]

\[
h_{2^{\prime \prime}} = (2\text{in} \cdot (2\text{in} \cdot 0.125\text{in}^3)) - (1.750\text{in} \cdot (1.750\text{in} \cdot 0.125\text{in}^3))/12 = 0.5518 \text{ in}^4
\]

Most bikes weight less than 40 pounds. An initial factor of safety of 2.5 was applied to this load, resulting in 100 pounds. This factor of safety was selected because product will be used repeatedly and in direct contact with the operator.

\[
F = \text{factor of safety} \times \text{force bike}
\]

\[
F = 2.5 \times 40\text{lb} = 100\text{lb}
\]
This would be the load used for the calculations with the bike hanging from the side of the car as shown in Figure 11. This is the worst case scenario with the arm being fully extended at 36 inches and without the support of the rubber stop. This would create the maximum bending and shear stress on the arm.

![Figure 11 Load from Hanging Bike](image)

The moment created by this loading condition and force was found to be 3600 inlb.

\[ M = F \cdot d \]

\[ M = 100 \text{ lb} \cdot 36 \text{ in} = 3600 \text{ inlb} \]

Using this moment, the bending stress on the arm was calculated. The bending stress was found to be 6524.10 psi.

\[ \sigma_b = \frac{M \cdot C}{I} \]

\[ \sigma_b = \frac{3600 \text{ inlb} \cdot 1 \text{ in}}{0.5518 \text{ in}^4} = 6524.10 \text{ psi} \]

The deflection due to this bending stress was calculated to be 0.282 in. This is acceptable because the roof rack will be static at this time and will be able to move freely.

\[ \delta = \frac{F \cdot L^3}{3 \cdot E \cdot I} \]

\[ \delta = \frac{100 \text{ lb} \cdot 36 \text{ in}^2}{3 \cdot (10 \times 10^6 \text{ psi}) \cdot 0.5518 \text{ in}^4} = 0.282 \text{ in} \]
After calculating the bending stress, the shear stress on the pivot pin was calculated. Due to the configuration of the bracket and arm, this is in double shear. Figure 12 shows a detailed view of the bracket, arm, and pin.

The shear stress was found to be 4329.01 psi, using a load of 1700lb caused by the moment of the bike hanging and the support of the rubber stop. This is shown in Figure 13.

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

\[
\tau = \frac{1700\text{lb}}{2\left(\frac{\pi \times 0.5\text{in}^2}{4}\right)} = 4329.01 \text{ psi}
\]

Due to the bike hanging on the side of the car, the wheel tray undergoes torsional stress. The
The force applied to the wheel tray is 3600 in-lb. The wheel tray has dimensions of 4” x 0.75”. With these dimensions, coefficients for rectangular bars are found to be $k_1=0.295$, and $k_2=0.295$. The torsional stress is found to be 5423.73 psi. With this stress, the angle of twist is found to be $3.82^\circ$.

$$\psi = \frac{T}{k_1 \cdot A \cdot D}$$

$$T = \frac{3600 \text{ in-lb}}{0.295 \times 4 \text{ in} \times 0.75 \text{ in}^2} = 5423.73 \text{ psi}$$

$$\psi = \frac{T \cdot L}{k_2 \cdot A \cdot D \cdot G}$$

$$\psi = \frac{3600 \text{ in-lb} \times 35 \text{ in}}{0.295 \times 4 \text{ in} \times 0.75 \text{ in}^2 \times (3.5 \times 10^6 \text{ psi})} = 0.666 \text{ rad}$$

$$\psi = 0.666 \text{ rad} \times \left( \frac{180^\circ}{\pi} \right) = 3.82^\circ$$

This loading condition with the bike hanging from the side of the car was most complex scenario. The other loading conditions and calculations, including wind load and centripetal force, can all be found in Appendix H.

**Factors of Safety of Concern**

Due to the loading conditions and stresses calculated, factors of safety were calculated for the bending stresses and torsional stresses on the arm, main bracket, and wheel tray. The maximum allowable stress for 6061-T6 aluminum in bending is 24,400 psi. The maximum allowable stress due to torsion is 10,000 psi. The final factor of safety for the arm under bending due to the hanging bike is 9.35. This may seem high but is set because of the material size chosen. Failure of this loading condition can cause damage to the bike or car, so this it is important to have a strong design. The factor of safety for the wheel tray under torsion due to the hanging load is 4.61. This is sufficient for the repeated loads that the wheel tray will support. The wind load causes torsion on the bracket, which produces a final factor of safety of 3.60. The wind load also causes a bending stress, which results in a final factor of safety of 17.71. This is also sufficient for the static load on the bike rack while driving, and is caused due to the size of material selected. Having this relatively high factor of safety due to wind loads is necessary because failure could cause injury and damage to other cars and people on the road. All calculations for these factors of safety can be found in Appendix H.
**Material and Component Selection**

The materials selected for this product had to meet various requirements due to its applications. The materials had to be able to withstand the stresses due to the load of the bicycle, the wind load, and the centripetal force. The materials also had to be lightweight. The operator would be lifting the weight of the bike, plus the weight of the rack above shoulder height. Finally, the materials had to be able to withstand the outdoor environment, whether it is rain, sun, or snow.

The material that was selected for the majority of the product was 6061-T6 aluminum. It is extremely light and still has very strong material properties. This material has an ultimate strength of 45,000 psi, and yield strength of 40,000 psi. This meets all the conditions found through the calculations. This material is also corrosion resistant. Aluminum will not rust like steel or other metals. Fabricating and welding aluminum is fairly easy too. This makes it a perfect fit for the roof rack application.

Polyurethane and rubber will be used for the bushings throughout the design. These materials are both strong and can withstand outdoor conditions. These materials will be very durable and affordable. All the ratchet straps will be plastic, and will be purchased complete from vendors. All hardware will be Grade 5 nuts and bolts. This material will meet the required stress due to shear without failure.

**Fabrication and Assembly Drawings**

Fabrication drawings were created for all specialized parts. They will be used to manufacture the bike rack to the specified dimensions. Assembly drawings were made to show critical assembly dimensions and details were shown for areas of the product that involve many different parts and hardware. An exploded assembly drawing was also made to show how all of the components go together. These drawings can be seen in Appendix I.

**Bill of Materials**

The Bill of Materials can be found in Appendix J.
FABRICATION AND ASSEMBLY

FABRICATION OF COMPONENTS

All materials were ordered within the first week of the spring quarter from Online Metals in Seattle, WA, and Grainger Inc. 6061-T6 Aluminum square tubing and plate was used to create the majority of the components. The aluminum tubing and plate was cut to length in the University Of Cincinnati- College Of Applied Science’s machine shop per the drawings found in Appendix I. A vertical bandsaw and vertical milling machine were used for all of the machining processes. In Figure 14, 0.25” aluminum plate is being cut for the main bracket using the vertical bandsaw.

In Figure 15, a vertical milling machine is being used to cut holes and a slot in the base member. The vertical milling machine was also used to create the bushing caps out of ultra-high-molecular-weight polyethylene, UMHW.
The cut material was welded together using an electric MIG welder, using aluminum filler wire and Argon shielding gas. Tack welds and finish welds were completed with help from Jerry Simpson at SportRaxx, who has been manufacturing aluminum truck bed utility racks for several years. As shown in Figure 16, the MIG welder was used to join the various materials to create the components of the bike rack. All welds were cleaned using a wire brush to remove any spatter and impurities.

Overall, fabrication went as planned. There were some issues with the machining of the bike tray, which was not completed to the print. Initial designs had been approved to be completed in the University Of Cincinnati- College Of Applied Science’s machine shop. When materials arrived, it was discovered that the clamps on the vertical milling machines would not safely hold the material for to the T-slots that were to be machined. Local machine shops were contacted, but outsourcing the part would have put the project over budget by $400. Due to this part not being completed as planned, the bike tray was not adjustable for different base bars at the time of testing. Velcro straps also had to be used to secure the wheels instead of the ratchet straps in the initial design.

The clamp was also modified slightly to simplify use for the consumer. Initially a ratchet strap was to be used to secure the bike in the bike rack. Industrial strength Velcro straps were used as a replacement allowing the customer to easily close the clamp with one hand. The foam bushings were also modified. Instead of rotating freely inside of the clamp, they were secured to the inside of the channels using high strength adhesive. This prevented the bushing from falling out with the clamps were being opened and close. These modifications were made to simplify the steps needed to load and unload the bike from the bike rack.
Assembly of the fabricated components went smoothly. Due to many of the fabrication processes being completed for the first time by the designer, some modifications were made. The sides on the main bracket had to be pulled apart to allow clearance for the base member, due to warping under the heat of the welding process. The welds on the clamp top and clamp bottom had to be grinded to allow for proper movement. All holes lined up well and the components were easily bolted together after small adjustments. As seen in Figure 17, the completed bike rack is mounted to the roof of the car after adjustments were made. The bike rack was then painted flat black for aesthetics and to prevent any chance of rust or corrosion due to the elements.

Figure 17 Completed Bike Rack Assembly
**TESTING**

Testing was completed by the designer as well as with the help of local cycling enthusiasts. Testing began with mounting the bike rack to the roof of the designer’s car. The bike rack was then used without a bike for numerous cycles ensuring that the main pivot was rotating freely. All other joint were used to ensure proper movement. After 30 trials without a bike, the strength of the system was tested. A 60lb weight was hung from the clamp while the bike rack was in the down position, hanging to the side of the car. This was to ensure that it would withstand the weight of a full mountain bike and meet the design requirement previously assigned. The designer then tested the bike rack with a road and mountain bike as shown in Figure 18 and Figure 19. There were no issues with the functionality so further testing was schedule.

![Figure 18 Testing - Mountain bike](image18.png)

![Figure 19 Testing - Road Bike](image19.png)
Local cycling enthusiasts in the Cincinnati, OH area were asked to use the bike rack mounted to the designer’s car and provide feedback on a survey. Each cyclist mounted two road bikes and one mountain bike to the bike rack multiple times. They then filled out the survey, rating their satisfaction of the product features from 1-5, with 5 being the most satisfied. (See Appendix K for full survey results). Table 6 shows the customer testing results beside the planned satisfaction for each product objective. The designer’s planned satisfaction was met with the affordability, resistance to outdoor environment, and compatibility with all bikes, durability, and ease of maintenance. The survey results showed that there could be improvement with the ease of operation, compatibility with existing roof rack systems, and bike security. Overall the local enthusiasts were very satisfied with the product and communicated interest in this product for their own personal use.

<table>
<thead>
<tr>
<th>Question Surveyed</th>
<th>Planned Satisfaction</th>
<th>Actual Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to access from side of car</td>
<td>5.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Easy to operate by one person</td>
<td>5.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Compatible with existing roof rack systems</td>
<td>5.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Affordable</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Provides bike security</td>
<td>4.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Resistant to outdoor environment</td>
<td>4.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Compatible with road and mountain bikes</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Durable</td>
<td>4.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Easy to maintain</td>
<td>4.0</td>
<td>4.6</td>
</tr>
</tbody>
</table>
RECOMMENDATIONS

Based on the results from the customer testing survey, there are a few recommendations to improve the functionality and satisfaction for the bike rack. Bike security received a very low result and needs to be addressed. While the bike is in the upright position on top of the car, a pin has to be placed through the main bracket and base member to lock it in place. This pin is a loose part and can be lost or dropped when loading the bike. A spring loaded pin needs to be fabricated so the consumer only needs to push the bike rack to a certain point and it automatically locks into place. This will provide a solution to the security problem relating to the locking pin.

Another recommendation relates to the fabrication of the bike tray. In order to gain the compatibility for all bike and existing roof rack systems, there have to be the three T-slots to allow for adjustments. Machining these slots out of flat plate is physically possible, but is also very expensive. In future this part could be extruded out of aluminum or a stronger material. This would reduce the cost to fabricate the part and reduce the overall weight of the entire bike rack.

Aesthetics are very important in cycling. The overall design of this bike rack is a little too large and bulky for consumers to put on top of their car. The design would need to be slimmed down, and even change the materials to some plastics to reduce weight. The bike rack also would need to fold backwards when not in use, creating a lower profile on the roof. This would allow the consumer to keep the bike rack on top of their car at all times.
PROJECT MANAGEMENT

SCHEDULE

The project schedule begins November 20, 2011 with the creation of design concept sketches. The prototype bike rack was completed and presented on May 17, 2012 to the faculty and staff at the University of Cincinnati- College of Applied Science’s Tech Expo. The project was completed June 2, 2012 with the completion and submission of the final report. Figure 20 shows the major steps needed to finish this project and the dates that they were completed. A full schedule can be seen in Appendix D.

Figure 20 Schedule of project milestones
BUDGET

The following is a budget for the completion of one bike rack. Table 7 includes the forecasted and actual amounts spent on the product. The completed product came out $230 under budget. The main sources of these savings were the aluminum materials, plastic clamps and ratchets, and hardware. Plastic clamps and ratchets were donated by the designer. Special tooling was needed due to machining issues and was not included in the original budget. Labor was not included as it was completed in a shop by the designer.

<table>
<thead>
<tr>
<th>Materials, Components, or Labor</th>
<th>Forecasted Amount</th>
<th>Actual Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Material</td>
<td>$400.00</td>
<td>$225.00</td>
</tr>
<tr>
<td>Bushings</td>
<td>$75.00</td>
<td>$65.00</td>
</tr>
<tr>
<td>Plastic Clamps/ Ratchets</td>
<td>$50.00</td>
<td>free</td>
</tr>
<tr>
<td>Hardware</td>
<td>$80.00</td>
<td>$30.00</td>
</tr>
<tr>
<td>Special Tooling</td>
<td>-</td>
<td>$60.00</td>
</tr>
<tr>
<td>Paint</td>
<td>$30.00</td>
<td>$25.00</td>
</tr>
<tr>
<td>Total</td>
<td>$635.00</td>
<td>$405.00</td>
</tr>
</tbody>
</table>
CONCLUSION

With the conclusion of this project, all the product objectives had to be evaluated for their completion. The bike rack was completed in the scheduled time and testing was completed. The first and most important product objective was ease of access from the side of the car. The bike rack pivots to a 90° angle and allows the user to reach the bike at shoulder with on the side of the car. The bike rack utilizes Velcro straps and very few moving parts. The size adjustments are clearly marked to allow for easy adjustment, and the front wheel can stay attached to the bike at all times. This makes it very easy to operate by one person. The bike tray was designed to have T-slots that allowed for the bike rack to be used with any existing bike rack system. The prototype did not meet this requirement, but future products will. This bike rack is compatible with road and mountain bikes. The size adjustments accommodate for 26”-29” wheels, covering a range of sizes on the market. The bike rack also can hold 60lbs as tested, meaning that it will hold the heaviest mountain bikes available. The bike rack did not supply efficient bike security for the consumer. It utilizes a wheel mounting system to secure it in place for transport, but the current design does not offer the ability to lock the bike or bike rack while in use. The bike rack was build under budget and could be produced and sold under the target price of $300. The bike rack is resistant to the outdoor environment with materials that are all corrosion resistant and painted. The bike rack is very durable due to the initial design load. The bike rack was designed to hold a weight of 100lbs, meeting the 60lb requirement, and providing a stronger product for longer use. The design life of 10 years cannot be proven at this time but continuous testing will be done. The bike rack requires no maintenance once mounted to the roof of the car. There are very few moving parts, and all materials are strong and durable. The Roof Mounted Assisting Bike Rack was completed and met 89% of the design requirements.
REFERENCES

251658240
You want stability for $89? You got it buddy. The Mega Joe is for the weekend warrior who races out the door at 5pm on a Friday - that's 1 pm in our time - to get to the trails. Made from ultra-valued bomber steel construction at a price that won't make your wallet ask, "why?"

- 3 Bike Trunk carrier
- Features an easy-to-install QUICKTRIGGER™ hub system
- Padded feet protect your vehicle's paint from being scratched or dented
- This rack's narrow arm design fits a wide variety of bike frames

Doesn't mount to roof
Blocks trunk on normal cars
Can’t tow trailer when in use
Bikes do not lock to rack
Easy to use
Fits 3 bikes
Fits all types of bikes
Adjustable
Cost $89

http://yakima.com/shop/bike/trunk/megajoe 9/26/11
Yakima Mega Joe Trunk Bike Rack, Yakima.com

Interview with cyclist, September 26, 2011, on CAS campus.
Chris Douglas, cycling enthusiast, Newtown Rd, Cincinnati OH, 45244.
Has been cycling for over 5 years.
Rides mountain and road bikes.
Often travels 20-45 minutes to riding destination.
Used to have SUV with roof rack, said it was hard to load bikes onto roof rack.
Doesn’t like taking front wheel off of bike to load.
Bike must easy and securely mount to the bike rack.
Must be durable and weatherproof.
Wouldn’t want to pay much more than a normal bike rail costs.
Must fit all bikes.
Doesn’t like tall bike rails due to wind noise.
Behold HighRoller—the finest bike rack mount in the known universe. This spectacular addition to your car roof rack keeps the widest range of bikes stable and secure without requiring you to remove the front wheel. So score a HighRoller rooftop bike mount today. Because no matter what you do at the craps table, you should never gamble with your bikes.

- Doesn’t touch the painted surfaces of your bike and makes for a great bike mount for your carbon rig
- Super-strong wheel tray with a double-sided strap for an extra-stable ride
- No problem handling disc brakes, thru axles or funky suspensions
- Easy-to-reach one-knob adjuster
- Fits car rack systems with round or square crossbars
- Fits factory aero bars with the use of Universal Mighty Mounts sold separately.
- Fits 20” kids’ wheels all the way up to 29” mountain and 700c road wheels Easy-to-adjust wheel tray fits a wide range of bike lengths (EXCEPT TANDEMS AND RECUMBENTS)
- Integrated cable lock for superior security (SKS LOCK CORE sold separately)

http://yakima.com/shop/bike/top/highroller
9/26/11
Yakima HighRoller Bike Mount, Yakima.com

Does not assist operator
Not powered
Fits many roof rack systems
Foldable, compact
Fits all bikes
Do not have to remove front wheel
Weather-proof
Bikes lock to rack
Costs $199
Some think the SprocketRocket is the finest fork-style roof rack bike mount ever made. And due to its sleek aerodynamic design, sturdy construction, ability to carry virtually any bike, and tongue-wagging good looks, we’re definitely among those who think that.

- Sleek design enables this rooftop bike mount to accommodate a variety of bike styles
- Fits a wide range of tire widths (UP TO 3.0”)
- Secure and lockable skewer with integrated adjustment knob for single-handed, easy access (SKS LOCK CORES sold separately)
- Fits car rack systems with round and square crossbars
- Fits most disc brakes
- Simple tool-free installation and removal of the bike mount from your car roof rack
- Easy-to-adjust sliding wheel tray fits a wide range of bike lengths (EXCEPT TANDEMS AND RECUMBENTS)
- Doesn’t touch the painted surfaces of your bike and makes for a great bike mount for your carbon rig

http://yakima.com/shop/bike/top/sprocketrocket
9/26/11
Yakima
SprocketRocket
Roof Mount,
Yakima.com

Does not assist operator
Not powered
Have to remove front wheel
Fork mount design
Compact design
Bike locks to rack
Fits on many bike rack systems
Weatherproof
Costs $189
The objective of the senior design project was actually quite simple, design a vehicle bicycle rack that is user friendly for any adult bicycle rider. In other words make it easier for the rider(s) to load and unload one or several bicycle(s) off or on to their vehicle. There were many objectives that this design was meant to satisfy. The ones listed below are the major ones that acted as guidelines towards the completion of this design. Below is a enumerated listing of the objectives.

MAJOR PROJECT OBJECTIVES:

1. A tool to assist riders who transport bicycles on top of their van.
2. Rid the task of actually having to reach roof racks of taller vehicles.
3. Eliminate any hassle of lifting free bicycles over the riders head.
4. Provides a spring actuated mechanism for helping the lift.
5. Make bicycle(s) weight seemingly lighter by at least 50%.
6. Possible to lift and carry any two wheeled bicycle.
7. Designed so bicycles and design never touches the vehicle side or roof.
8. Still possible to transport up to four bicycles total.
9. Each extension arm will be able to operate an 70 lb. capacity.
10. Will build the proposed project at actual size.

Assists operator for taller vehicles.
Roof rack bicycle mount.
Bike does not touch car.
Holds up to 70 lbs.
Carries up to 4 bicycles.
Have to remove front wheel.
APPENDIX B – CUSTOMER SURVEY AND RESULTS

ROOF MOUNTED ASSISTING BICYCLE RACK

CUSTOMER SURVEY

The purpose of this survey is to determine which features are important in a new roof mounted assisting bicycle rack. The results will help in the design and building of a quality product with the most desired characteristics.

**How important is each feature to you for the design of a roof mounted assisting bicycle rack?**

Please circle the appropriate answer.

<table>
<thead>
<tr>
<th>Feature</th>
<th>1 = low importance</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5 = high importance</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatible with road and mountain bikes</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5(5)</td>
<td>N/A</td>
</tr>
<tr>
<td>Compatible with existing roof rack systems</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(2)</td>
<td>5(3)</td>
<td>N/A</td>
</tr>
<tr>
<td>Easy to operate by one person</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(1)</td>
<td>5(4)</td>
<td>N/A</td>
</tr>
<tr>
<td>Provides bike security</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(2)</td>
<td>5(3)</td>
<td>N/A</td>
</tr>
<tr>
<td>Easy to access from side of car</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(3)</td>
<td>5(2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Durable</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(1)</td>
<td>5(3)</td>
<td>N/A</td>
</tr>
<tr>
<td>Easy to maintain</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(1)</td>
<td>5(4)</td>
<td>N/A</td>
</tr>
<tr>
<td>Resistant to outdoor environment</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(3)</td>
<td>5(2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Affordable</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(3)</td>
<td>5(1)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**How satisfied are you with the current roof mounted bicycle rack?**

Please circle the appropriate answer.

<table>
<thead>
<tr>
<th>Feature</th>
<th>1 = very UNSatisfied</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5 = very satisfied</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatible with road and mountain bikes</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4(1)</td>
<td>5(4)</td>
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**How much would you be willing to pay for this product?**

- $100- $150 (1), $150-$200 (3), $200-$250 (1), $250-$300, $300+

Thank you for your time.
APPENDIX C – QUALITY FUNCTION DEPLOYMENT

251658240

Robert Magness

Roof Mounted Assisting Bicycle Rack

9 = Strong
3 = Moderate
1 = Weak

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Compatible with road and mountain bikes       | 3 | 9 |   |   |   |   | 5 | 4.8 | 5 | 1.0 |
Compatible with existing roof rack systems    |   |   |   |   |   |   | 4.6 | 4 | 5 | 1.3 |
Easy to operate by one person                 | 3 | 9 |   |   |   |   | 4.8 | 3.8 | 5 | 1.3 |
Provide bike security                         |   |   |   |   |   |   | 4.6 | 3.6 | 4 | 1.1 |
Easy to access from side of car              | 3 |   |   |   |   |   | 4.4 | 3.4 | 5 | 1.5 |
Durable                                      |   |   | 3 |   |   | 4.4 | 4 | 4 | 1.0 | 4.4 |
Easy to maintain                              | 3 |   |   | 3 |   | 4.8 | 4.4 | 4 | 0.9 | 4.4 |
Resistant to outdoor environment              |   | 3 |   |   |   | 4.4 | 3.6 | 4 | 1.1 | 4.9 |
Affordable                                   |   |   | 3 |   | 4 | 3.2 | 4 | 4 | 1.3 | 5.0 |

Abs. importance                             0.73 0.99 1.61 0.97 0.32 2.04 1.09 1.39 0.95 0.31 0.87 1.23 12.5 47.5 1.0
Rel. importance                             0.06 0.08 0.13 0.08 0.03 0.16 0.09 0.11 0.08 0.02 0.07 0.10

Appendix C1
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</table>
## APPENDIX E – BUDGET

### Budget

<table>
<thead>
<tr>
<th>Materials, Components, or Labor</th>
<th>Forecasted Amount</th>
<th>Actual Amount</th>
</tr>
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<tr>
<td>Aluminum Material</td>
<td>$400.00</td>
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<tr>
<td>Bushings</td>
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<td>$65.00</td>
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<tr>
<td>Plastic Clamps/ Ratchets</td>
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<tr>
<td>Hardware</td>
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<td>Special Tooling</td>
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<td>Paint</td>
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<td><strong>Total</strong></td>
<td><strong>$635.00</strong></td>
<td><strong>$405.00</strong></td>
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</table>
APPENDIX F – DESIGN ALTERNATIVES

Design #1: Pivoting Arm
Design #2: Telescoping-Pivot Base

Bicycle mounts to rack with front wheel

adjustable wheel brackets

ratchet strap

front

back

ratchet strap

telescopes

base pivots
Appendix F1

Design #3: Sliding Base

- Adjustable clamps for wheels
- Slides and rotates over back of the car
- Compresses down on wheels holding bike in place
- Tire
- Wheel tray
## APPENDIX G – WEIGHTED DECISION MATRIX

<table>
<thead>
<tr>
<th>Design Criterion</th>
<th>Weight Factor</th>
<th>Score</th>
<th>Rating</th>
<th>Score</th>
<th>Rating</th>
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<th>Rating</th>
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<td>0.14</td>
<td>3</td>
<td>0.42</td>
<td>2</td>
<td>0.28</td>
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<td>Easy to operate by one person</td>
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<td>3</td>
<td>0.39</td>
<td>2</td>
<td>0.26</td>
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<td>Compatible with existing roof racks</td>
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<td>0.36</td>
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<td>3</td>
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<td>0.22</td>
<td>3</td>
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<tr>
<td>Provides bike security</td>
<td>0.11</td>
<td>2</td>
<td>0.22</td>
<td>2</td>
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<td>0.18</td>
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<tr>
<td>Easy to maintain</td>
<td>0.09</td>
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<td>0.27</td>
<td>2</td>
<td>0.18</td>
<td>2</td>
<td>0.18</td>
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<td><strong>Total</strong></td>
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<td><strong>2.22</strong></td>
<td><strong>2.42</strong></td>
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</table>
Appendix H – Calculations

General Calculations
6061-T6 Aluminum

\[ \sigma_{\text{max}} = S_p \times 0.61 \]

\[ \sigma_{\text{max}} = 40,000 \text{ psi} \times 0.61 = 24,400 \text{ psi} \]

\[ \tau_{\text{max}} = S_p \times 0.25 \]

\[ \tau_{\text{max}} = 40,000 \text{ psi} \times 0.25 = 10,000 \text{ psi} \]

Moment of Inertia of Tubing

\[ I = \frac{(b \times h^2) - (b \times h^3)}{12} \]

\[ I_{2\text{"}} = \frac{(2\text{"} \times (1\text{"})^2) - (2\text{"} \times (1\text{"})^3)}{12} = 0.5515 \text{ in}^4 \]

\[ I_{2.5\text{"}} = \frac{(2.5\text{"} \times (2.5\text{"})^2) - (2.5\text{"} \times (2.5\text{"})^3)}{12} = 1.1195 \text{ in}^4 \]

Bike Hanging on Side of Car

Force Bike

\[ F = \text{factor of safety} \times F \]

\[ F = 2.5 \times 40 \text{ lb} = 100 \text{ lb} \]

Moment

\[ M = F \times d \]

\[ M = 100 \text{ lb} \times 3 \text{ ft} = 3600 \text{ ft lb} \]

Bending Stress

\[ \sigma_{\text{b}} = \frac{M \times C}{I} \]

\[ \sigma_{\text{b}} = \frac{3600 \text{ ft lb} \times 1 \text{ in}}{0.5515 \text{ in}^3} = 6524.10 \text{ psi} \]
Shear Stress on Pivot Pin (Double Shear)

\[ \tau = \frac{F}{A} \]
\[ \tau = \frac{1700 \text{lb}}{2\left(\frac{\pi \times 0.5 \text{in}^2}{4}\right)} = 4329 \text{psi} \]

Factor of Safety (Arm)

\[ \text{Safety Factor} = \left(\frac{\sigma_{\text{min}}}{\sigma_a}\right) \times 2.5 \]
\[ \text{Safety Factor} = \left(\frac{24,400 \text{psi}}{6524.1 \text{psi}}\right) \times 2.5 = 9.39 \]

Deflection

\[ \delta = \left(\frac{F \times 16}{3 \times B \times I}\right) \]
\[ \delta = \left(\frac{100 \text{lb} \times 16 \text{in}^2}{3 \times (10 \times 10^6 \text{psi}) \times 0.5518 \text{in}^3}\right) = 0.282 \text{ in} \]

Torsion on Wheel Tray
\[ a = 4.0 \text{in} \]
\[ b = 0.75 \text{ in} \]
\[ k_1 = 0.295 \]
\[ k_2 = 0.295 \]
\[ G = 3.8 \times 10^6 \text{ psi} \]

\[ \tau = \frac{F}{k_2 + a \times b^2} \]
\[ \tau = \frac{3600 \text{inlb}}{0.295 \times 4 \text{in} \times 0.75 \text{in}^2} = 5423.73 \text{ psi} \]

Angle of Twist on Wheel Tray

\[ \phi = \frac{F \times L}{k_2 + a \times b^2 \times I} \]
\[ \phi = \frac{3600 \text{inlb} \times 35 \text{in}}{0.295 \times 4 \text{in} \times 0.75 \text{in}^2 \times (3.5 \times 10^6 \text{psi})} = 0.666 \text{ rad} \]
\[ \phi = 0.666 \text{ rad} \times \left(\frac{180^\circ}{\pi}\right) = 3.82^\circ \]
Factor of Safety (Wheel Tray)

\[ \text{Safety Factor} = \left( \frac{F_{\text{max}}}{F} \right) \times 2.5 \]
\[ \text{Safety Factor} = \left( \frac{10,000 \text{psi}}{5423.78 \text{psi}} \right) \times 2.5 = 4.61 \]

Wind Resistance

Wind Load (drag force)

\[ F_d = \frac{1}{2} \cdot \rho \cdot v^2 \cdot A \cdot C_d \]
\[ F_d = \frac{1}{2} \cdot 1.298 \text{kgm}^{-2} \cdot \frac{37.99 \text{m}^2}{s} \cdot 0.0539 \text{m}^2 \cdot 1.2 = 93.939 \text{ N} \]
\[ F_d = 93.939 \text{ N} \cdot \left( \frac{0.2248 \text{ lb}}{1 \text{ N}} \right) = 21.118 \text{ lb} \]

Bending Stress

\[ \sigma_b = \frac{M \cdot C}{I} \]
\[ \sigma_b = \frac{21.118 \text{ lb} \cdot 36 \text{ in} \cdot 1 \text{ in}}{0.5516 \text{ m}^2} = 1377.76 \text{ psi} \]

Factor of Safety (Arm)

\[ \text{Safety Factor} = \left( \frac{F_{\text{max}}}{\sigma_b} \right) \]
\[ \text{Safety Factor} = \left( \frac{24,400 \text{ psi}}{1377.76 \text{ psi}} \right) = 17.71 \]

Torsion on Bracket

a = 3.0 in
b = 0.56 in
k1 = 0.291
k2 = 0.291
G = 3.8 \times 10^6 \text{ psi}

\[ \tau = \frac{k_2 \cdot a \cdot b^2}{I} \]
\[ \tau = \frac{21.118 \text{ lb} \cdot 36 \text{ in}}{0.291 \times 2 \text{ in} \cdot 0.56 \text{ in}^2} = 2776.93 \text{ psi} \]
Angle of Twist on Bracket

\[ \theta = \frac{T \cdot L}{R_2 \cdot a \cdot b^2 \cdot c} \]

\[ \theta = \frac{21.11 \text{lb} \cdot 36 \text{in} \cdot 6 \text{in}}{0.291 \cdot 3 \text{in} \cdot 0.50 \text{in}^3 \cdot (3.5 \times 10^6 \text{psi})} = 0.008 \text{rad} \]

\[ \theta = 0.008 \text{rad} \cdot \left( \frac{180^\circ}{\pi} \right) = 0.44^\circ \]

Factor of Safety (Bracket)

\[ \text{Safety Factor} = \left( \frac{F_{\text{max}}}{\tau} \right) \]

\[ \text{Safety Factor} = \left( \frac{10,000 \text{psi}}{2776.98 \text{psi}} \right) = 3.60 \]

Centripetal Force

Centripetal Force of Pin

\[ R_c = m \cdot v^2 \]

\[ R_c = \frac{194 \cdot 528 \text{in}^2}{3543.3 \text{in}^2} = 15.28 \text{ lb} \]

Shear Stress on Locking Pin (Double Shear)

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

\[ \tau = \frac{15.28 \text{lb}}{2 \left( \frac{\pi \cdot 0.25 \text{in}^2}{4} \right)} = 311 \text{ psi} \]
APPENDIX I – FABRICATION AND ASSEMBLY DRAWINGS

Fabrication Drawings
1. Base Member
2. Bike Tray
3. Bushing Cap Large
4. Bushing Cap Small
5. Bushing Clamp
6. Clamp Base
7. Clamp Top
8. Main Bracket
9. Rubber Bushing Large
10. Rubber Bushing Small
11. Upper Member

Assembly Drawings
1. Assembly Complete
2. Assembly Exploded
Senior Design

Bushing Cap, Large

bushing cap large
## APPENDIX J – BILL OF MATERIALS

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<td>Rubber Bushing, Lg.</td>
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<td>3</td>
<td>bike tray</td>
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APPENDIX K – CUSTOMER TESTING SURVEY AND RESULTS

ROOF MOUNTED ASSISTING BICYCLE RACK
CUSTOMER SURVEY

The purpose of this survey is to determine the satisfaction of the new roof mounted assisting bike rack. The results will help in the design and modification of future prototypes to ensure complete consumer satisfaction.

How satisfied are you with the prototype of the roof mounted assisting bicycle rack?
Please circle the appropriate answer.

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<tr>
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<th>3</th>
<th>4</th>
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<td>Easy to operate by one person</td>
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<td>4(1)</td>
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<td>Provides bike security</td>
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<td>3(2)</td>
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<td>Easy to maintain</td>
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<td>4(2)</td>
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<tr>
<td>Resistant to outdoor environment</td>
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<td>2</td>
<td>3(1)</td>
<td>4</td>
<td>5(4)</td>
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<td>3(1)</td>
<td>4(3)</td>
<td>5(1)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

How much would you be willing to pay for this product?

$100- $150 (1), $150-$200 (1), $200-$250 (3), $250-$300, $300+

Thank you for your time.