August 2016

Designing a Bike Trailer as an Alternative for Transportation and Distribution of Goods

Cameron Alfred Hastings
Worcester Polytechnic Institute

Gregory Michael Port
Worcester Polytechnic Institute

Karl Torsten Sundberg
Worcester Polytechnic Institute

Richard Joseph Coffin
Worcester Polytechnic Institute

Designing a Bike Trailer as an Alternative for Transportation and Distribution of Goods

An Interactive Qualifying Project

Sponsored by

HIGHER GROUND FARM

August 22, 2016

By

Cameron Hastings
Mechanical Engineering

Gregory Port
Robotics Engineering

Karl Sundberg
Mechanical Engineering

Richard Coffin
Mechanical Engineering

Abstract

This report explores the process taken and results of a project in creating a system of sustainable urban transportation. First, the problems facing cities with regards to transportation are identified and analyzed. A solution to these problems is then offered in the form of bike and bicycle trailer transportation. Research was then done to create designs of bicycle trailers to be utilized for businesses. An examination into the design process and evolution used in this project was also done to show why decisions were made with regards to the final design. The final designs, both general for a multitude of businesses and a specialized design for Higher Ground Farm. Ultimately, a framework for sustainable transportation was created by this project and analyzed by the report.

Acknowledgements

We would like to thank John Stoddard and Higher Ground Farm for sponsoring this project, Professor Elisabeth Stoddard and Professor Laureen Elgert for advising our team, and Adrian Pickering for helping us weld parts of our housing box.

Executive Summary

Each year, an estimated 53,000 people die prematurely in the United States as a result of exposure to emissions from road transportation (Caiazzo et al, 2013). These emissions are linked to a higher rate of asthma in children, a higher risk of heart disease, and many other health complications. Additionally, these pollutants can also damage the environment by contributing to the greenhouse effect and acid rain (Demidov & Bonnet, 2009). Boston, with 1.9 million commuters, suffers from these effects and more (Daily Free Press Admin). The vast number of vehicles needed to facilitate this volume of transport also requires a large amount of space. This leads to congestion in roadways and an incredible loss in productivity, totalling to over 100 million hours lost each year (Daily Free Press Admin). These crucial issues need to be addressed to protect the health of people and the environment.

In this project, we explored the use of bicycle trailers as a component of a more sustainable commercial transportation system in cities, particularly in Boston, Massachusetts. Proof of the success of bikes and trailers for urban product transportation is provided through numerous case studies. One study was conducted in Germany concerning eight companies that performed deliveries using both cars and freight bicycles. It concluded that implementing electric cargo bike as delivery vehicles could save up to half of the distance travelled by combustion-engine vehicles for deliveries, and all of the problems that this travelling causes. The currently used manual cargo bikes also reduce this distance travelled, meaning that manual and electric bikes could replace cars in the vast majority of considered deliveries. In fact, based on travel distance and package weight, cargo bikes could have replaced cars for a vast majority of the studied deliveries. Additionally, based on this study, freight bikes and electric freight bikes are much cheaper to own and operate than cars (Gruber, Erhler, & Lenz, 2013). Another study in New York City states that not only can bikes be used for food deliveries, but that food deliveries were the most common product moved by freight bike (Conway, Fatisson, Eickemeyer, Cheng & Peters, 2011). Additionally, the use of bicycles significantly reduces related air and noise pollution (Lenz and Riehle, 2013)

In order to explore the use of bicycles with trailers as a way to reduce commercial delivery vehicles in Boston, we worked with Higher Ground Farm to develop a prototype bike

trailer. As a rooftop farm in Boston, Higher Ground Farm is committed to environmental sustainability. Currently, John Stoddard, who owns Higher Ground Farm, uses a bicycle and trailer for delivering the produce. However, his current system of using a makeshift trailer and bike rack with bungee cords was both inefficient and unsafe. Due to these concerns, Stoddard worked with our team to develop a better means of delivery.

While the use of commercial bikes and trailers has the potential to reduce traffic congestion, this system does have problems that must be addressed in order for bikes to be more widely used. The primary concern is the safety of the rider, due how exposed the rider is. In Boston alone, at least thirteen people have been killed while cycling in the past five years (Ramos and Cloutier, 2015). Additionally, there are specific laws in Massachusetts that concern bicycle operation and trailer usage. For instance, any trailer in use must not severely inhibit the handling of the bicycle, and the bike must be able to be parked in a manner unobstructive to both motorists and pedestrians (General Court of The Commonwealth of Massachusetts, n.d.).

Project Goals and Objectives

In order to reduce the damage caused by internal combustion engines, we established the goal of designing and creating a bicycle trailer to be used as a part of a sustainable system of transportation for businesses to move goods and services. In order to reach this goal, we established the following objectives:

Objective 1- Research Bicycle Trailers That Are Currently in Use

The first object of this project was to research preexisting bicycle trailer designs to determine what characteristics work or do not work. This objective was carried out primarily through two methods. The first method was to interview companies that make or use bicycle trailers. To accomplish this, we conducted interviews with the Pedal People, Tony's Trailers, and Bikes at Work. From these interviews, we learned what weights could be reasonably moved with a trailer, what materials were generally the best to use for the trailer, the attributes of two different hitch arrangements, and the most common sources of failure in bike trailers. In addition to the interviews, we also conducted research of existing trailer designs online, through sources such as company websites and the US patent office. From resources such as these, we gained more specific information about topics such as dimensions for certain parts of the trailer.

Objective 2- Design a Bicycle Trailer for Food Deliverers in Boston

Our second objective was to design a bicycle trailer for food deliveries in Boston. This was achieved through the creation of multiple design iterations on SolidWorks CAD software that were based on the information from the first objective and input from our sponsor. The design was divided into several parts based on the different functions. These parts included: the housing box and racking system, frame, hitch, suspension, electronics and signaling, exterior, insulation, and a cooling system. For each part, the design was formed through several iterations, each of which followed a general process. First, we started with a basic idea based on the necessary function. Then, we changed the design based on the information from objective one, the manufacturability of the materials, cost, ease of use, and other factors. Once the design incorporated these ideas, we re-checked the specifications to ensure that it was compatible with our other designs. Finally, a secondary design was made for the specific needs of Higher Ground Farm. Finally, we presented our design to our sponsor for approval. Occasionally, steps of this process were repeated due to new ideas, needs, or information.

Objective 3- Build a Functioning Bike Trailer to Aid Higher Ground Farm as a Case Study of Objective Two

The third objective was to build a functioning prototype of our trailer to be used by our sponsor, Higher Ground Farm, to serve as an example of the effectiveness of the design. This was accomplished in Washburn Shops using materials purchased by our sponsor. The specific design that was built was chosen due to the availability of materials, cost, and the needs of our sponsor. The finished trailer was then presented to our sponsor for testing its effectiveness and ease of use.

Results

The primary result of this project was an iterative design process that resulted in a final bike trailer design. This design process in general involved three steps, starting with a preliminary component design based on our research and interviews. Then, the design was edited after discussing with our sponsor what he specifically needed. Finally, we evaluated our design for each component based on structural soundness, budget, building time considerations, and our sponsor’s needs.

We developed our design though different components divided on function. These components and functions were: frame, racking system, exterior, hitch, suspension, wheels, ventilation, refrigeration, and electronics for signaling and power regeneration.

Upon the completion of Stoddard's trailer, it was delivered to him. At this time, we gained initial feedback. We later checked in with him and gained further, more detailed feedback. This feedback allowed us to see how effective the design was for Stoddard and Higher Ground Farm as well as the potential it has for other businesses.

Our bicycle trailer and others like it have an effect on society. The use of bike trailers within cities has the potential to reduce several prominent issues in cities, including pollution and traffic, as well as reducing costs for the cyclist. These benefits can be clearly seen through the wide use of bicycles in Europe and Asia. As this trailer goes into use, it will set an example of sustainable transportation that others can follow over time. Bicycle transportation can also create and sustain a new job market within cities. This is possible through the use of distribution centers, where packages are delivered to the edge of the city by truck, then distributed throughout the city through smaller vehicles such as bicycles.

Recommendations

1. Further research is needed to determine the potential market for commercial bike trailer use and obstacles to commercial trailer use.
2. We recommend that the government provide incentivizes such as tax breaks to promote the use of bicycles, and increase the number of bike lanes to promote safety during use.
3. In order to prolong the life of a bike trailer, we recommend that operators follow a routine maintenance schedule in checking and replacing brakes, tires and inner tubes.
4. We recommend the operator to carry water, a first aid kit, and a bike repair kit, and wear a cycling helmet to enhance their safety.
5. We recommend that a website be designed to provide information to people interested in bike trailers, including trailer designs and the benefits of using a trailer.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

As cities grow, traffic congestion severely damages the health and finances of commuters and cities, as well as the environment. An excess of vehicles on the road causes more than 100 million hours of productivity to be lost each year in Boston alone (Daily Press Admin). Greenhouse gasses and other pollutants are created more abundantly, resulting in an estimated 53,000 premature deaths in the United States each year (Caiazzo et al, 2013). Even finding an efficient route and method of traversing a city becomes far more difficult. This is particularly troublesome for local business owners, as they often have deadlines they must adhere to and want to ensure a good product is maintained during delivery. For example, local farmers want to ensure their produce remains fresh during delivery so restaurants have the best possible ingredients these farmers can provide. As a result, this project aims to develop a more efficient and effective model for transporting goods and services around a city with Higher Ground Farm as an initial beneficiary. Eventually, this could be applied as a model for other businesses around the United States.

Higher Ground Farm (HGF) is a commercial rooftop farm located in the Seaport District of Boston and supplies fresh produce to Boston restaurants and farmer's markets. The farm is located on top of the Boston Design Center and uses an acre of roof space to grow twenty varieties of heirloom tomatoes, greens, herbs, flowers, carrots, eggplant, and a dozen or so other vegetables. The farm has also started raising snails for escargot. HGF started growing its first crop in July of 2013 with support from friends, Recover Green Roofs, the city of Boston, a structural engineering firm (Simpson, Gumpertz & Heger), a Kickstarter campaign, and the Boston Design Center management. The founding farmers, John Stoddard and Courtney Hennessey, both graduated from the University of Vermont with a major in environmental studies in the College of Agricultural Life Sciences, and have worked as farm managers and restaurant employees. Their passion for bringing fresh produce to the community stems from their passion for food and their goal of making urban life more sustainable. Raising food on a rooftop can help to cool cities, reducing energy costs in the summer, can insulate buildings, and slow run-off precipitation into storm drains.

Figure 1: Higher Ground Farm

In interviews, Stoddard has emphasized his goal of maintaining a sustainable business. This includes growing quality produce through organic means and transporting this produce to restaurants in a sustainable manner. He has been using a bicycle with a small trailer as a means of transporting his produce to restaurants. His delivery method involves fastening coolers to both the trailer and the front and back racks of his bike with cords. This, however, was inefficient and raised numerous safety concerns. As such, Stoddard was interested in an improved method of sustainable delivery to replace his inadequate and unsafe system.

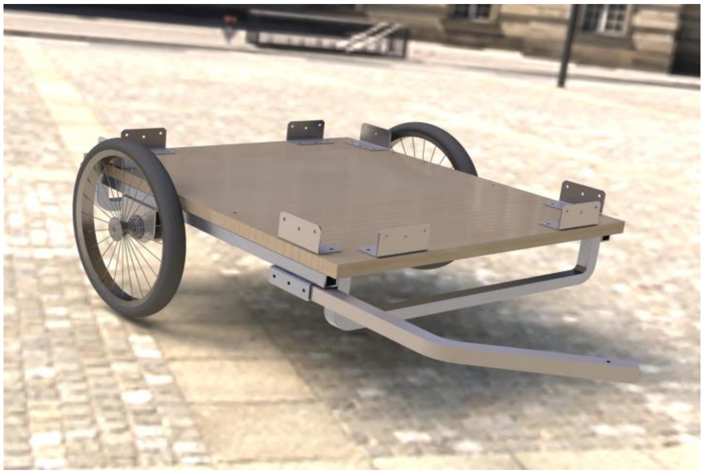

Figure 2: John Stoddard's Delivery System

As a result of these problems and Higher Ground Farm's goal, this project aimed to design and create a bicycle trailer to be used in a system of sustainable transportation for businesses to move goods and services. The design generated could be beneficial to not only the business in question, but also to the city in which the business is located. Having the design available as a green initiative for others to follow would support a city in reducing emissions and pollutants, as is also the goal of Higher Ground Farm. Transportation models of this type exist, though they are few and far between, and even less documentation is available for the food industry, in particular.

Our goal was further broken down into four primary objectives. The first stage of the project was to research bicycle trailers that are currently in use. The purpose of this involved gaining information and inspiration from existing designs and documentation. The next objective was to design a bicycle trailer for food deliverers in Boston. This design was meant as a general design that could be tailored for different businesses' needs. Next, this concept was applied in designing and building a functioning bike trailer/farm stand to aid Higher Ground Farm in their urban farming initiative. This acted as a prototype to verify this model's effectiveness while supporting a beneficial local business's ability to efficiently deliver its products. Lastly, the project aimed to begin the process of gauging potential interest and reasonable usage of this design for food businesses in the Boston area. This objective was meant to see how viable this design would be in Boston and cities in general, how widely it could be adopted, and ensure that considerations for other businesses were taken into account in the general designs. The next section will examine some literature that will assist in our goal and objectives.

Chapter 2. Literature Review

In this chapter, we describe the transportation problems in cities like Boston, MA, and the impact that they have on those in the city. Next, we describe a solution to these problems in the form of bicycle transportation as well as the challenges surrounding it. We also describe one company called Higher Ground Farm that aims to use this form of transportation for deliveries. Lastly, we describe how bicycle trailers could be utilized to aid businesses for their delivery needs.

2.1 - The Problem

Cities undergo a wealth of issues as a result of transportation. For instance, crowding becomes a major issue due to the sheer number of cars in the confined spaces of a city. Pollution is also of great consideration for this same reason. For our purposes, we will focus primarily on Boston, MA, when analyzing these issues.

2.1.1 - Crowding

Boston is a city known for crowding. In a study by Texas A&M Transportation Institute, Boston was ranked fifth in yearly delay-per-commuter among 498 United States cities with an average of 53 delay hours per year (Daily Free Press Admin). Furthermore, “Boston was ranked 11th nationally in total daily commuters by car, logging approximately 1.9 million auto commuters a day, according to the 101 Urban Areas statistics” (Daily Free Press Admin). This ultimately equates to around 100.7 million hours lost by commuters in the city of Boston alone. As such, it can be concluded that crowding is a substantial issue in Boston.

Figure 3: Traffic in Boston

2.1.2 - Pollution

The vast number of cars and trucks operating within cities like Boston produces pollutant with environmental and health consequences. The exhaust of an internal combustion engine includes chemicals like nitrogen oxides, carbon monoxide, sulfur dioxide, ozone, particulate matter, and many different hydrocarbons. These byproducts can alter a person's health in several different ways. For example, some of the remaining hydrocarbons are carcinogenic. Studies have also linked these products with an increased chance of heart disease and thrombotic events (Demidov & Bonnet, 2009). Additionally, a study conducted in Europe estimated that 14% of cases of children with asthma can be attributed to road pollutants. (Perez et al, 2013). These pollutants can cause the symptoms of respiratory issues such as asthma and infection to be more severe as well. To summarize these health effect, an estimated 53,000 people die prematurely each year in the United States as a result of exposure to emissions from road transportation (Caiazzo et al, 2013)Outside of direct health effects, sulfur dioxide and nitrogen oxides undergo further reactions and contribute to acid rain and smog (Demidov & Bonnet, 2009).

2.2 - The Solution

Based on the criteria of aiding these issues, bicycles present themselves as a solution to the transportation problems of Boston. First, studies show that bikes have the potential to be faster than cars in areas of traffic (Chow, 2015). Furthermore, bicycles use far less space than automobiles (Baskin, 2010). Next, due to the lack of gasoline and other fluids, bikes produce virtually no pollution (Baskin, 2010). Beyond this, bicycling offers additional benefits. To name a few, they are generally cheaper than cars, they are cheaper and easier to maintain, and they support a healthier lifestyle due to the exercise they provide (Baskin, 2010). All of these benefits have lead John Stoddard, the founder of Higher Ground Farm, to dedicate his company's transportation needs to bicycle transportation.

2.2.1 - Higher Ground Farm

Higher Ground Farm (HGF) is an independent organization with a goal of supplying fresh food to the community of Boston by their urban farming initiative. The idea became a reality in July of 2013 with support from friends, Recover Green Roofs, a Kickstarter campaign, and the Boston Design Center management. Both Stoddard and Hennessey graduated from the University of Vermont with a major in environmental studies in the College of Agricultural Life Sciences, and have worked as farm managers and restaurant employees. Their passion for bringing fresh produce to the community stems from their mission to develop and teach others about sustainable lifestyles. The best way the company could achieve this mission and help support the community was by the urban farming initiative, specifically with the development of this rooftop farm.

Figure 4: Higher Ground Farm

In interviews with him, Stoddard has emphasized his ideal of maintaining a sustainable business. For him, this includes both ensuring high quality produce while using only green methods as well as using sustainable forms of transportation. He has been using a bicycle with a small trailer as a means of transporting his produce to restaurants. His delivery method involves fastening coolers to both the trailer and the front and back racks of his bike with cords. This, however, was inefficient and raised numerous safety concerns. As such, Stoddard looked for a better method of sustainable delivery.

Figure 5: John Stoddard’s Delivery System

2.2.2 - Problems Raised Through Bike Use

While bicycle transportation has the potential to help the problems described in Section 2.1, a couple of other problems arise. First, safety becomes a large concern with the exposed nature of a bicycle. With approximately 500,000 emergency room visits due to bicycle-related injuries in the United States alone in 2013, bicycle safety and regulations are clearly of utmost importance for bike riders (Center for Disease Control and Prevention, 2015).

Next, a number of laws exist solely meant for bicycles. With regards to Massachusetts, The General Court of The Commonwealth of Massachusetts has set forth several laws around bicycle operation and goods transportation with bicycles. A few examples are listed below:

• "[The] operator shall give an audible warning whenever necessary to insure safe operation of the bicycle; provided, however, the use of a siren or whistle is prohibited." • "[The] operator shall park his bicycle upon a way or a sidewalk in a manner as to not obstruct vehicular or pedestrian traffic." • "The operator shall not tow any other vehicle or person, except that bicycle trailers properly attached to the bicycle which allow for firm control and braking may be used…. The operator shall not carry any package, bundle or article except in or on a basket, rack, trailer or other device designed for such purposes. The operator shall keep at least one hand upon the handlebars at all times" (General Court of The Commonwealth of Massachusetts, n.d.).

Table 1: General Court of The Commonwealth of Massachusetts Bicycle Operation Laws

With regards to transportation for businesses, this presents an issue of how businesses can move their goods while remaining in accordance with this law. These two concerns lead to the solution on which this project focuses.

2.2.3 - Bike Trailers to Address These Issues

In order for bike trailers to be a viable method of goods transportation, the problems stated in the previous section must be addressed. Since a bike is powered by a person, using an enclosed system to protect the rider is impractical due to its weight. Therefore, the best way to address this issue is through communication. A bike trailer that is highly visible and can signal the rider's intentions through the likes of brake lights and turn signals will greatly improve the overall safety of using a bicycle trailer. Additionally, there are laws that concern safety of bicycle operation that must be followed. A bike trailer can fit these laws well while also enabling the rider to carry a much larger load. While loading a bike rack on the front or back of the bike can limit the field of view of the rider, a trailer will be positioned so that it does not while often allowing more to be carried. Additionally, the placement of a trailer close to the ground will not limit the maneuverability of a bicycle as much as a top heavy load on a bike rack.

2.2.4 - Case Studies of Using Cargo Bikes for Short-Range Freighting

Bicycles have been used for short range transportation for many years, and they were the predominant means of urban transportation in the early 1900s (Gruber, Erhler, & Lenz, 2013). While this mode of transportation fell out of general favor as cars became more common, it is not extinct; in fact, it is present in many cities, and growing in several more as a means of both personal and cargo transport. For instance, Germany has several companies that use freight bikes (in addition to cars) for “courier, express, and parcel deliveries” (Gruber, Erhler, & Lenz, 2013), and test fleets have been successfully implemented in Paris and London (Gruber, Kihm, & Lenz, 2014). These bikes are generally used for two kinds of deliveries. The first is “last mile” deliveries, where a package is dropped off at the edge of a city in a consolidation center, then bikes or small cars transport the package to its final destination. (Conway, Fatisson, Eickemeyer, Cheng & Peters, 2011) The second is a “point-to-point” delivery, where a package is picked from one site inside the city and delivered to another site inside the city (Gruber, Erhler, & Lenz, 2013).

The idea of using freight bikes to transport food locally is not a new idea. In fact, according to Conway et al, in Manhattan, “[f]ood is clearly the most commonly moved commodity, especially restaurant deliveries, baked goods, and locally grown produce” (2011). This idea is further illustrated by the actions of La Patite Reine Vehicles, a French company that makes and operated freight bikes in Paris. In order to meet customer demand for food and medicine delivery, they have developed a refrigerated and electrically assisted freight bike named the Frigocycle, which is capable of supporting almost 400lbs (Conway et al, 2011). Similarly, Revolution Rickshaws, a company that performs deliveries in New York City by bicycle, keep their contents cool by using things such as refrigeration plates, since they do not operate refrigerated freight bikes. (Conway et al, 2011).

A significant percentage of deliveries that cars make could be made using freight bikes. There are several factors that decide if a cargo bike can be used or not. The primary factors are delivery range and package weight or volume. Sometimes a client of a freight service wants a package delivered by a certain time, so average speed is a factor as well. Based on these criteria, freight bikes may become advantageous to many businesses.

Besides the logistical factors listed previously, there are several other benefits to using cargo bikes. From a social viewpoint, bikes are favorable as they limit road congestion in the populated urban centers, as they are significantly smaller than cars. Using cargo bikes also provides a substantial health benefit to riders over drivers, as they are actively cycling instead of sitting sedentarily. A study in Copenhagen revealed that 32% of cyclists used bikes instead of cars because they consider it to be “healthy” (Gossling, 2013), presumably with respect to cardio-training. An environmental benefit of using cargo bikes is the reduction of greenhouse gas emissions. As Gruber, Erhler, & Lenz concluded, implementing electric cargo bike as delivery vehicles, without considering the currently used cargo bikes, could save “between 19% and 48% of the distance travelled by combustion-engine vehicles” for deliveries (2013). Cargo bikes are good for business as well. Cargo bikes and electric cargo bikes are both significantly cheaper than cars for this usage by potentially over $3300 per year for electric cargo bikes and $7300 per year for a standard cargo bike (Gruber, Kihm, & Lenz, 2014).

There are other excellent examples of using bicycles to move materials traditionally moved by cars. One of these examples is the Pedal People, a cooperative that operates in Northampton, Massachusetts. While they started out as a waste removal business, since Northampton does not have municipal waste removal, their business has expanded considerably. The Pedal People originally had two workers, Alex Jarrett and Ruthy Woodring, who founded the cooperative. Currently, the Pedal People employs fifteen people, who provide service to a town about of about 30,000 people. (Pedal People, n.d.) Now they offer a range of services, such as package delivery and furniture moving. One service especially important to this IQP team is their farm share delivery to the members of the Valley Green Feast cooperative. To provide this service, the Pedal People move a variety of farm products, including fruits, vegetable, meat and eggs (Pedal People, n.d.). This case provides substantial evidence to the viability of using a bike trailer to move produce locally within Boston. Particularly, moving meat and eggs means that temperature can be controlled and shock can be limited in a bike trailer, both of which are desired traits for the completed prototype bike trailer.

Several other companies exist that also do bicycle deliveries within cities. As an example, Boston Collective Delivery is a company that delivers a variety of goods, including food, throughout Boston (Boston Collective Delivery, n.d.). Metro Pedal Power is another example in Somerville, MA. They use electric bicycle trailers powered by pedaling to move goods and produce that use some sort of electric assist or device, such as refrigeration (Metro Pedal Power). The fact that these companies exist show the viability of bicycle transport within cities.

2.3 - Summary

In short, reviewing literature regarding this topic has revealed key points. First, cities like Boston have numerous issues surrounding their transportation system. Next, there are green alternatives, namely bicycles, which can help fix these issues. Businesses exist that aim to utilize these alternatives to help maintain a sustainable business. These businesses, however, need a more effective way to move produce than a bike alone. As such, bicycle trailers present themselves as a potentially effective solution.

Chapter 3: Methodology

The overall goal of this project is to design and create a bicycle trailer to be used as part of a sustainable system of transportation for businesses to move goods and services. In order to accomplish this, we need to create a versatile and effective design that businesses could easily implement. From this, the following objectives arise:

1. Research bicycle trailers that are currently in use
2. Design a bicycle trailer for food deliverers in Boston
3. Build a functioning bike trailer to aid Higher Ground Farm as a pilot of objective two

We had also hoped to conduct a survey of other food delivery businesses to assess interest in further use of our design, but we were unable to complete this entirely due to time restrictions. The following sections describe how we planned to accomplish these objectives.

Objective 1. – Research Bicycle Trailers That Are Currently in Use

The first objective is to determine the capabilities and limitations of current bicycle trailers. From this information, we can learn what design features are effective and reliable and should, therefore, be incorporated into our design. Additionally, we can learn what areas have been problematic and redesign these features to improve their functionality.

A primary method utilized to obtain this information was through interviews. We have interviewed members of organizations that use or make bike trailers or have other pertinent knowledge of or related to this subject. For instance, one such organization was the Pedal People, representing an active group of bicycle trailer users, due to their wealth of experience delivering various items, including food, with bike trailers under a variety of weather conditions. For those in this group, questions regarding usage, their experience, benefits and drawbacks, failure points, etc. were asked to gain a deeper insight in how society already applies these trailers and what could be improved to help these businesses. A similar process was taken for interviewing groups who currently design and produce bike trailers, such as Bikes at Work in Iowa. However, from these interviews, a more personal look at how these were designed and their abilities and downfalls from the perspective of their designers was obtained to aid us in our own design process.

For these interviews, we contacted several businesses and were able to schedule interviews with three of them: The Pedal People, Bikes at Work, and Tony's Trailers. The questions that were asked in each interview changed depending on the interviewee's area of expertise. For example, we asked the Pedal People what they do in order to make the bikes and trailers usable on snowy roads as well as general operating conditions. A full set of questions that were asked at each interview is available in the Appendix. We asked questions such as:

● What kinds of challenges do you face in operation of the trailer? ● How do you get the necessary parts for the trailers you make? ● What are some limitations that you have found in your trailer design, other that weight capacity?

Table 2: Interview Question Examples

To further expand on the knowledge gained from these interviews, we also researched current trailer designs through examination of available plans and schematics. This provided some us with helpful empirical data, such as dimensions and geometries that have been effective in trailers. Some of the designs that we analyzed were obtained from the previously stated interviews, provided the interviewee informed us of how to obtain schematics of the trailers that they use. This provided supplemental quantitative data to the other qualitative data gained from the interviews.

The interviews we conducted were open-ended interviews or semi-structured interviews. Interviews were chosen for this objective since they are "valuable as a means of allowing and enabling people to discuss their own experience, their own position, and encouraging them to reflect on their understanding of it" (Ward, 2014, 49). In particular, with regards to open-ended interviews, "more open-ended approaches… are largely concerned with understanding exploring the meanings given by people to the lives that they lead and relationships of which they are a part" (Ward, 2014, 43). Open-ended interviews were used so there are not restrictions on the interviewee, giving them ample opportunity to express what they think is most important about the current topic of discussion, making them ideal when interviewing this project's sponsor and getting feedback from him. In this manner, the interviewee can raise a point that we, the writers of the interview questions, did not consider. With regards to the semi-structured interviews, "a semi-structured interview schedule also has the advantage of providing a framework that helps to ensure that all the important issues are covered in the time” (Ward, 2014, 44). However, it is not overly structured, meaning the interviewee can provide more open-ended responses. This results in the interviewee to more easily provide their opinions than structured interviews while still providing a framework as to allow all of the interviewer's questions to be answered. At the end of the interviews, the participant was asked if they could refer us to another potential interviewee, resulting in a snowball interview.

Objective 2. - Design a Bicycle Trailer for Food Deliverers in Boston

The design process follows after the initial research and data collection has been completed. This information collected from interviews with groups such as the Pedal People, Bikes at Work, and Tony’s Trailers were largely considered during this phase. To produce the best prototype and design, we completed a few design iterations in which we started with simple sketches and designs and finish with complete design schematics of the trailer.

The first phase was the conceptual phase. This involved forming a checklist of requirements and ideas from discussion with the sponsor and interviews of companies that currently are involved with bicycle delivery systems. The framework of this checklist can be found in the Appendix. This checklist represents the design’s quality control characteristics in which it provides all the key points that we decided to target for the highest functioning bicycle trailer. Some features listed are options that consumers/users of the website described in objective five can select during the customization process of their trailer. This list was altered as needed as we obtain more information from interviews with experts and research.

The next phase was to use computer aided design (CAD) to generate drawings and simulations based on ideas derived from user interviews. These were mainly meant to act as conceptual drawings during this phase. From this point, a series of schematic views created for each component of the bicycle trailer which were provided for the users and experts to verify, making sure we have accurately represented all the needs of the users.

Once the design was agreed upon, the final phase involved creating detailed sketches and drawings with dimensions, material selection, and descriptions about each piece and its purpose. Each part of the trailer was considered as a key element that needed to be carefully considered and discussed to secure the best parts and materials that ensure a successful functioning design. As such, each part system was meticulously designed and/or sourced to ensure this goal.

Objective 3. - Build a Functioning Bike Trailer to Aid Higher Ground Farm as a Case Study of Objective Two

Once all the designs were completed and shown to the sponsors and experts for review, the building phase commenced. A large amount of the manufacturing occurred within Washburn Manufacturing Labs at Worcester Polytechnic Institute. To match our sponsor's desire of being as environmentally friendly as possible, we used as many recycled parts and materials as possible to make the production process as environmentally friendly as possible. New parts and materials were purchased from various hardware retailers while recycled materials were obtained from Save that Stuff, a recycling facility located in Boston. Using prior knowledge of manufacturing with Computer Numerical Controlled (CNC) Machining, custom parts were made for the trailer to ensure the quality of the design. Parts that did not work as expected were recorded and redesigned as necessary.

The building process started in D term. This included assembling all components, troubleshooting, and polishing the design. As the building took place, we discovered new problems or challenges that needed to be addressed and accordingly made design modifications. This, in turn, resulted in a design that was constantly up to date and a more effective end-product.

Chapter 4: Results

Due to the nature of this project, our results chapter was separated into two primary sections. This first discusses how the design of the trailer evolved over time as a result of the research, interviews, and other methods discussed in the Methodology chapter. The second portion analyzes the final result of the trailer, its social impact on our sponsor, John Stoddard, and its potential impact on society, with businesses being the primary focus.

4.1 - Design Development

As requirements, parts, preferences, and other factors change for a project, so too does the design for that project. Requirements change; new ideas arise; and discoveries about old ideas are made. In this project's case, this resulted in multiple iterations of several systems within the trailer. Frame, electronics, racking, and even the trays underwent numerous changes for various reasons, which culminated into the final design.

4.1.1 - General Designing Process

Our design process involved an iterative process of: 1) designing components of the transport system based on information from primary and secondary sources, 2) discussing our designs with our sponsor, and 3) evaluating our designs based on structural soundness, budget, building time considerations, and our sponsor's needs.

First, we had to fully understand what the desired outcome of the product was for our sponsor. Based on multiple interviews with our sponsor, we prepared a budget and constructed a list of usability requirements. One major consideration was efficiency: our sponsor wanted a more efficient way to load and unload his trailer compared to his current system. He also wanted his new trailer to be affordable, technologically simple, and eco-friendly (J. Stoddard, personal communication, September 13, 2015) (Pedal People, personal communication, February 5th, 2016) (Tony's Trailers, personal communication, February 25th, 2016).

To aid with design organization, it was helpful to plan the design through a series of steps to attain a completed design. At first, we thought designing our components from the ground up would be the best strategy. We planned to start with the wheels and suspension and move on to the frame, hitch, housing box, electrical system, racking system, and finally end with the trays.

Just before we started designing, we found that it would be better for us to design in the opposite order. This way, the trailer would be constructed around its cargo. We would pick out a properly sized tray, design a racking system for that tray, then build a housing box to hold the racking system and so on. This order also helps to minimize the amount of modifications we would have to make.

Each component was designed in three steps: First, we designed the part in SolidWorks. We chose to use Solidworks because the majority of the team had prior experience with this computer aided designing software. The purpose behind designing with Solidworks was to take our two-dimensional drawings and turn them into three-dimensional parts that we could run simulations on to test the structural integrity of the components. Second, we researched the materials needed to manufacture each part, where to purchase the materials and created a cost estimate. Third, we would show our final results to our sponsor, John Stoddard, to obtain his feedback. From there, we would make changes, get his approval and move on to the designing of the next part. Building would not start until all components were designed and approved.

4.1.2 - Frame

The frame is the backbone of the entire trailer. It supports the weight of every component, except for the wheels and suspension. It needs to allow the hitch, wheels, suspension and housing box to connect to it.

Figure 6: The Housing Box Welded in Washburn Manufacturing Labs (Photo by Cameron Hastings)

To make the frame more versatile, we designed it to be able to be hauled by bicycle without the housing box. This allows the user to transform the trailer from a box trailer to a flatbed trailer. Companies would be able to haul more than food, if this feature was incorporated into the design. For example, a rooftop farm could haul bags of soil, planter crates and other business equipment. This helps eliminate the need of a company van, car, or truck.

The frame will be in contact with many different corrosive substances because of how low and exposed it is to the ground. As such, we choose aluminum, a corrosive resistant material, to protect the frame from oxidation and other damaging reactions from substances such as road salt and water.

4.1.3 - Hitch

The hitch plays a very important role in making this bicycle trailer a success. It is used to connect the trailer to the bike. The hitch, despite its small size, needs to be able to withstand large compressive and tensile forces and be universal to all bicycle types. Because of this challenge, we decided to purchase a pre-existing hitch from Bikes at Work.

Figure 7: Bikes At Work’s Hitch (Bikes At Work)

During our interview with Bikes at Work, they supplied us with valuable information regarding bike trailer design. They also explained that their trailers evolved over the past twenty years, and their current design incorporates modifications to failed components. A feature that fascinated us the most was their re-enforced, universal hitch. It uses clear rubber hosing which allows it to attach safely to any bicycle. It is capable of pulling a 600 lb. trailer without breaking. This is a component that we knew would work for our sponsor's needs and for most commercial transport within the city. At $60, the price would be close to what we would have to pay to make our own, while saving us time in designing and building (J. Gregory, personal interview, February 5, 2016).

Another hitch option presented itself during our interview with Tony's Trailers in the form of a seat post-mounted hitch. It was argued in this interview that this hitch better distributes weight throughout the bike since the weight is not located on just the rear tire. Furthermore, it offers greater adjustability and is more easily attached to a wider variety of bikes. In addition, based on Mr. Hoar's experiences with this hitch, the hitch is capable of similar loads as Bikes At Work's (approximately 600 lbs.), making it a viable option (T. Hoard, personal communication, February 25, 2016).

We ultimately decided to buy Bikes At Work's hitch (pictured above in Figure Y) to include in our trailer design. Due to the design of John Stoddard's bike, a seat post-mounted hitch would not be feasible due to the luggage rack over the back tire, as seen in Figure X below. Stoddard expressed that he would still like to have this rack usable should the need arise. As such, using a seat post-mounted hitch would inhibit his ability to use this rack as the rack itself would need to be removed. In addition, due to the design of our frame and overall trailer, the wheel-mounted hitch is far more secure. For the seat post hitch to be used, the hitch would need a mounting point on our housing box (described in section 4.1.5) or an extension to the frame would need to be constructed, neither of which we felt was desirable due to complexity, cost, time, and structural-integrity reasons. As such, the wheel-mounted hitch from Bikes At Work presented itself as the most desirable option for this project.

Figure 8: Stoddard's Bike Luggage Rack

4.1.4 - Suspension

Another feature that was included in the trailer with be a suspension system. We believe that this is an important feature because it absorbs shock from potholes and other road defects. This will, in turn, protect the quality of the produce that is being transported.

Our first thought was to use a standard Macpherson strut suspension system. In this case, we would likely use the suspension from a moped. This idea was rejected because it requires a substantial amount of vertical room, which would limit our storage space. This would also raise the center of mass of the trailer, which would make it unstable. The second option that was considered was the use of a simplified version of a pushrod or pull rod suspension system. This system works in a similar manner to the strut suspension system, but it is can be oriented in several different directions. This would enable our design to have a suspension system, but still maintain a reasonably low center of gravity. The major problem with this system is that it is fairly complicated, making production for us and maintenance for our sponsor difficult. Also, it is difficult for both wheels to share an axle with this system, which would be necessary if a regenerative system is included in the design of the trailer. A regenerative system is similar to alternator in a car, where wire is coiled around a rotary shaft and as it turns a magnetic field is produced creating charge which is routed through a diode to a battery which charges. A third option that was considered is a leaf spring suspension. This would allow the design to still have a low center of gravity, limit the complexity, and keep a single axle for both wheels. The disadvantage of a leaf spring system would be that it is less effective than the other systems considered since they do not have dampeners. The leaf spring system could give the trailer more body roll, which refers to the mass of the trailer and the contact of the wheels. There is only one axle in a leaf spring suspension and when the rider takes a turn the trailer will lean towards the direction of the centrifugal force, thus the trailer will start to tilt with the transfer of load internally, and potentially falling over. The rider must exert caution in sharp, fast turns and exercise slower, wider turns like trucks do.

After much consideration, we decided on a leaf spring suspension system. This is largely due to the fact that leaf springs are easy to obtain, relatively cheap, and widely used for trailers. During our research, numerous kits were found to help mount the suspension and plenty of documentation existed to help guide this process further.

4.1.5 - Housing Box / Racking System

The racking system was primarily influenced by the decision of what trays would be used to hold the produce, which is a choice we left to our sponsor. After conferring with the sponsor, he choose to use trays similar to the ones used in restaurants would be ideal since they are designed for holding food already and are made of a material that is approved by the FDA. Once the size of the trays was established, we were able to define how many trays the trailer needed, based on the size of the trays and the total storage space our sponsor wanted in the trailer. The result of this estimate was a design that could hold five trays in a single column. This first design also included spring loaded “skis” to hold the trays in place and limit errant motion while the trailer was in use. Additionally, the door through which the trays could be accessed was placed on the back, so it would not interfere with the wheels.

Once we had created detailed drawings of this design, we realized that it would not work because it was too tall, which would lead to instability. To rectify this, we changed the racking system to a two-column design. This change made the height of the trailer much more practical, and it had some unexpected benefits as well. First, since five trays of equal size cannot be evenly split into two stacks, there would have to be some extra space, which we could use for storage of other component of the trailer, such as the battery, a first aid kit, and a bike repair kit. Second, the two-stack design creates separate, independent areas. This would enable us to refrigerate only a portion of the trailer, which lowers the energy consumption for the trailer without a large loss of utility. However, a two-stack design would not work with our current door. Therefore, the plan was changed from one door on the back to two doors on the right side, and a small door to the storage space on the back. In order to prevent the wheels from being in the way of the doors, the wheels would be placed outside of the storage space, with one of the doors to the trays over the right side wheel. The doors were placed on the right side of the trailer so that it could be easily loaded and unloaded at the curbside, without the need to go into the road, creating an important safety feature.

After this design iteration was finished, we learned that our sponsor wanted 6-8 trays instead of five. To accommodate this, the design was changed to include a third column to hold an additional three trays. The resulting design, as viewed in Solidworks, can be seen in Figure X below.

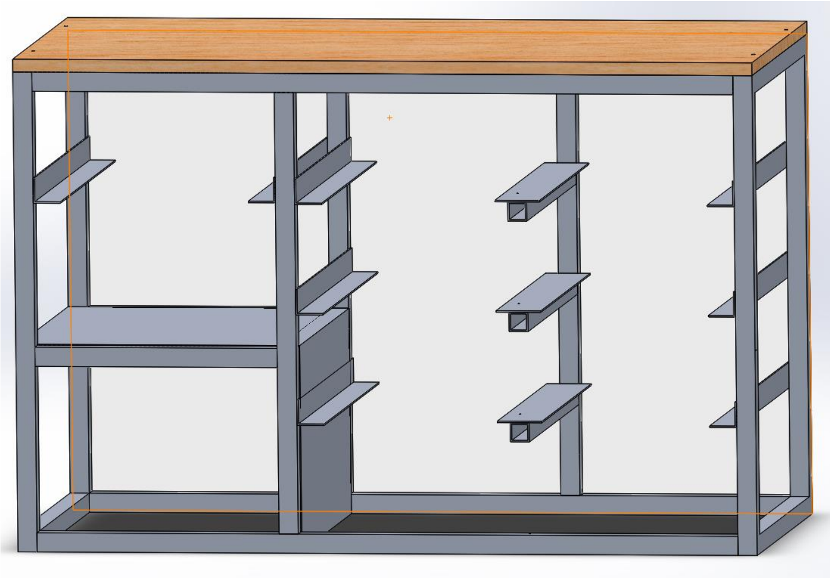

Figure 9: Housing Box

This design was later modified again to address concerns of the weight distribution. Originally, we planned for the wheels to be mounted near the rear of the trailer. However, this raised concerns about too much force being applied to the rear axle of the bike where this trailer would be mounted. As a result, we moved the wheel closer to the center of the trailer. This, in turn, caused the rear-most and center shelving sections to be switched, as seen in Figure X below.

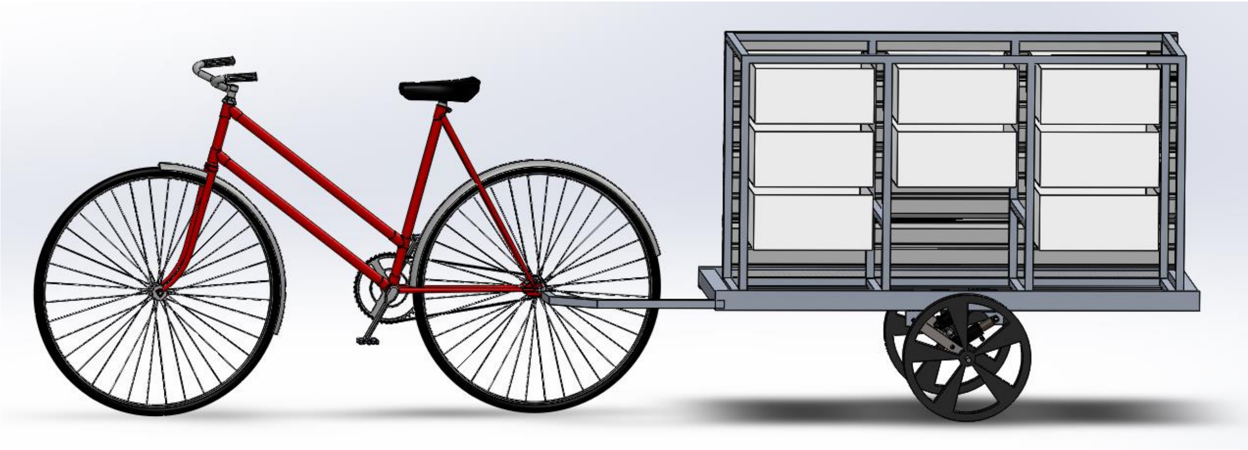

Figure 10: Final Trailer Design

4.1.6 - Insulation / Exterior

Another factor that can affect the produce is heat. The primary source of heat is a resultant from sunlight which affects the ambient or surrounding temperature around the trailer. To account for this, the outer surface should be made of a reflective material, so that the sunlight is not absorbed and transferred throughout the trailer.

To control ambient heat and increase the effectiveness of the cooling system, the refrigerated section of the trailer would have additional insulation. There are many different options for choosing what kind of insulation can be used, depending on weight, efficiency and cost.

Another important set of factors to consider in choosing the exterior body panels are the properties of the material. Since the panels are not weight bearing, the material does not need a large compressive strength, the materials ability to hold applied loads without reducing size. However, the material should have a high impact strength, materials ability to survive sudden applied loads, so that it will remain intact if the trailer is hit by an outside object. The material needs to be stable in the working environment as well. Therefore, it should be thermally stable from about 0 degrees Fahrenheit to about 110 degrees Fahrenheit. The material should also be stable when exposed to moisture and sunlight, especially ultraviolet light. Additionally, since the trailer will be used to transport food, an FDA approved material would be preferred, though not necessary.

Based on these requirements, ultra-high molecular weight polyethylene (UHMW) was initially selected as a material for body panels. While UHMW fit our needs very well, it difficult to obtain. As a result, acrylic panels were used, since it has sufficient material properties and could be easily obtained. We were able to reuse acrylic panels from a recycling facility in Boston, called Save that Stuff. This was also beneficial as a way to implement the idea of environmental sustainability into the design.

4.1.7 - Ventilation

Something that it is important to consider while containing produce is the production of ethylene gas. This gas is emitting to varying degrees by different types of produce, and its presence causes produce to ripen at an accelerated rate. Because of this, our trailer must be properly ventilated in order to preserve the freshness of the fruit (Blankenship, 2015).

This is an important design consideration because it necessitates a hole in the wall of the trailer to allow air flow. This would make refrigeration of this area extremely difficult, and there must also be a way to keep contaminants out of the trailer's interior. Since the trays use breathable lids, we decided to make the rest of the trailer air permeable. We found that the lids effectively prevented foreign contaminants from polluting the produce, which allowed us to place narrow gaps between our side panels. This grants ethylene gas to vent out of the trailer.

4.1.8 - Electronics

Electronics were involved with early design concepts and continued into later designs. These, in turn, co-evolved with their mechanical counterparts. As such, the concepts surrounding the electronics changed along with the evolving mechanical aspects and improved as more discoveries and ideas were made.

The first considerations involving electronics were those regarding safety. With this trailer being used on the streets of Boston, taking safety into consideration is vital. The trailer must be visible at all times of day by all types of vehicles and by pedestrians to ensure the safety of Stoddard and others on the road. Therefore, we decided that lights were necessary in the order for others to be able to see the trailer from a distance and to act as turn signals. A distance sensor was suggested to help detect cars behind the trailer. This would allow Stoddard to be able to know if anything is behind him and react accordingly, without taking his eyes off of the road.

Given that each of these components, along with other possible additions, need power, the question was raised about keeping the necessary batteries charged. Upon initial brainstorming, solar power and pedal-to-electricity systems were considered. Solar was initially discarded due to cost. As a result, using an alternator or DC motor was considered the primary choice. An alternator is designed for this exact purpose of converting the movement of a rotor which produces a magnetic field for the charging of a battery, and a DC motor generates electricity when turned without being powered and could, in theory, be connected in such a way that would allow the motor to be used as an assistive device when powered. A concern with these methods, however, was the added resistance from these being directly connected to one of the sets of wheels. The connections between an assisted power and the bicycle could increase the frictional force and therefore cause the rider to have to exert a greater force to overcome this increased friction.

Upon further research, more affordable solar panels were found, putting this option back into consideration. We presented our findings to our sponsor to get his opinion. Based on this conversation with him, we decided that either solar (due to its passive nature) or a DC motor (due to its ability to recharge the battery with pedal power and to assist with the pedaling if desired) were the best options.

After further consideration, we determined that solar panels would be the most effective choice. Using a DC motor would add far greater complexity to the system, making it harder to design and build. It would also add resistance as a result of having the DC motor attached to the wheel. To combat this problem, a clutch system to engage the motor when needed and disengage the motor when not needed would have to be added. However, this would add further complexity and parts are not readily available for this application, based on our research. As such, the solar panel was determined to be the best option for this particular trailer.

4.1.9 - Refrigeration

Another system that we considered in the design of the trailer was a refrigeration system in order to help protect the produce from the effects of heat while travelling. This component would be especially important for the future utility of the trailer, as our sponsor may add snails for escargot to the goods he delivers, and the temperature must be controlled in that case. Additionally, it may prolong the freshness of the produce, which would be helpful if the trailer were to be used as a farm stand.

First we considered using a standard compressor based system in the trailer. However, this idea was quickly rejected, because of the high weight and power consumption of this kind of a system. After more research, it was determined that a different system using Peltiers and fans could be utilized to cool the trailer. This design would be much lighter, though it would still consume electrical power. Another, far simpler method that was considered was the use of ice packs. While this method of cooling would be very easy from a design standpoint, it would increase to the loading time and decrease the capacity of the trailer. From this point, we had to choose between a system that operated within the trailer and a system that required external resources.

Another important change in our plans for refrigeration occurred after additional research suggested that a refrigeration system may not be necessary for most produce. However, since our sponsor may choose to deliver snails, some degree of refrigeration would still be necessary. After this was considered, we changed the design so that only a specific, separate portion of the trailer would be refrigerated. This new design would also require less power for cooling. Therefore a smaller, lighter and cheaper battery could be used.

In the final design, a refrigeration system was not included due to budget restrictions. This was also influenced by the fact that the contents could be cooled through the means of ice packs, if necessary.

Design Part	**Design Considerations**	**Design Changes**	**Reasons for Changes**
Hitch (from Bikes at Work)	- universally attaching hitch which ensures others can use this trailer - guarantees that the hitch will attach to our Sponsors bicycle - extremely well designed and durable hitch which will ensure few to no malfunctions and a longer lasting life of the hitch - design difficult to reproduce	- instead of designing and building our own custom hitch we decided to go with the hitch from Bikes at Work	- design difficult to reproduce due to amount of welding required - proven design that is being used by other companies, see no need to reinvent a hitch that has been working well

	due to amount of welding required		

Frame	- detachable trailer frame from the racking system
	- allows for the this trailer to be used separately without the racking system case
	    - multi-functional
	- the entire system is currently being designed in two parts
	    - racking system with an externally housing case
	    - trailer frame
		- the idea of an externally attaching housing that encases the racking system that can detach from the trailer frame has been considered
		- use 1” square aluminum tubing for the frame,
			- potentially might use this idea, still discussing possible negatives are how to detach the racking system case from the trailer frame and the stress that this will put on the latches or bolting rods holding the two together
			- Tubing chosen based on information from the interview with Bikes at Work

Suspension / Wheels	- need a suspension system that can support a considerable load of a few hundred pounds	- considered using basic moped suspension - moved to idea of pushrod/pullrod - considering leaf-spring system - Decided on leaf-springs	- the moped suspension could get in way of compartment(s) - pushrod/pullrod is an extremely complex system that if off by ever so little won’t work effectively - the leaf-spring system is simple and easy to assemble on trailers - Chosen for simplicity, large availability, and plenty of documentation and parts
Lights / Safety	- Certain laws exist regarding necessary components of trailer/bike - Also want the rider of the bicycle trailer to be safe as possible - lights increase visibility of trailer and allow for use of turn signals	- lights for turning - sensors for backing up - distance sensor in back to allow John to tell if a car is too close to the back of the trailer	- back up sensors and/or distance sensor are not essential since cars are always going to be around the trailer when using in the city - lights for turning and braking are good features to include since the trailer will

			be used on city roads with cars and lights will ensure other drivers know which way the trailer is moving
General Electronics	- assisted power for riding with full trailer load - assisted braking to help slow down the trailer - Regenerative power supply system - Could add to the attractiveness of the trailer, which helps to draw in customers	- either solar or DC motor (for assist as well as regenerative) - considered alternator - Decided on solar	- he wanted either assist or something that wouldn't inhibit the rider's pedaling that much - also cost is a big factor and these options are not cheap - Solar was chosen as a smaller panels could be purchased for relatively low amounts and it would add very little motion resistance since it wouldn't add parts to the wheels or axle
Racking System (pair with Housing Box)	- Started with one compartment/column - Allows for easy installation and removal of trays - also included spring loaded skis (low tolerance fittings to keep tight fit over lid of tray) -	- The trailer originally was designed to be one large compartment - Moved to multiple compartments - two normal produce storage sections - one refrigerated section - one general storage section	- design too tall- leads to unstable trailer - Good height to be used as farm stand (~3.5 feet) - Limit refrigerated are to increase efficiency - the skis are too complex, and not needed if the racking system is designed properly
Refrigeration	- refrigeration to keep the produce cold during transportation and fresh for the client - Designed mostly for leafy	- refrigerate the entire interior- standard compression - considered	- high weight and power concern - use active or passive system - decided not necessary to

	greens, which wilt at high temperatures	peltiers and ice packs - only refrigerate one section of the trailer	cool entire trailer -
Ventilation	- to prevent the ethylene build up and rotting of the produce - John's #1 crop is tomatoes, which are very sensitive to ethylene.	- filter between compartments	- Will need a filter to prevent contamination of the main compartment. Keeps road dust and debris from getting into the trailer.
Insulation	- primarily from solar radiation - also the "refrigerated" section will need insulation - possibilities: ○ Styrofoam ○ fiberglass ○ foam ○ wood		
Shell / Housing	- Impact resistance - UV protection - Heat/cold resistance - Cost	- Plastic - Wood - Ultra-high molecular weight polyethylene - Acrylic	- Simple and relatively cheap - Plastic is not durable enough for our purposes - Lighter than wood, very good strength - We were given a large amount of acrylic that would work well enough for the trailer, so, for cost reasons, it was chosen

Table 3: Design Considerations and Changes

4.2 - How the Trailer Affected Higher Ground Farm

In order to assess how well the trailer served its intended purpose for Higher Ground Farm, an interview was conducted upon the delivery of the trailer, at which point Stoddard performed the initial test, and again roughly a month following the delivery. During Stoddard's initial test of the trailer, Stoddard seemed very pleased. He made numerous positive comments, including that the trailer was very maneuverable and he could hardly feel it behind him (J. Stoddard, personal interview, July 1, 2016). During the interview, he also stated that the trailer will "literally change his life" (J. Stoddard, personal interview, July 1, 2016).

Figure 11: Stoddard Testing the Trailer

To check in with Stoddard and gain feedback from him and his experiences with the trailer, another interview was conducted over email on August 10, 2016. This stretch of time allowed Stoddard to give more detailed feedback. In particular, Stoddard mentioned, "the trailer has been working great. It has much greater capacity which has reduced the number of trips I need to make and allows me to sell at higher volumes. It is also much easier to load and unload than what I was doing before. The handling has been smooth. It is heavier than I was used to which makes me go a bit slower but I have been able to navigate through town just fine" (J. Stoddard, personal interview, August 10, 2016). To summarize, Stoddard's trailer solved a plethora of the issues of his original trailer, the loading and unloading and overall volume to name two. The increased weight making him slightly slower was expected with the increased volume. Furthermore, the fact that Stoddard saying that despite this increased weight, the trailer maneuvers effectively and is controllable is very encouraging towards the effectiveness of the design.

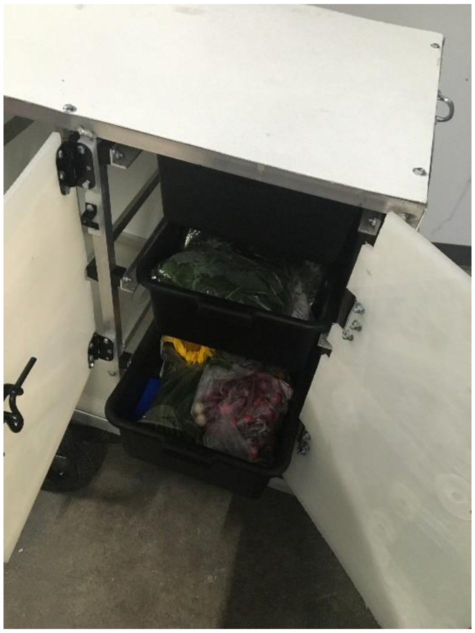

Figure 12: Loaded Trailer for Delivery (Stoddard)

Overall, based on these interviews, the trailer's design seemed effective for Stoddard. He gave very positive feedback and seemed very happy with the design. Additionally, this feedback shows promise of the design being practical for other businesses as well. With the design being effective for Higher Ground Farm and the trailer showing its prowess in moving items that fit within the containers, other businesses could theoretically use it for their own purposes.

4.3 - Societal Implications of our Bicycle Trailer

The bicycle trailer is a widely used resource in locations around the world, such as Europe and Asia for multiple reasons. They are easy to maintain, less costly compared to trucks or cars and are perfect for densely populated areas. There still is a need for trucks to carry out long distance hauling of products from one city to another, but within the city, a bicycle trailer can provide positive environmental and social impacts. In cities that are overrun with traffic, pollution and trucks, the use of a bicycle trailer can reduce these factors. The effects of using a bicycle and bicycle trailers will gradually take effect when more people choose to use alternative eco-friendly energy solutions. John and bicycle advocates throughout Boston have had a great influence on the community of Boston by setting an eco-friendly example.

The use of bicycle trailers for the transportation of goods can create a new job market by helping to deliver more business to local bike shops and creating new jobs to deliver the goods. This concept is known as the last mile concept in which these large trucks drop off the products at a warehouse and smaller units such as bicycle trailers will distribute the goods. Bicycle messengers are quite common in New York City because they are able to move through heavy traffic with ease. This can be a benefit in other cities as well that suffer from slow moving traffic. Bicycles have the freedom to maneuver around traffic since a bicycle is smaller than a car and with bike lanes in Boston the use of bicycles is even easier. The use of bicycles can help inspire others, once others see the options they are provided and that normal practices aren't always the best then more positive results will be seen.

Chapter 5: Recommendations

1. **Further research is needed to gauge the interest in and feasibility of bicycle trailers for business use.**
    a. To assess broader interest in the use of commercial bike trailers, we recommend interviewing and/or surveying restaurants and other food purveyors in Boston who self-identify or who advertise as being committed to sustainability. Using a trailer as a component of their delivery system could both meet their business philosophy as well as promote and highlight their image as a “green” business.
    b. Responses would help locate obstacles that must be resolved in order to gain more interest in the concept.
    c. A preliminary set of survey questions developed during the course of this project can be found in the Appendix

2. **We recommend that the government take various steps to both incentivize the use of bicycles and promote safety during use.**
    a. With the addition of bike lanes, a city becomes much more bike friendly. Larger vehicles would have more room to pass bicyclists, which reduces congestion and the dangers bicyclists are exposed to from passing vehicles.
    b. Local governments could offer tax breaks or other incentives for businesses that use bike transportation. This would help encourage businesses to use bicycle transportation.

3. **In order to prolong the life of a bike trailer, we recommend that operators follow a routine maintenance schedule.**
    a. Bike brakes will wear down much more rapidly due to the added weight of the trailer.
    b. Tires will eventually require replacing in order to maintain safe handling.

c. If these components are ignored over time, the safety of the operator may be put at risk when they finally fail. These items should be frequently inspected and replaced when need.

4. **We recommend the operator to carry and wear specific items to enhance their safety.**
    a. The operator should wear a helmet, so that in the event they are struck by a moving vehicle, their head would be better protected.
    b. A first aid kit should be kept within the trailer. This would better prepare the cyclist in the event of an emergency, or collision.
    c. A tool kit would allow the operator to perform basic roadside repair on their trailer, or bicycle.
    d. Problems, such as a flat tire, could happen at any time. An operator should carry spare tire tubes and other parts for their trailer and bicycle.
    e. A bottle of water is important to keep the cyclist hydrated during a delivery.

5. **We recommend that a website be designed to provide access to people interested in bike trailer designs.**
    a. A website would make trailer designs widely available to anyone with an internet connection. It would enable interested people and businesses who don't have a lot of money to be able to build their own commercial bike trailer, which would help the movement gain momentum and be more viable for all.
    b. A website could provide information about the benefits of bike transportation.
    c. Several different designs with different functionalities could make bike trailers usable in fields other than food transportation.
    d. It would allow trailer designers to improve our existing design.

Chapter 6: Conclusion

This project ultimately aimed to design and create a bicycle trailer to be used in a system of sustainable transportation for businesses to move goods and services. The use of bicycles provides many benefits such as the reduction of greenhouse gas emissions and reduction of congestion on city streets. However, numerous considerations needed to be taken into account when creating designs for this concept.

Higher Ground Farm was featured as a functioning case study in tailoring the design to their delivery method by applying this model, making it more efficient by specifically targeting development of their bicycle trailer. Furthermore, expansions towards how the model can be applied were be examined.

Ultimately, the project was successful in creating designs for urban businesses to utilize for sustainable transportation. This design was successfully implemented into Higher Ground Farm's sustainable transportation model and proved effective for the business. Furthermore, research was started to aid in the spread of this concept in the form of interviews and the creation of a survey.

This project has the ability to aid in issues raised in urban transportation. If it becomes widely adopted, city congestion could become less prevalent, pollution levels could drop, and cities, as a result, could become cleaner and more efficient. The framework has been created for this implementation and spread. From this framework, we hope to inspire businesses all around the United States to implement our sustainable alternative transportation method.

Appendix

Pedal People Interview Questions:

- What is it about your trailers that make them winter -capable?
- What kind of refrigeration system do you use to transport meat and eggs?
- What are some things you considered when designing your trailers?
- Do you have any advice for us with regards to designing our trailer?
- What are some restrictions/limitations you have found with your current design?
- What weight limits exist for your trailers?
- How much do you typically deliver at a time?
- What kinds of challenges do you face in operation of the trailer?
- Where do you get your parts for the trailers you make?
- How do you think having an enclosed system would change your deliveries, considering all the trailers you currently use are open-topped?
- Have you ever broken a trailer? What caused the failure?
- Do you purchase new parts or recycled parts?
- How do you think a closed design would affect delivery, specifically for food items?
- What attachment system(s) do you use to attach a trailer to your bicycles?

Bike Trailer Designer Interview Questions

- What are some things you considered when designing your trailers?
- Do you have any advice for us with regards to designing our trailer?
- What are some restrictions/limitations you have found with your current design besides the weight limits on the website?
    - How much do you typically deliver?
    - How were your weight limits tested?
- What kinds of challenges do you face in operation of the trailer?
- How do you get your parts for the trailers you make?

  - Do you purchase new parts or recycled parts?
  - Do you have any suggestions for places to get materials?
- How do you think a closed design would affect delivery, specifically for food items?
- Have you ever broken a trailer?
  - What caused the failure?
- Lastly, do you have any suggestions for other people to interview about bike trailer design?

Survey Questions

1. What type or types of food do you deliver?
2. What is your current delivery method?
3. How long do these deliveries take to complete?
4. What is a typical range (distance) for your delivery?
5. Would you consider using a bike trailer to transport company product?
   a. Why or why not?
6. If you were to use a bike trailer for your business, what components would it require?
7. Would your business be willing to test a bike trailer prototype for a few hours?

Design Checklist

General Considerations:

- Safety
- Power regeneration
- Power consumption
- Size / (must fit in active streets of Boston) and space efficiency
- Functionality
- The rider/seller’s needs
- Easy to assemble and or disassemble
- Ability to combine bike and trailer.

- Ability to clean it
- Will it have to be compatible with multiple bikes?

Power and Safety:

- Solar panels?
- Batteries
- Regenerative braking for braking
    - Either a magnetic or spring loaded system
    - Keep power consumption in mind
- Turn signals
- Brake lights
- Add motor to aid in movement
- Parking brake for holding farm stand in place

User specifications:

- Any colors, or design styles preferred.
- The amount of produce carried
- How/where will it be stored?

Frame Integrity:

- Weight
- Stability
- Durability / reliability
- Maintenance (replaceable parts)
    - Roadside Repair
- Center of gravity

Aesthetics:

- Style
- Advertisement
    - Higher Ground Farm logo, colors
- Professional

Cargo Compartment Considerations:

- Vegetable preservation
- Refrigeration unit
- Mister
- Water tank

- Size of water tank and refrigeration unit - FDA food storage regulations

Table 4: Design Checklist

Works Cited

Ackerman, K., Conrad, M., Culligan, P., Plunz, R., Sutto, M., & Whittinghill, L. (2014). Sustainable Food Systems for Future Cities: The Potential of Urban Agriculture. *The Economic and Social Review*, *45*(2), Pp. 189-206.

Baskin, C. (2010, March 18). *12 reasons to start using a bicycles for transportation*. Retrieved From http://www.mnn.com/green-tech/transportation/stories/12-reasons-to-start-using-a-bicycle-for-transportation

Bikes At Work (n.d.). Bicycle Trailer Hitches. *Bikes At Work*. Retrieved from http://www.bikesatwork.com/store/bicycle-trailer-hitches

Blankenship, S. (2015). *Ethylene: The Ripening Hormone. WSU-TFREC/Postharvest Information Network*. Retrieved from http://postharvest.tfrec.wsu.edu/pages/PC2000F

Boston Bikes. (n.d.). *Boston Bikes.* Retrieved from http://www.bostonbikes.org/

Boston Collective Delivery. (n.d.). *Boston Collective Delivery*. Retrieved from http://bostoncollectivedelivery.com/

Caiazzo, F., Ashok, A., Waitz, I., Yim, S., & Barrett, S. (2013, June 25). Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231013004548

Center for Disease Control and Prevention. (2015, August 17). *Bicycle Safety* [Data file]. Retrieved from http://www.cdc.gov/motorvehiclesafety/bicycle/index.html

Chow, L. (2015, May 20). Biking Is Faster Than Driving in These Major Cities. *EcoWatch*. Retrieved from http://ecowatch.com/2015/05/20/biking-faster-than-driving/.

City of Boston. (n.d.). *Boston Bikes.* Retrieved from http://www.cityofboston.gov/bikes/default.asp

Conway, A., Fatisson, P. E., Eickemeyer, P., Cheng, J., & Peters, D. (2011). Urban micro-consolidation and last mile goods delivery by freight-tricycle in Manhattan: Opportunities and challenges. In *Conference proceedings, Transportation Research Board 91st Annual Meeting 2012*.

Daily Free Press Admin (2013, Feb. 11). Boston ranked fifth most traffic-prone city in nation.

The Daily Free Press. Retrieved from http://dailyfreepress.com/2013/02/11/boston-ranked-fifth-most-traffic-prone-city-in-nation/

Demidov, S., & Bonnet, J. (2009). *Traffic related air pollution and internal combustion engines*. New York: Nova Science.

de Zeeuw, H., Guendel, S., & Waibel, H. (1999). *The Integration of Agriculture in Urban Policies*. Retrieved from http://www.ruad.org/index.php?q=node/62

Enete, A. A., & Achike, A. I. (2008). Urban Agriculture and Urban Food Insecurity/Poverty in Nigeria: The Case of Ohafia, South-East Nigeria, *Outlook on Agriculture, Vol. 37, No. 2*, pp.131-134.

Environmental Protection Agency. (2015, September 9). *Heat Island Effect*. Retrieved from http://www.epa.gov/heatisld/

Food and Drug Administration (1998, October 26). *Guidance for Industry: Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables*. Retrieved from http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ucm064574.htm#viii

Food and Drug Administration (2008, February). *Guidance for Industry: Guide to Minimize Microbial Food Safety Hazards of Fresh-cut Fruits and Vegetables*. Retrieved from http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ucm064458.htm#ch9

General Court of The Commonwealth of Massachusetts. (n.d.). Bicycles; operation and equipment; regulations; federal product safety standards, effect; races; violations; penalties. In *General Laws* (Part I, Title XIV, Chapter 85, Section 11B). Retrieved from https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter85/Section11B

Gössling, S. (2013). Urban transport transitions: Copenhagen, city of cyclists. *Journal of Transport Geography*, *33*, 196-206.

Graefe, S., Schlect, E., &. Buerkert, A. (2008). Opportunities and Challenges of Urban and Peri-Urban Agriculture in Niamey, Niger, *Outlook on Agriculture, Vol. 37, No. 1*, pp. 47-56.

Gruber, J., Ehrler, V., & Lenz, B. (2013). Technical potential and user requirements for the implementation of electric cargo bikes in courier logistics services. In *13th World Conference on Transport Research*.

Gruber, J., Kihm, A., & Lenz, B. (2014). A new vehicle for urban freight? An ex-ante evaluation of electric cargo bikes in courier services. *Research in Transportation Business & Management*, *11*, 53-62.

Hornick, S. B. (1992). Factors affecting the nutritional quality of crops. *American Journal of Alternative Agriculture, 7(1-2)*, 63-68.

Jarrett, Alex. "Pedal People Interview." Telephone interview. 3 Dec. 2015.

Kretschmer, F., & Kollenberg, M. (2011, July 22). Can Urban Agriculture Feed a Hungry World? *SPIEGEL ONLINE International News*.

Leistner, L. (2000). Basic aspects of food preservation by hurdle technology. *International Journal of Food Microbiology, 55(1)*, 181-186.

Lenz, B., & Riehle, E. (2013). Bikes for urban freight? Experience in Europe. *Transportation Research Record: Journal of the Transportation Research Board*, (2379), 39-45.

MassBike. (n.d.). *Bike Law Update*. Retrieved from http://massbike.org/resourcesnew/bike-law/bike-law-update/

Metro Pedal Power. (n.d.). *Metro Pedal Power*. Retrieved from http://metropedalpower.com/

Nugent, R. (2002). *The Impact of Urban Agriculture on the Household and Local Economies*. Retrieved from http://www.ruaf.org.index.php?q=node/57

"Open-source." Dictionary.com. Dictionary.com, n.d. Web. 10 Dec. 2015. <http://dictionary.reference.com/browse/open-source>.

Pedal People. (n.d.). *pedal people*. Retrieved from http://www.pedalpeople.coop/

Perez, L., Declercq, C., Iniguez, C., Aguilera, I., Badaloni, C., Ballester, F., . . . Kunzli, N. (2013). Chronic burden of near-roadway traffic pollution in 10 European cities (APHEKOM network). *European Respiratory Journal, 42*(3), 594-605. doi:10.1183/09031936.00031112

Sapers, G. M., Garzarella, L., & Pilizota, V. (1990). Application of browning inhibitors to cut apple and potato by vacuum and pressure infiltration. *Journal of Food Science, 55(4),* 1049-1053.

Schrank, D., Eisele, B., Lomax, T., & Bak, J. (2015, August). 2015 Urban Mobility Scorecard. Retrieved April 30, 2016, from mobility-scorecard-2015.pdf

Social Security. (2013.). *National Average Wage Index*. Retrieved from https://www.socialsecurity.gov/oact/cola/AWI.html

Stewart, H., Hyman, J., Buzby, J., Frazao, E., & Carlson, A. (2011, February 1). *How much do Fruits and Vegetables Cost?* Retrieved from http://www.ers.usda.gov/media/133287/eib71.pdf

Stoddard, J. (2016, August 10). *Loaded Trailer* (Photograph).

Vagneron, I. (2007). Economic Appraisal of Profitability and Sustainability of Peri-Urban Agriculture in Bangkok, *Ecological Economics*, *Vol. 61*, pp. 516-529.

van Averbeke, W., 2007. Urban Farming in the Informal Settlements of Atteridgeville, Pretoria, South Africa, *Water SA*, *Vol. 33*, *No. 3*, pp. 337-342.

Ward, Kevin (Ed.). (2014). *Researching the City*. London: Sage Publications.

Watada, A. E., & Qi, L. (1999). Quality of fresh-cut produce. *Postharvest Biology and Technology*, *15(3)*, 201-205.