Design for Low-Power High-Density Helmet
Dispensing and Collection Systems for Urban Environments
by
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and
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Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degrees of Bachelor of Science in Mechanical Engineering
at the MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 2012 [June 2015]

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Abstract

In this thesis, we designed and implemented a machine to dispense and collect helmets for bikeshare programs such as Boston’s Hubway. Design of the machine was guided under several constraints including size and power for tight integration with existing bikeshare stations. The machine itself is divided into subsystems, including dispensing, reloading, and return components as well as software and electronics, power, and industrial design choices. The first prototype of the machine was implemented in December 2011, with refinement of the mechanisms occurring between January and May 2012.

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Chapter 1

Introduction

1.1 Bikesharing

Bikesharing programs are short term urban bicycle rental schemes that enable bicycles to be picked up at a self-service station and returned to any other station. People use bicycles on an “as-needed” basis and the system eliminates the cost and responsibility of ownership while promoting cycle use within urban environments, helping people realize the advantages cycling offers against automobiles and public transit systems.

1.1.1 Growth

Although it has been present in one form or another, recent advances in mobile networking technology have enabled growth of bikeshare programs around the world by making the transaction process simpler for users, and the tracking of bikes easier for the bikeshare operator. As of 2010, there are approximately 160 bikesharing programs around the world, with a 74% increase year over year [16]. Program growth has continued to accelerate in North America, with 15 US cities already hosting their own bikeshare programs and more planning to launch programs in the coming year.

Within existing programs, the number of stations is expected to increase annually as well, with NY adding 600 stations in 2012[11], and Boston adding 30 stations as well[14]. This growth is due to popularity and success of bikeshare programs among
users in these cities, who view the programs in a largely positive light.

1.1.2 Importance

Bikesharing programs serve an increasingly important role for urban transportation by providing the "last mile form of mobility in the public transportation hierarchy, as can be seen in Figure 1-1. These programs also help to decrease emissions, increase public health, and improve the public image of a city while using little infrastructure and requiring a low investment compared to other forms of public transportation[17, p.18].

Figure 1-1: Transportation Modes in Urban Environments as a function of Trip Distance[17]

With city population densities projected to continue to increase, its clear that bikeshare programs have the potential to increasingly shape urban transportation in many positive ways.[12]

1.1.3 Challenges for helmet use in bikeshares

According to a report from the United Nations on bikeshare programs, the issue of helmet use was identified as one of 5 challenges faced by bikesharing programs[13, p.19], and in particular:
"The self-serve nature of bicycle-sharing programmes limits their ability to provide helmets...for many people this poses a safety risk"[13].

The results of this report indicate that the challenge of providing an adequate supply of helmets is a worthwhile undertaking in the context of promoting bikeshare programs.

To quantify this impact, a recent study conducted by Beth-Israel indicates that approximately 80% of bikeshare users in Washington D.C. and Boston, MA do not use a helmet while cycling, less than half the rate of helmet use compared to cyclists who used their own bikes.[10] Additionally, men were at a higher risk of riding unhelmeted when compared with women, as were weekend riders compared to weekday riders.

The study concludes that the “Use of bicycle helmets by users of public bikeshare programs is low. As these programs become more popular and prevalent, efforts to increase helmet use among users should increase.”[10] This conclusion corroborates the primary motivation of designing a machine to increase the number of helmets dispensed in bikeshare programs, and lends credibility to the belief that a machine such as ours that makes helmets readily available and convenient at the same location as the bikeshare station should increase helmet use among users.

1.2 Thesis Overview

This thesis articulates the design requirements and process for a bike helmet dispensing machine, and describes a prototype machine built to these specifications. Chapter 1 is an introduction to the bike sharing market and an overview of the prototype. Chapter 2 focuses on the dispensing mechanism development and Chapter 3 and 4 detail the helmet reloading and return mechanisms. Chapter 5 includes the design of the electronics hardware and software operated in the machine. Chapter 6 outlines the power requirement and feasibility calculations for the prototype. Chapter 7 is an exploration of the industrial design concepts and requirements. Chapter 8 is a conclusion of the findings of this thesis and some of the potential for future work.
1.3 Machine Overview

1.3.1 Key Design Considerations

Consumer Behavior

In order to design a machine capable of dispensing and collecting helmets in bikeshare systems, the way in which users interact with the kiosks is important. The bikeshare kiosks are largely autonomous, mobile and self-serving meaning that a machine designed to incorporate helmets into the market needs to be similarly autonomous, mobile and self-serving. Many users of the bikeshare programs rent a bike spontaneously instead of purchasing a monthly membership. The spontaneous nature of the users means that they are unlikely to have a helmet at the time they decide to rent a bicycle, and that helmet acquisition should be conveniently located with respect to the bikeshare kiosks. Hubway[5] currently displays a map along the stations that shows the nearest place to acquire a helmet, but these areas are far from the stations, and too sparse in the city, and as a result are ineffective in supplying helmets to bikeshare users. According to usage data from Hubway, a method for supplying helmets to bikeshare users would need to be able to supply at least 12 helmets a day/week in order to match current usage rates. Similarly, helmets that are dispensed should be able to be sized appropriately for users, and should be ready to use without removing packaging in order to minimize waste and maximize convenience for users.

Size

One of primary advantages of bikeshare programs in urban spaces is the vehicle density they can achieve. In order to successfully integrate into these spaces with minimum impact to existing station designs, our machine needs to be at most 24” wide by 48” long. Fitting these dimensions allows our machine to occupy the space currently used for maps and advertisements, while still preserving the ability to display both maps and advertisements.
Power

In order to be rapidly and maximally deployable and environmentally friendly, bike-share programs are solar powered and wireless, two constraints that would need to be matched in designing our machine. The use of solar power in urban environments, where solar panels can suffer lower performance from dust and dirt accumulation, decreased sun exposure in the shadows of buildings, and the usage of the machine long into the night means that the power budget for the machine needs to be minimal.

User Experience

A key concept throughout the development of this machine for us was that of a fun, unique user experience. We don't believe that vending machines have to be mechanical distributors that unemotionally spit out the consumers product of choice. Instead we want to attempt to transfer the customer-salesman interaction from stores into the world of vending machines. To represent this goal, we attempt to make each mechanism in the machine user actuated, or at the least require more of an interaction than simply pushing a button, in an attempt to make the machine more memorable. User actuation in turn will help us meet our energy budget of being a stand-alone machine, as it decreases the amount of electrical components necessary.
Chapter 2

Dispensing

2.1 Design Requirements

A good starting point to summarize the design requirements for our dispensing system is to consider the main aspects of operation that will allow us to maximize efficiency of the machine. One of the two main factors is maximizing helmet storage capacity in the dispensing side, while minimizing the size and power requirement of the machine.

The larger the capacity of the machine is, the longer it will allow the machine to go without maintenance, and as a result will decrease our operating costs. Initially Hubway requested a capacity of 12 helmets per machine based on their statistic that there was an average of 12 rides per station per day in the Summer of 2011. However, the frequency of use of a station has great variance among the city with the most used stations averaging 70 trips per day downtown. As such, considering our desire to maintain a footprint that does not exceed that of a traditional vending machine, and limiting our height to around 7ft, we determined that our capacity goal would be to fit 36 helmets in one machine.
2.2 Earlier Versions

2.2.1 Carousel

The dispensing mechanism underwent several rapid iterations in design in order to best fulfill the design requirements. The first prototype was essentially a large partitioned carousel, which rotated the helmets through an area that could be accessed by an automated outer door sliding open and closed, as shown in Figure 2-1.

Figure 2-1: First Prototype of Carousel-type Helmet Dispensing Mechanism

Once a helmet was removed, the door was locked and the carousel advanced the next helmet into the area. The design had several such carousels stacked on top of each other. This iteration posed several challenges to the design requirements. The power requirements for the motorized carousel were considered to be too high to be feasible, and the utilization of space and the packing density of helmets were both too far from our design requirements.

This design also reflected the design of the inadequate machine in Melbourne. As
a group of Engineers dedicated to creating an innovative solution to the problem of helmet vending, mimicking a failed machine was not the correct approach.

2.2.2 "Pez" Dispenser

The next iteration of the mechanism developed the concept of stacking the helmets vertically in order to improve the space and density specifications. By stacking the helmets on top of each other, they were slightly nested within one another. This decreased the volume consumption of a helmet by around 20% compared to stacking the side by side. This was also the first iteration that moved to a manually operated dispensing mechanism in order to meet the power requirements, and our goal for a more interactive experience.

![Figure 2-2: The "Pez" Dispensing Mechanism](image)

This design held helmets in a vertical stack on top of a spring-loaded base, as shown in Figure 2-2. As users opened the lid of the machine, helmets would be individually separated from the stack and advanced toward the users to take. This prototype was abandoned in its design phase as it became clear that the mechanical complexity of the dispensing mechanism caused significant challenges in implementation and questions of reliability.
2.2.3 The Tube

In the next iteration, the concept of dispensing helmets from the bottom of the stack instead of the top was developed. By dispensing from the bottom of the stack, the design could be significantly simplified by removing the complicated lifting mechanism from the base and allowing gravity to do most of the work. The dispensing process was split into four stages, as shown in Figure 2-3.

Figure 2-3: The 4-stage Dispensing Process

This process was implemented into a design shown in Figure 2-4, where the helmets are held in place using a flexible throat, actuated by a solenoid. Beneath the throat assembly, there is a trap door that is locked/unlocked by a solenoid. The distance of the trapdoor beneath the throat is designed so that while the rest of the helmet
stack is held in place by the throat, the bottom-most helmet is not, and when the trapdoor is unlocked, it swings open, and the helmet falls off the bottom of the stack and into the dispensing area. When the trap door closes, the throat opens and the stack drops down onto the trap door. Once the throat closes, the remainder of the stack is held in place and the mechanism is returned to its initial state.

Figure 2-4: 4-stage throat dispensing mechanism model

This design was carried through to the prototyping stage, but quickly it became clear it was infeasible because of a lack of components that could address the power and material properties needed for it to function. The solenoid needed to actuate the throat mechanism needed a throw length and force beyond the specifications of readily available for our power requirements, and a linear actuator proved to be too costly for both our fiscal and power budgets, as well as being too slow. In addition, there were questions on the ability of the flexible throat being able to constrain a tall stack of helmets through the friction generated by its spring-like properties alone.

2.2.4 The Claw

The design was once again iterated by re-examining the 4-stage process outlined in Figure 2-3 and simplifying it to two stages by combining the “constraining helmet stack” and “opening dispensing mechanism” states, as well as the closing dispensing mechanism and releasing helmet stack states. This simplified process led us to explore designs in which constraining the helmet stack was coupled with opening the dispensing mechanism under the assumption that it would simplify our design.
The first implementation of this new process was a mechanism affectionately dubbed “The Claw”, as shown in Figure 2-5. “The Claw” operated by using a linear motion of pulling a handle to simultaneously withdraw a platform from beneath the helmet stack and pull on a linkage attached to a 4-bar claw mechanism shown in Figure 2-6. When the platform was fully removed from under the stack, the compressive force from the claw would hold the helmet stack up. The platform was allowed to travel beyond the point where the claw held the helmet stack by attaching the actuating linkage to a spring. This way, the farther the handle was pulled, the tighter the claw would grasp the helmet stack.

With the claw, we realized that the helmets could be held in a rigid stack by using a rod that ran through the central ventilation holes of the helmet. This allowed us to decrease the constraints around the helmets in the form of large guide plates, while
maintaining the nesting property of the helmets to maximize the packing efficiency. This design was carried through to implementation, but failed because of considerable complications. The number of moving parts required careful coordination in assembly to ensure the mechanism would perform reliably, and the entire mechanism was large in geometry, especially vertically. Linking the entire mechanism increased the complexity, and in addition the force required from the user to actuate the system was too high, and is this became apparent, the claw mechanism was abandoned to try and find a simpler solution.

2.2.5 Keyhole Plates

In examining the way the claw mechanism worked, it became clear that the two most important principles in its operation were that the bottom helmet was only free to fall after a point where the upper helmets constrained, and that the upper helmets should only be free once they were constrained by the dispensing plate was in place to hold them. This led to the final design iteration utilizing two parallel plates with offset keyholes for both the constraining plate and the dispensing plate in one unified mechanism. The concept was proven in Figure 2-8 and refined into the mechanism used in the alpha prototype shown in Figure 2-7.

The mechanism dimensions were designed so that the keyholes were large enough for clearance with a falling helmet, modeled as an ellipse. Their centers were offset
Figure 2-8: Proof of concept for parallel plate-type dispensing mechanism

by the throw length of a handle attached to the mechanism so that the helmet would only fall through the plates at either the fully open or fully closed positions.

The design parameters of the plates are illustrated in Figure 2-9 as a function of helmet dimensions and the throw length of the actuating handle.

Figure 2-9: Dispensing Plate Design Parameters

This design was implemented in the alpha prototype as a proof-of-concept for low power helmet dispensing from the bottom of a vertical stack.
Both the claw and the alpha prototype reflected the user actuation design requirement well. However, after user surveys we have realized that there is a necessity for stocking various sizes of helmets. The control of which helmet size is dispensed (assuming they are separated by size in stacks) is difficult by solely mechanical means, and would require a somewhat more advanced, electronically controlled gearbox or switch to link to the user control mechanism.

As a result, the current dispensing mechanism design is electronically actuated, however this approach is taken mainly to provide for a working prototype in a faster timeframe. Future design will attempt to incorporate user actuation on the dispensing side again.

In addition the physical size of the keyhole mechanism makes fitting multiple stacks of helmets into our constrained space very difficult, and moved us to design a new solution, which had the main design criteria of occupying as little footprint as possible. To approach this in a novel fashion, we decided to utilize an already existing part of the machine, the rod holding the helmets in a stack. If the dispensing could be performed using solely the rod, this would allow us to decrease the footprint of the dispensing mechanism significantly.

2.3 Current version

2.3.1 Mechanism Overview

The current iteration of the mechanism is the first machine developed to utilize the ventilation holes of the helmets to their full potential. The current Bell helmets that we use have a central ventilation hole that is elliptical in shape, and we modeled our dispensing system to take advantage of their unique geometry.

Instead of only using the rod to hold the helmets in a neat stack, the rod will also be used to singulate the helmets from the machine. On the bottom of the rod we installed two physical stops that mimic the shape of the ventilation hole. The two stops are vertically offset from each other by 2.5" and also rotated 90 degrees in the
horizontal plane with respect to each other. By rotating the shaft back and forth by 90 degrees, and maintaining the helmets in place rotationally, the mechanism is able to separate one helmet from the stack.

An RFID reader is placed in between the two stops. By limiting the range of the reader to a specified distance, it will read only the tag of the helmet that falls between the two stops in the transitional period. This will allow the machine to record which helmet is being dispensed for each transaction.

The main benefit from this iteration is the decrease in space required around the helmet for the dispensing mechanism, as was apparent with former versions. This will allow multiple stacks of helmets to be stored in the same ground footprint. Ideally we would be able to install three 12-helmet stacks in one machine for a vending capacity of 36 helmets.

In our mock-up model of the mechanism the physical stops will be round aluminum stock that is long enough to prevent the helmet from passing it sideways, but short
enough to fit through the long dimension of the elliptical ventilation hole. By using a thin long protrusion instead of stop the fully follows the shape of the ventilation hole, it allows for some compliance in the radial direction to account for such factors as misalignment of the pole, rotation of the helmet stack, and lack of accuracy of the drive mechanism.

The shaft will be rotated with the use of a 180 degree rotation servomotor, which is an ideal controller due to its accurate position feedback system. The mechanism will be geared so that the range of motion of the servo will be sufficient to allow necessary rotation of the shaft, while maintaining enough torque.
2.3.2 High-cycle failure modes

The current design motion control has a fixed 90 degree angle of rotation of the shaft. Therefore the main mode of failure will occur if the stack of helmets changes angular orientation within the machine, or the stack is not uniform in direction. Either of these conditions could arise from either vandalism i.e. significant impact to the machine, or the stack rotating through contact with the moving dispensing mechanism. In addition to the physical stop being in contact with the bottom helmet, there are also contact points between the outside of the rod and the ventilation holes of the helmets. Interaction between these surfaces could cause the stack to shift slightly.

We have considered two different solutions to this problem: either use a second smaller, guide rod the threads through a side ventilation hole through the stack of helmets or introduce a funneling guide plate onto the bottom of the dispensing mechanism that would hold the 2-3 bottom helmets fixed in the angular direction.

Of the two possibilities the funneling guide plate seems to be more adaptable to a variety of helmets, while the secondary guide rod might not be applicable for all types of helmets due to a lack of a second, appropriate ventilation hole. However, one concern for the guide plate is the constraint it introduces on the reloading system and possible interference with other helmet stacks. This is an issue that will require more extensive testing than we have had time to conduct to determine the amount of helmet motion that will occur as a result of the dispensing rod, and the negating effect of the above proposed solutions.

2.3.3 Possible Refinements

The current dispensing mechanism is limited to helmets that have an elliptical or oval center vent hole. However, a large number of different helmet styles (including all of Berns helmets, which is a large Boston based helmet manufacturer and an ideal future business partner) have a circular central hole. In order to facilitate our current design choice of embedding a dispensing mechanism in the central rod, the physical stops have to be dynamic with respect to the rod, instead of static, as they are currently.
Conceptual models to solve this issue have been brainstormed, of which one currently rises as the most conceivable in terms of maintaining costs low and ease of manufacturing. It consists of two concentric rods, of which the outer rod would be fixed in both the longitudinal and angular directions. The inner rod would have two sets of spring-loaded clips attached on a hinge. When the inner rod is rotated, it allows for one of the sets of clips to extend through openings in the outer rod, and act as a stop for the helmet stack. An initial drawing of a possible solution can be seen below.

Ideally, the spring would be unnecessary and it would be possible to use a strip of metal that would bend elastically and perform the same function.

A future design problem to tackle is re-introducing user actuated control into the system. To avoid the use of a complex gearbox or clutch system a possible approach to user actuating a number of stacks of helmets could be to offer multiple handles on the user interface of the machine, which are unique to each stack. This way the user could choose the size helmet they wish by actuating the corresponding handle.
Chapter 3

Reloading

3.1 Design Requirements

The main requirements for the reloading mechanism of the machines can be expressed by two different factors: it needs a simple mechanical interface, and it has to be as fast as possible to use. As the dispensing mechanism is dependent on holding the helmets on a vertical rod, we grouped all possible reloading solutions into three different groups defined by the basic geometry of how it would be reloaded: bottom feeding helmets on to the pole while it is still attached to the machine, removing the pole and top feeding the helmets on to the pole, or replacing the empty pole with an already stocked pole. Our current dispensing mechanism is actuated from the top of the pole through a gear system. Removing the pole completely would require an easy-locking mechanism to be designed into the drive system, and for the pole to be correctly oriented each time before reattachment. If the pole is not oriented, there is a distinct possibility of the dispensing mechanism failing during use.

The next generation design of the dispensing mechanism, which will be functional for circular ventilation holes as well, will not have a constraint on its angular position. Depending on the eventual actuation mechanism, the issue of disengaging the rod may not be an issue.

In addition, the rod replacement strategy requires a large stock of dispensing rods to allow for multiple machines to be reloaded in day and not be limited by the
amount of rods. The additional rods would constitute an extra capital cost for the process to be possible. Further economic analysis into the reloading time and cost of maintenance against rod cost would have to occur for a final decision to be made. Based on the analysis of our current requirements, and current design of the dispensing mechanism, we have chosen for our reloading mechanism to be bottom-feeding onto a rod, which is fixed to the machine.

3.2 Current version

3.2.1 Mechanism Overview

The current reloading mechanism consists of the top plate, which the rod and dispensing drive system is attached, sliding out of the machine completely on linear sliders. This allows for easy access to the rod for a maintenance worker, and no points of interference in the area near the bottom of the rod to slide helmets onto the rod.

The rod has two physical stops near the bottom, but the upper stop is hinged in one direction, which allows helmets to be slid up. As the helmet is slid up, the sides of the ventilation hole come into contact with the upper stop, which can hinge upward into the pole, making the width of the stop the same width as the rod. With this added feature, the maintenance worker reloading the machine does not have to rotate the helmet multiple times as he slides it on the pole, and must only align the central hole with the bottom stop. The bottom stop is kept stiff, however, for the reason to eliminate the possibility of user interference when the machine is in operation, by reaching up the dispensing opening and manipulating the lower stop.

3.2.2 Failure modes

One of the main modes of failure for the reloading mechanism is possible inaccuracy when the rod is slid back into position. If the rod is not returned to the appropriate position to align with the dispensing opening of the machine, it may result in failure to dispense any helmets. This problem can be avoided by using sliders that feature
an easy-stop and utilize that feature to determine the accurate positioning of the rod. This feature will make realigning the rod a very intuitive procedure for maintenance workers.

3.2.3 Possible Refinements

Depending on the dimensions and geometry of the layout of possibly multiple helmet stacks in the dispensing side of the machine in future iterations, the method by which the rod is moved outside the machine may have to be refined. Instead of using linear sliders, it may be more efficient to hinge the rod out of the machine around a pivot point. This could allow for a higher packing efficiency of helmets in the horizontal plane and keep the overall size of the machine down. This could also decrease costs by utilizing a bearing on a pivot point instead of linear sliders, which can be more complex, and expensive. In the case of pivoting rods, it is essential to have a feedback mechanism to determine the correct position of the rod with the machine, as mentioned in section 3.2.2 "Failure Modes".
Chapter 4

Return

4.1 Design Requirements

At a basic level return mechanisms in vending machines (e.g. RedBox[7]) have much more complex design requirements than most return receptacles, such as trash cans or recycling bins, we see in our environment. The main requirement as such is that the return mechanism should only be able to accept the product that it is designed for, and nothing else. For companies such as RedBox this is not that challenging of a demand as they have a product that is small, and has a geometrically unique shape. However, due to the size of a helmet the sheer size of the opening for return requirement raises an issue of different type of litter being thrown in, e.g. rocks, bricks and bags of trash, and possible vandalism. The design should be focused on creating as few opportunities as possible for vandals to introduce foreign content into the machine. Not only will this help maintain sanitary conditions inside the machine, but it will decrease costs of cleaning the helmets and create a healthier work environment for the staff who maintain the machines.

In addition, we also require that we are able to detect the presence of a HelmetHub helmet via the use of RFID both before unlocking the return mechanism in order to limit the accessibility of the return space to those who have a helmet on them, and inside the machine before the transaction is processed to confirm that a helmet has in fact been returned. As of this moment we see this as the most effective method to
prevent transaction fraud against us, and will decrease the amount of manual work on our back-end in the form of manually checking and registering which helmets have been returned.

Finally, as with the rest of the machine, we want the user experience to be both fun and interactive. The more unique the method the user interacts the machine, while maintaining a level of simplicity and ease of understanding for the user, the better the experience for the user will be, and the rate of retention of customers will be higher.

Based on this approach, we developed the following criteria for design

1. User actuated, interactive mechanism

2. The return door will not open unless an RFID tagged helmet is presented

3. When the mechanism is open
   (a) it will only accept objects shaped like a helmet
   (b) Other objects should either drop through the mechanism, or not fit into it.

4. When the mechanism is retracted into the machine, it must detect the helmet again before completing the transaction

4.2 Earlier Versions

4.2.1 Two-door with trapdoor

The initial design for the return system was an independent return station, that was half the height of the dispensing machine. It introduced a modular approach that would allow us to allocate a unique ratio of dispensing-to-return capacity to each station.

The return mechanism involved a two-stage process, which consisted of an "air-lock" type system, where the helmet was first inserted inside the machine through a
front door, and once the front door was closed was dropped in to the return box via a trapdoor. This approach, however did not meet our 3rd design requirement of keeping trash out of the machine as it was possible to place trash into the machine through the front door. Even though the trash would not be dropped into the container, it remained inside of the machine and would be an obstruction and nuisance for the following customer, who would have to remove it in order to place their helmet in the machine. As such, this warranted a complete redesign of the return side of the machine.

4.2.2 L-door (trashcan)

The second iteration of the return mechanism involved a simple L-shaped door that is used in many of the solar-powered garbage compactors visible in public areas, including MIT's campus. This design was a quick-solution for our alpha prototype machine to be presented at the end of 2.009[1] as a result of a quickly approaching deadline. While the design was simplistic, and elegant, it still did not meet our 3rd requirement to make placing trash in the machine a manually challenging and near impossible task as one could still place trash in the door and drop it in the machine. In addition it did not meet our 4th design requirement as the helmet would simply drop into the return box when the door was closed.

As a concept, our team still considers this the most cost-effective, user-friendly and ideal solution in an ideal world for returning a large object such as a helmet, however our concern for potential vandalism and helmets stewing in rubbish during the hot summer days makes this design solution an unacceptable one to implement in the market-ready version of the machine.

4.2.3 Sliding Drawer

The third iteration of the return mechanism consisted of a cabinet-like drawer that slid out of the machine. The drawer slid on two concentric pairs of poles, and had a circular outer frame. The helmet was designed to be placed curved side down on to
the two poles, which were at such a distance that most garbage would fall through them. Once retracted back inside the machine, the handle could be rotated to force the helmet to fall into the machine. In the back of the mechanism, which was attached to middle wall of the machine, was a key mechanism that prevented the drawer from rotating when it was not fully retracted.

Figure 4-1: The First Version of a Sliding Mechanism, Drawing

There were a number of problems with this mechanism, that eventually led the team to do a complete redesign. The mechanism retracted too far outside the machine, ca. 12”, which would not only be uncomfortable for the user, but would allow a significant amount of leverage for any possible vandals. The long throw also allowed for a considerable amount of space for trash to be thrown directly into the machine while the mechanism was only half-retracted. Finally, it became difficult to determine a position for the RFID reader to be placed appropriately that did not involve placing a horizontal beam between the two rods.
4.3 Current version

4.3.1 Mechanism Overview

The most recent iteration plays off of the last return iteration by sliding out the return space from the machine. The return mechanism consists of a return box, with the top side open and shaped like a helmet, and the bottom side being nearly completely open, with actuated stops near the bottom that extrude into the opening only slightly. Geometrically the mechanism is designed to accept helmets with their longest dimension in the vertical axis, and the spherically curved top of the helmet facing the machine. By inserting helmets with this geometry, it minimizes the distance the mechanism extrudes from the outside face of the machine, and thus minimizes the leverage a possible vandal may have to attempt to break the mechanism.

There are two tabs on each sidewall designed to catch the helmet from the bottom. By only protruding 1/2" on each side this creates the largest possible opening in the middle of the machine to allow any non-wanted materials to simply drop straight through the return box and onto the ground. The tabs are actuated by twisting the front handle 90 degrees in either direction and are driven through a solid bar linkage.

By twisting the front handle the user also actuates two tabs on the bottom of the
machine that move vertically down. The purpose of these is to act as a mechanical stop for actuating the handle when the mechanism is outside of the machine, through interaction with the frame, and prevent premature helmet release inside the machine due to interaction with a locking mechanism. An RFID-20 RFID reader will be placed in the fitted curved part at the appropriate height to detect the RFID chip in the helmet independent of which direction the helmet is entered at. The box is attached to the middle plate of the machine by two linear sliders, which are each rated to 300 lbs at full extension.

4.3.2 Possible Refinements

The main refinement we see with the mechanism right now is the stopping tabs on the bottom have a small range of motion, ca. 1/2”. This creates a requirement for any tolerance between the frame, the lock and the return box to be quite tight to allow minimal free “backlash” rotation of the handle when locked.
In addition, the return box is quite large, which is due to the size of the helmet, and has a lot of area for possible vandalism or drawing.

Also, the shape of the box is cubical at the moment, and may not be the best looking solution. Once the mechanical aspect of this solution is proven, further development should go into making the mechanism appear sleeker and less bulky.
Chapter 5

Software and Electronics

5.1 Design Requirements

Once put into the field, the HelmetHub units would be required to record and send rental and return transactions and transfer credit card information from the reader to a centralized server. As one of the main physical design requirements of the machine was for it to be freestanding and free of any physical connection to the ground this communication will have to be done wirelessly, and considering the location of the machines and their mobility, this interaction would occur over mobile networks instead of wi-fi. We will be sending credit card information over these wireless networks, and therefore a major requirement is that we have a secure connection to our central server. The most straightforward option is to create a VPN network, however, more research into this subject has to done.

In addition to wireless communication, the software side of the infrastructure requires a database to track the movement of helmets and inventory of each machine. Also to ease the processing of the database information we have to build a web app that will compile necessary and relevant information on helmet movement patterns and the status of each helmet and machine. This web app needs to built on a platform that allows easy mobile interfacing, to keep maintenance workers who are moving around the city to be constantly updated on the stock of machines and respond quickly to shortages at specific stations.
To summarize the design requirements in a list, they are as follows:

1. Secure wireless communication over mobile networks
2. Database system for automated helmet tracking
3. Web app to ease user interaction with the database

5.2 Web Application

The design space for a back-end web application has a lot of room to implement advanced features, but would consist of the following basic necessities.

First

A list of machines with their location and their current stock of helmets in the rental and return compartments. This would allow our maintenance workers to have an idea of which machines are next in turn for restocking and would allow consumers to check the locations of the closest machine to them and which stations have a machine.

Second

A full list of transaction history for each helmet. This will allow us to determine the amount of cycles a helmet has been through, and how long it has been out on the market. This data is also very useful in tracking the most frequent routes and direction for helmet movement within the city.

The initial version of the web application was built using the Django[4] open source web application framework. Django is designed to allow for quick production of web applications in Python utilizing a relational database management system (MySQL in our case), by allowing developers to focus on coding the framework of operation and producing the relevant HTML code automatically from users specifications. The main benefits in our development situation were its small learning curve and turnover time to a functional application.
5.2.1 Current Web Application Structure

Figures 5-1 through 5-4 are collected screenshots of the bare necessities for a back-end application as presented earlier, with explanation of each pages functional purpose.

Figure 5-1: The front page of the web application

Machines

- 1 50 Massachusetts Ave Cambridge 02139
- 2 32 Vassar Street Cambridge 02139

The front page of the application currently presents two dummy machines that I entered, which will be located at the two upcoming MIT Hubway stations in front of Stata and Bexley buildings. Currently it only shows a list of the machines, but ideally it would be developed to have an interactive map, perhaps integrated with Google Maps that would allow for a faster look-up of machines in a certain location. By clicking on the hyperlink of the machine id number, it will take you to a page that shows more detailed inventory information for that machine.

Figure 5-2: Inventory page for a machine

Machine 1

50 Massachusetts Ave
Cambridge, 02139

- Helmets for Rent : 0
- Helmets Returned : 1

The machine inventory page shows the number of helmets in both the rent and return compartments of the machine. Once the capacity of a machine is increased to 36 helmets. It would be beneficial to separate the rent and return capacities to reflect the availability of different sizes of helmets as well. In addition a nice expanded feature would be to see the average number of rentals per day, and the respective statistics
of the 2-3 closest machines to this one. This would allow insight into which machines are most used in the area, and could be useful in determining new installations or reallocation of machines.

Figure 5-3: Return stock of machine

**Machine 1**

**Helmets Returned**

- **Bell 3**

The following page is quite straightforward, and simply recounts the specific helmets in stock in the machine.

By clicking on a specific helmet you are taken to the helmet history page, which shows all of the past transactions, both user and maintenance. As you can see this particular list is stocked full of transactions as a result of testing the underlying code. More information could be added to this page in the form of the time that the helmet has spent in rotation, and the amount of rental cycles it has been through.

In its current state the back-end software for monitoring machine use, inventory and helmet motion within the machines is inadequate, but represents a proof of concept for a very basic level of service that is required. In beta testing I see this structure sufficing due mainly to the small amount of machines and helmets in use, but with expansion significant effort should be made not only to make the system look nicer, but make it faster to navigate and be user-friendly for a maintenance staff that will not be as technologically proficient as the developer. Integration with already existing technology such as Google Maps would allow for the development of visual aids that could show rental frequency and helmet movement in ways that could assist in quick adjustments and consumer demand.
5.3 Database

The database structure has been made to be as simple as possible. This is a result of both the initial stages of set-up for a back-end infrastructure and the lack of large amounts of experience working with database systems.

The relational database management system of choice for this project was MySQL[6]. MySQL is the most commonly used software for this purpose and is both easily integrated with the hardware used in development and the Django software used in the web application.
5.3.1 Database Structure

Figure 5-5: Relational database model

Overview

The database consists of five tables, which within them are able to contain enough information to track all movements of each helmet, all transactions that have occurred, and the inventory in each machine.

The annotations on the graph are as follows:

"A" Auto-increment, each new entry in the table gets a unique id number

"P" Primary Key, value in the table that uniquely identifies a table

"F" Foreign Key, value that interconnects tables amongst each other

"i" indexed value
"N" Not Null, an entry in this column of the table is required, a null entry is only allowed in the sum total section for maintenance transactions and the helmet and sale location entries for maintenance purposes.

Customer

The customer table as of now is very simplistic and only contains the customer number and the credit card that they used. In the initial beta testing stages we do not plan to have users register or buy a membership, and we simply consider each customer as unique. In the future this table would expand to include customer name and address and would allow us to track purchase history of each customer and habilitate registration of customers.

Sale

The sale table is the record of information for each sale, which can include several helmets, but only one customer. It records the date of sale, sum total of the sale and type of transaction. There are 5 different types of transactions that will be used by our web application, two of which are user transactions and three of which are maintenance transactions. The different transaction types are

- Rent
- Return
- Remove for Maintenance*
- Finished Maintenance* (i.e. has been cleaned and inspected)
- Restock*

As each helmet passes through each stage of the cycle, the transaction log allows us to determine what stage it is currently in by referring to its last form of transaction.

*Maintenance transaction
Transaction

The “transaction” table is simply an intermediate table between the “helmet” and the “sales” table as they have a many-to-many relationship (one sale can have several helmets, and one helmet can be a part of several sales). Every helmet-sale relationship is linked uniquely through a transaction and each transaction is uniquely identified by the combination of both the sale id and the helmet id.

Helmets

The “helmet” table contains all the necessary information of each helmet and its current state. The helmet is defined by its manufacturer, size and uniquely identified by its RFID tag by the machine in a transaction. The rental and return price of the helmet will be determined by the price at which we buy it, our price point in the market and the requirements of our customer and will be unique for each helmet type and market we are in. The status of the helmet is present in this table to allow quick look-up of which stage it is in of the cycle, and this value is updated during the transaction process.

Machines

The “machine” table is simply used to give every machine a unique id and location so that the machines positions are known and the physical movement of the helmets around the city can be tracked.

5.4 Systems Control

5.4.1 Current System

Microprocessor

The current model of the machine is controlled with an Arduino[2] microprocessor. The vending process is modeled as a state machine in the Arduino framework, which
is an intuitive solution for the developer to compare the different states of the machine to steps that the consumer takes in the transaction process. The software framework is designed to have both the dispensing and return side of the machine to be controlled with separate Arduinos.

**User Interfaces**

On the dispensing side of the machine the customer interacts with two different electronic interfaces: a credit card reader and a touch screen system. The credit card reader is used to gather the payment information of the customer, while the touch screen is used to navigate through the transaction purchase and determine the customers exact requirements for size and number of helmets they want.

On the return side, the customer will only interact with an RFID through the use of the helmet. They will receive information on the transaction process through a small LCD screen. The user does not swipe their credit card on the return side, as the refund will be credited to the credit card number that was used to purchase the helmet initially.

**5.4.2 Possible Refinements**

The current control system creates extra costs and a more complex system to integrate. The plan in the short run is to modify the software structure to accommodate for both sides of the machine to be under one Arduino microcontroller. This will require a more intricate design model for the software to avoid conflicts when accessing shared hardware resources. Since they do not share any electrical components for the operating mechanism or user interface, the only situation I see this a problem arising is the use of the connection to the wireless router.

In addition we will desire to move away from the Arduino product as we approach larger-scale manufacturing due to costs and limitations of the platform. One possible option is to either take the useful components and features from an Arduino and add other required components (e.g. Ethernet connectivity) into a custom PC board and
print that in bulk. This would accommodate a simple transition of code as the system fundamentals would be the same, as well as the internal wiring of the machine. One drawback to this approach is the expertise to design such a board is foreign to our current core engineering team and would require outside talent.

Another option is to implement a more advanced processor capable of parallel processing, which would not only allow for a simpler way to manage the separate dispensing and return control systems, but would also come with a variety of plug-and-play interfaces necessary for wireless integration. A more detailed cost-benefit analysis of the two options would be necessary to determine the appropriate course of action, and should be performed over the coming months.

5.5 Wireless communication

5.5.1 Hardware

Wireless communication of the machines is not in place yet, but research has been done on how to implement it. An initial solution to the problem would be to outsource the design of the wireless system to a vendor experienced with machine-to-machine communication and install a stand-alone wireless router in the machines that would communicate with the Arduino over Ethernet or RS232. This would provide a quick solution that could be implemented quickly. However, it would be more costly, and more energy intensive. In the short-run it is a viable solution. However, in the long run, we would wish to implement a modular, integrated solution into our control board. This would not only decrease the power requirement of the electronics, but also be a more cost-effective solution as the technology would be more bare-bone and specific to our needs. Possible vendors experience in this field are USA technologies[8] and Digi[3]. However, we desire to maintain the majority of the design control to be able to make sure that our product represents what we want to put out on the market, and therefore wish to outsource as little work as possible.
5.5.2 Transaction

Since wireless communication costs money, and in some areas the reception may not be at an ideal level, the transaction communication has been designed to contain only the essential information. In our current design the machine will send 4 different pieces of information to our central server:

- RFID tag number (there can be multiple tag numbers passed on)
- Transaction type (rent, return, reload or remove for maintenance)
- Credit Card number
- Machine ID

Based on these 4 pieces of information our central server will be able to process the data appropriately, and update the database.

5.6 Payment Processing

Payment processing will be run through our central server and our bank. After each transaction is recorded on the machine, the payment information is sent to our central server, and from there passed on directly to our bank. The bank will handle billing our customer on our behalf. However, once we reach an appropriate scale of cash flow, it might be more cost-efficient to outsource this to a cheaper, payment-processing firm.
Chapter 6

Power

6.1 Power Requirements

The power requirements of the machine are determined by the electrical components in the machine. These can be divided into three different groups: Common processing, dispensing electronics and return electronics. The energy use of the components is determined by the following expectations: the Arduino and wireless router are active 24 hours a day, the dispensing and return components of the machine see 12 rentals/returns a day each. The total requirements are detailed in Table 6.1

6.2 Solar Panel Use

Table 6.2 on 61 presents the average solar insolation values in Boston over the last 10 years by month and the hours of daylight for the current year, 2012. Solar insolation

\footnotesize
1 Please refer to Appendix E
2 Please refer to Appendix D
3 Please refer to Appendix B
4 Please refer to Appendix F
5 Please refer to Appendix I
6 Please refer to Appendix H
7 Please refer to Appendix C
8 Please refer to Appendix B
9 Please refer to Appendix G
10 Please refer to Appendix I
11 Please refer to Appendix C
Table 6.1: Power Requirements for Machine

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Component</th>
<th>Energy Consumption (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing and Wireless</td>
<td>Wireless Router(^1)</td>
<td>32.00</td>
</tr>
<tr>
<td></td>
<td>Arduino(^2)</td>
<td>60.00</td>
</tr>
<tr>
<td>Dispensing</td>
<td>Magnetic Card Reader(^3)</td>
<td>2.40</td>
</tr>
<tr>
<td></td>
<td>LCD (large)(^4)</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>Receipt Printer(^5)</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>Touchscreen(^6)</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Servos (x3)</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>RFID-12(^7)</td>
<td>0.5</td>
</tr>
<tr>
<td>Return</td>
<td>Magnetic Card Reader(^3)</td>
<td>2.40</td>
</tr>
<tr>
<td></td>
<td>LCD (small)(^9)</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Receipt Printer(^10)</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>Solenoid</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>RFID-20 (^{11})</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>104.00</td>
</tr>
</tbody>
</table>

represents the amount of radiation incident on a given surface area that is parallel to the ground over time. The standard unit is \(\frac{kWh}{m^2\text{ day}}\).

In Boston the Hubway bike system is launched in March and removed in October or November. For HelmetHub to be operational the entire season, it has to be able to perform under the most limited conditions. Therefore, our energy design requirement is modeled for the machine to be operational through November, which supplies an average of \(1.74 \frac{kWh}{m^2\text{ day}}\) over 9 hours and 47 minutes of daylight on average.

The current footprint of the machine is 4'x2', of which applicable space for a solar panel is 80%. Given that the efficiency of a solar panel is around 10%, and the solar panel will be charging a traditional lead acid battery, which has an efficiency of 95% we get the following equation for available energy per day in November:

\[ I A B_{eff} S P_{eff} = E \]

Where \(I\) is, \(A\) is the applicable area for the solar panel, and \(B_{eff}\) and \(SP_{eff}\) are the efficiencies of the batteries and solar panel, respectively. From this calculation, the available energy for use will be \(180 \frac{Wh}{day}\).
Table 6.2: Solar Insolation in Boston, MA

<table>
<thead>
<tr>
<th>Month</th>
<th>$\frac{kWh}{m^2\text{-}day}$ [15]</th>
<th>Daylight (h) [18]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.66</td>
<td>9:29</td>
</tr>
<tr>
<td>Feb</td>
<td>2.50</td>
<td>10:35</td>
</tr>
<tr>
<td>Mar</td>
<td>5.11</td>
<td>11:58</td>
</tr>
<tr>
<td>Apr</td>
<td>4.13</td>
<td>13:24</td>
</tr>
<tr>
<td>May</td>
<td>5.11</td>
<td>14:37</td>
</tr>
<tr>
<td>Jun</td>
<td>5.47</td>
<td>15:13</td>
</tr>
<tr>
<td>Jul</td>
<td>5.47</td>
<td>15:53</td>
</tr>
<tr>
<td>Aug</td>
<td>5.05</td>
<td>13:49</td>
</tr>
<tr>
<td>Sep</td>
<td>4.12</td>
<td>12:26</td>
</tr>
<tr>
<td>Oct</td>
<td>2.84</td>
<td>11:01</td>
</tr>
<tr>
<td>Nov</td>
<td>1.74</td>
<td>9:47</td>
</tr>
<tr>
<td>Dec</td>
<td>1.40</td>
<td>9:08</td>
</tr>
</tbody>
</table>

Since our power requirement was $104\frac{Wh}{day}$ this gives us a safety factor of nearly 2 in case there is a cloudy day. In addition the battery has an energy capacity of $720Wh$, which is equivalent to one week of operation time.

Given a worst case situation of continuous cloud coverage for a full week, a backup solution for our system would be to simply exchange the drained batteries from the machines with fully charged batteries on maintenance runs.
Chapter 7

Industrial Design

The way each of the subsystems come together constitutes the industrial design of our machine, which itself has its own considerations for design beyond simply housing our components. The physical space occupied by the machine as well as the way users might interact with it, both productively and destructively, has helped guide the design decisions.

7.1 Machine Shape

7.1.1 Space Constraints

As mentioned earlier, one of the largest challenges in implementation was the space constraints placed on the machine. In consultation with the City of Boston, it was recommended that our machine occupy a space no larger than 48"x48". Our original conceptualizations revolved around having two smaller machines, one for dispensing and one for return, as shown in Figure 7-1.

Refinement of the concept led to the idea of integrating the two machines together into a shape that could also be used to house other station components, such as maps and advertising. By combining the machines, our machine could easily replace the existing map station as illustrated in Figure 7-2, meaning no changes to the station locations or overall physical footprint would need to be made.
7.1.2 Paneling

As can be seen in Figure 7-2, the sides of the machine are made of clear panels that can each contain an advertisement or map of the city. These panels duplicate the functionality of existing bikeshare station components so that our machine can easily replace those components. In addition not only is our machine larger, but the advertisement space is larger as well, thus increasing the value of the ad space.

Each panel is made from 4 pieces of angle iron to make a frame, and a large panel of polycarbonate as a window. Polycarbonate was chosen for its resilience against scratching and durability against impact. The polycarbonate would be sealed into the frame with some sort of waterproof adhesive in production, but in our prototype its held in place from the rear by the advertisement panels.
Each panel is attached to the machine by a piano hinge, which allows the assembly to swing away from the machine for access to the internal components. In our prototype, the panels are locked in place during operation by a key-lock similar to the ones found on filing cabinets, though this is an area of further refinement before production.

### 7.1.3 Vandalism

As a freestanding machine in an urban environment, the risk of vandalism is a major concern in design. In our design, we've tried to minimize how users can interact with our machine in non-desirable ways while nonverbally informing them on how the machine should be operated.

The first step in designing our machine for robustness in urban environments was sealing off service areas from user access. The internals of the machine are secured from access by the side panels with tamper resistant locks, and all the exterior fasteners are tamper resistant screws as shown in Figure 7-3. Additionally, the dispensing and return mechanisms are locked from public access while not in use during a transaction.

![Figure 7-3: The Tamper-Resistant Security Torx Screw](image)

We also designed the machine to withstand physical trauma it may encounter in an
urban environment by constructing the frame from AISI 1035 Steel 2" square tubing. The steel welded frame is robust enough to withstand physical impacts from vandals, while still maintaining a large interior volume for the components. The steel frame also adds considerable weight to the machine, which helps deter theft of the machine. We have also thought of methods to prevent the machine from being moved or tipped over. One is to attach the machine to a large steel plate at the bottom, as is done with the bikeshare stand, while another method would be to fill the bottom portions of the steel frame with concrete, thus adding weight to the bottom and making the machine heavier.

It was also important to design the machine in such a way to prevent the insertion of trash or liquids into the areas helmets are dispensed or returned into. For the dispensing area, we prevented this form of interaction by designing a tubular frame to catch the helmets, which has a large open space, as shown in Figure 7-4. The frames

Figure 7-4: The helmet catch mechanism in the dispensing area

openings are too small to allow the helmet to fall through, but are open enough to allow refuse or liquids to pass through. The area underneath the dispensing area is also open, as can be seen in Figure 7-2 to prevent garbage or dirt from accumulating.

Similarly, the return mechanism has a largely open bottom, as can be seen in Figure 4-4 on page 45. This is also designed so that it holds a helmet placed into the mechanism, but allows refuse and liquid to pass through the bottom.
7.2 Interfaces

The interfaces constitute the ergonomics, user experience, and informative design choices made so that operating the machine is intuitive, easy, and enjoyable. The first priority of overall machine design from a human-use analysis was to inform users from a distance that the front and back of the machine serve different functions. We accomplished this with the asymmetric closed and open forms on the return and dispensing sides of the machine, respectively, as can be seen in Figure 7-2. We also chose heights for the dispensing area, and lengths for throws on the dispensing handle and return mechanism based on human factors data.[9]

Control Panels

The interfaces are very interactive for the user, but have been made to be as intuitive and simple to follow for a first time user as possible. The phases of operation on each side of the machine move from top to bottom in steps. E.g. on the dispensing side the touch screen interface is on top, below which is the credit card reader, the receipt printer and the dispensing interface in that order as can be seen in Figures 7-5 and 7-6.

Figure 7-5: The Dispensing Control Panel
Figure 7-6: The Return Control Panel

Component Interaction is laid out Left-Right, Top-Down, the same direction as English writing.

Round handle is similar to dispensing handle implying its similar use.

Height of handle is ergonomic

Square objects are interacted with together

1. Instructions
2. LCD
3. Credit Card Reader
4. Receipt Printer
5. Return Handle
The order of operation and instructions for use are also visible on the front of the machine through an informative sticker, and each interface module is labeled with a number that represents the order it is used in.

**Helmet Interaction Areas**

The dispensing and return mechanisms interface with the exterior of the machine in “Helmet Interaction Areas”. These areas were designed so that the way the user should interact with the helmet is clear.

We have also attempted to make the dispensing and return mechanism user actuated, and as enjoyable, and unique of an experience as possible. On the return side the user is prompted to pull the return box out, insert a helmet, push it back and turn the handle. The shape of the box implies proper use by forming the opening profile in the same shape as the helmet silhouette in the orientation the helmet should be inserted. Since the machine is in an urban environment, we chose stainless brushed steel for the handle materials so that the appearance is consistent, and implies a cleanliness that would be important in a users state of mind.

For the dispensing area, the helmet is held by the catch shown in Figure 7-4. This piece, as with all parts the user grabs or the helmet touches, is made from stainless steel for consistency with the design decisions made for the dispensing and return handles. When the helmet is in the catch, the brim of the helmet protrudes beyond the face of machine, making it clear when it has been dispensed and making it easy to remove.

The movement of the helmet in these areas is also carefully designed so that it does not fall a long distance or bang loudly into other components, as this might compromise the users confidence in the helmets integrity.
Chapter 8

Conclusion

From conception through implementation, the design of our dispensing and collection machine has been illustrative of the product design process. Our ideas were implemented quickly so that we could fail fast and iterate toward a better solution. The resulting mechanisms from that process are novel and designed to meet the particular design requirements of bikeshare programs, yielding a machine with high helmet density, low power consumption, a compact physical footprint, and a user experience that is compliant with bikeshare stations.

The process also continues to guide refinement of these mechanisms and designs so that the project may succeed in providing an optimized solution for the challenge of supplying helmets in bikeshare programs, in turn promoting bikeshare systems as a solution for urban transportation.

Our research in dispensing mechanisms indicates that a user-actuated solution tailored to dispense helmets free of packaging is ideal for power consumption and stock density. Dispensing using the ventilation holes appears to be a novel and efficient solution to dealing with the unusual shape of helmets. Utilizing a rod to hold a stack of helmets to be dispensed also provides an efficient means of reloading the stock in the machine either by reloading the machine at the station, or by replacing the entire rod with a preloaded one. To return the helmets, it was important to distance the association of the mechanism with a trash receptacle to avoid misuse, and that has led to a mechanism that is both low-power, and less prone to abuse.
All of these mechanisms can be powered using off-the-shelf electronic components, whose primary jobs include processing payment, tracking stock, and locking/unlocking the machine for use. Since the electronic load is relatively low, solar power from the roof of the machine is a viable option for recharging a battery large enough to power the machine daily. In case of unfavorable weather conditions, the battery can be large enough to power the machine for up to 7 days by itself.

All of the internal components can be housed into a relatively compact 4’x2’ footprint so that the machine can easily fit alongside the bikeshare kiosks. The sides of the machine can house a map and advertisement space while also being resistant to vandalism. The control panels for interacting with the machine can be designed with user-experience in mind so that using the machine is both intuitive and easy.

While all of this research helps promote the idea that a helmet vending solution for bikeshare programs is feasible, there is still ample opportunity for refinement. All of the subsystems have been developed and refined in parallel, leading to a modular architecture for the machine, but now that the individual components are more resolved, an integrated architecture can be explored to see if there are any more optimizations for space, power, or overall cost. The industrial design can be refined with feedback from usage testing, and the software that operates the machine can be improved to provide useful logistics for helmet usage, trip length, or other operations data.
Appendix A

HelmetHub Business Plan

Underneath you can find the recently refined business plan for the HelmetHub corporation, which utilizes the machine outlined in our thesis.
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Chapter 1

Executive Summary

HelmetHub Corporation is a product development company with an interest in the development and adoption of bike-share systems across the United States. Our company's namesake, HelmetHub, is an automated bicycle helmet vending and return machine that complements citywide bike share systems. Helmet usage among bike-share users is much lower than that of regular cyclists, which is caused by the lack of availability of helmets, and the inconvenience and disinterest for a daily commuter to carry a helmet around all day.

The creation of a helmet-vending network can potentially increase bike-share systems usage, thus encouraging a safe and healthy mode of transport for urban dwellers. The increased adoption of bike sharing programs in cities would also decrease carbon emissions and traffic congestion. In addition, bike-share leads to increased urban economic development. Cities throughout the world have realized the benefits associated with bike share systems, and are rapidly implementing the technology.

Currently, there are more than 400 citywide bike-share systems across the globe. Surprisingly, only one of the 400 bike-share systems has attempted to provide helmets to users using a self-service machine. This helmet vending machine (developed in Melbourne, Australia) is technologically inadequate, and neither possesses the ability to stand on a street corner independently powered nor provides users with the options to return helmets at the end of their bicycle ride. The machine itself is not designed for the purpose of helmet vending as it is a modified version of a cold-food vending
machine, and is does not meet the design requirements of most bike share system operators. A much more innovative approach is needed to cut down on the power and space consumption of such a machine to make the large-scale implementation of the technology possible.

While bike share systems have been around for nearly forty years, they have not experienced significant success. Technological advancements in the last decade have increased their popularity and adoption. Since 2010, there has been a nearly 74% year-to-year increase in the adoption of bike-share systems. This increased adoption of bike-share systems is expected to continue to grow in a pattern similar to car-sharing system.

The United States has been slow to adopt bike-share technology in the past, but the recent success of bike-share systems in major cities across the country is encouraging the provision of these systems. Despite this encouraging level of expansion, helmet regulations are disrupting the growth of this innovative transportation solution.

At this point in time, we are the only known company with a machine that allows for helmet vending and return on-location at bike-share stations. A few other companies claim to be developing their own prototypes, but these are unlikely to be street ready by this summer. Their efforts should not be discounted, however, as they have the ability to fully integrate their helmet vending system with their bike share system. Additionally, these companies already possess the capital and manufacturing channels to produce large quantities of product.

Our initial target market will be the growing bike-share systems in the Northeastern Region of the United States, specifically in major cities like Boston, Washington D.C, and New York City, which have already adopted and implemented bike-share systems, and are looking for solutions to the issue of providing helmets. The implementation of our helmet vending system in these cities will serve as an introduction of our company to the market, allowing us to expand to cities throughout the US with already existing and upcoming bike-share programs. Bike-share systems are generally funded by a public/private partnership where municipalities partner with private companies to finance the purchase of physical bike-share systems. The revenue gen-
erated by bike-share systems cover the funding needed to cover the operational and maintenance costs of bike-share systems. A similar financing and funding model will be used for the implementation and operation of our helmet vending system.

The current operational team of this start-up is made up of four MIT researchers and engineers. While the core team is new to the field of bike-share, the passion and diverse interests of these individuals lead to a dynamic and productive team. In addition, the team has a strong set of advisors who have significant experience in product development, industry, start-up development, and marketing.
Chapter 2

Introduction to HelmetHub

2.1 HelmetHub Corporation An Overview

HelmetHub Corporation solves the lack of helmet availability to bike-share system users. Our team has designed an automated vending machine that will increase the helmet usage among bike-share users. Helmet adoption by bike share users is restricted by the inconvenience of obtaining a helmet. Our machine allows for bike-share users to access helmets with the same level of ease as renting and returning a bicycle. This allows for the seamless integration of our machine into the current bike-share system design.

Since no city has truly addressed this problem, the current means of obtaining a helmet is to walk to the nearest vendor, to purchase a helmet, and to return the helmet to the nearest vendor at one destination. Often these vendors are located a considerable distance away from a specific bike-share system. The inconvenience of obtaining a helmet is in direct contrast to the quickness and simplicity of renting a bike from a bike-share station.

Our machine can be sold to municipal governments, who are interested in complementing their current bike-share systems, or its technology can be sold and licensed by bike-share manufactures for the integration of our machine into their system.
2.2 What We Offer

2.2.1 To Owners of Bike Share Systems

HelmetHub Corporation allows for municipal governments to increase helmet availability. Our machine integrates with or stands independently of existing bike stands throughout their city, increasing helmet usage and the safety of cyclists. Since municipal governments purchase a majority of bike-share systems, there is a focus on public safety as related to bike-shares. The lack of helmet usage among bike-share users is a significant concern to government entities. Our company offers a solution to this safety problem.

2.2.2 To The Bike Share Manufacturer

While bike-share manufactures are beginning to see importance of offering a solution to the lack of helmet availability, most are just now beginning to come up with a solution. Our company has a working, solution that can easily be integrated into the design of most bike-share systems, allowing for bike-share manufactures to offer an all-in-one solution to urban transportation congestion. Licensing our technology will allow for bike-share manufactures to penetrate the helmet-vending market immediately, rather then spending valuable time and resources on developing a new solution.

2.2.3 To Our Clients Customers

Bike-share users will interact with our machine on a daily basis. Currently the entire potential clientele of bike share programs is limited because of the lack of availability of helmets. Since convenience is a primary concern for daily commuters, the idea of carrying a helmet around for an entire day is a drawback to the adoption of bike-sharing.

HelmetHub makes helmet rental easy, convenient, and inexpensive for users making bike-share a safe commuting option.
2.3 Our Goal

Our method of providing helmets to bike-share users is faster, simpler, cheaper, and more eco-friendly than the existing method and those being developed by our competition. Our goal is to make it easier for an average bike-share user to access helmets, thereby making cycling safer and more convenient. Not only does our solution increase the adoption of bike-sharing by users, it increases the potential for the spread of bike and helmet share to cities that have mandatory helmet laws.
Chapter 3

Market

3.1 Bike Share Overview

Bike-sharing (also referred to as: public use bicycles, bicycle transit, bikesharing, smart bikes) are short term urban bicycle rental schemes that enable bicycles to be picked up at a self-service station and returned to any other station. People use bicycles on an as-needed basis and the system eliminates the cost and responsibility of ownership. Bike share has been around for nearly 40 years, but has been relatively unsuccessful until the last 5 years. Recent success is due to both technological innovation in bike share technology and a shift to a more greener mentality in developed
countries as it reduces the travel-related carbon footprint and introduces additional green jobs in management and maintenance.

Current bike share technology simplifies tracking the movement of the bikes, and simplifies the transaction process as the user is only required to have a credit card and/or a phone to put down a marginal deposit for a bicycle. The bikes are robust and of high quality with full fenders, chain guards, bike locks and a GPS unit and are designed to withstand abuse. The stations are self-service with automated locks and a computerized system to handle payments, which is all powered by photovoltaic solar panels and are 24 hours a day, 7 days a week.

According to the New and Innovative Concepts for Helping European Transport Sustainability (NICHES) consortium a minimum population of 200,000 is required to support an automatic bicycle-sharing system (Bhrmann, 2007). Installation and expansion of the bike share network is fast e.g. in Paris 700 stations with 10,000 bikes were installed in less than six months, and then doubled in size six months later.

3.2 The Needs

A bike share program requires the right political vision and support mainly focused on environmental sustainability and integrated city planning. The success of bike share program is dependent on the appropriate integration and the right timing for implementation, which is backed by effective marketing and communication. The growth of bike share has been fueled by the emergence of megacities where the ways vehicles are being used are being re-defined and there is a heavy focus on the development of transit systems and alternative private transportation options.

Bike shares emerging in Europe and Asian countries can be largely explained by this trend. Europeans have always highly valued green tech and a strong public transit infrastructure. In Asian countries there is a high demand for affordable transit, especially in booming megacities.
3.3 The Problems Related to Bike Share Programs

The main hindrances to the spread of bike shares are theft and vandalism of bikes, topography and climate of the market, and the lack of helmets.

Vandalism causes extra costs to the bike share system in the form of bikes needing repair, the need for new bikes as they break down and maintain the stations from damage or cleaning from vandalism. As a result this can deter bike share operators from installing bikes in certain parts of town or even to the city at all.

Bike share is marketed as a relaxing, healthy and quite leisurely way to commute short distances around the city without having to deal with the hassle of traffic or congestion in trains, metros or buses. In cities or towns with a hilly landscape or tendency for cold, rainy weather bike share looses its appeal. Further development in bike technology is being made to allow for hillier markets to adopt bike share in the form of electrically assisted bicycles. In addition to lowering the entry barrier of heavy physical work, electrically assisted bicycles would also allow for more elderly people to use bike share as a mode of transit.

This in turn would increase the demand and usage rates of helmets, as when the people age they tend to become more risk averse, and knowledgeable of their own physical limits and tend to use helmets more often.

The lack of helmets for bike share systems not only limits the amount of users, based on whom is willing to cycle without a helmet, but it also introduces a legal complexity. Several municipalities have mandatory bicycle helmet use laws, and without a proper helmet sale infrastructure, these markets are unable to implement a bike share system. Some cities have gone as far to discuss repealing helmet use laws in order to bring a bike share into the market.

3.4 System Costs

The capital cost of a bike share system is between $3000-$5000 per bicycle and they carry a high yearly operation cost to maintain the bicycles, but also to make sure
that each station is stocked by moving the bicycles around town. In NYC, a 49,000 bicycle program would cover most areas with 32,000 people/square mile and incur approximately $200 million in capital costs and around $100 million annually in operations costs. Advertising revenues, plus membership/use fees could fully offset the operations costs (Midgley, 2011). However, the value of the advertising space is dependent on the location of the stations, the size of the advertisement and the size of the market.

Figure 3-2: Capital costs of Bike share systems (Midgley, 2011)

<table>
<thead>
<tr>
<th>City</th>
<th>Canadian $</th>
<th>New York</th>
<th>Washington DC</th>
<th>Lyon</th>
<th>Paris</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Montreal</td>
<td>Bike</td>
<td>2007 Estimate</td>
<td>SmartBike Expansion</td>
<td>Velo'</td>
<td>Vellib'</td>
</tr>
<tr>
<td>Operator</td>
<td>Stationnement de Montreal</td>
<td>ClearChannel Adsnel</td>
<td>ClearChannel Adsnel</td>
<td>JCDecaux</td>
<td>JCDecaux</td>
</tr>
<tr>
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<td>500</td>
<td>500</td>
<td>1,000</td>
<td>20,600</td>
</tr>
<tr>
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<td>$1,800,000</td>
<td>No Data</td>
<td>$90,000,000</td>
</tr>
<tr>
<td>Capital Cost/Bicycle</td>
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<td>$3,600</td>
<td>$3,600</td>
<td>$4,500*</td>
<td>$4,400</td>
</tr>
</tbody>
</table>

All data provided by the operators or providers unless otherwise noted.

* This figure is cited to European programs in general in Becker, Berrie, "Bicycle-Sharing Program to Be First of Kind in U.S.," The New York Times, 27 April, 2008


The capital cost of our helmet vending system is on the order of $10000 per machine. We estimate one helmet vending machine per 30 bikes be necessary, thus making the system costs to implement helmet vending significantly lower. In addition, our machine is much larger than bike share stations and offers significantly larger and more noticeable advertising space.

3.5 The Bike-Share Market

Today there are over 400 bike-share schemes in 33 countries. In North America they are mainly focused in metropolitan areas and around university campuses.

Over the last few years there has been extensive expansion of bike share worldwide. In 2008 there were 213 bicycle-sharing schemes operating in 14 countries using
73,500 bicycles. With the exception of the system in Washington D.C., all systems were operating in Europe. Within two years there has been a 76 per cent increase in the number of systems and the bicycle fleet has more than doubled. There are currently over 400 bike-share schemes operating in 33 countries using 236,000 bicycles. Although just over 90 per cent of the systems are located in Europe, nearly 50 per cent of the global bike-share fleet is now located the Asia and Pacific region.

It is estimated that 32 systems are currently being planned in 16 countries, the majority of which would be outside Europe. New countries include: Colombia, Cyprus, Israel, and Turkey. Program is well developed in Europe, but it is still in its nascent stage of growth in North America.

Figure 3-3: Growth in Bike-sharing schemes and fleet 2000-2010 (Midgley, 2011)

3.6 The Players

Typical consumers of bike share systems fall in the following demographic and exhibit these interests. (CityRyde LLC)
• 18–35 years of age
• high level of education
• require high level of mobility
• may not own a personal vehicle
• cognizant of environmental and social issues

These factors basically describe the modern, young urbanite of today, and have major implications on how helmet use with bike shares should be marketed, considering the customer population appears quite uniform.

There are several bike share manufacturers out in the market currently (CityRyde LLC)

• Clear Channel Adshel
• Public Bike System
• JCDecaux
• B-Cycle
• Bixi

The two main leaders in North America are BIXI and B-Cycle (F&S, 09/2010). Bixi has most of the major markets thanks to their more sleek industrial design, while B-cycle is more in control of the smaller markets and college campuses. This division in markets creates an interesting problem for our business. Partnering with B-cycle exclusively could help us create an integrated solution and give B-cycle an edge in the market over Bixi.

Bixi, on the other hand has announced that they are developing a helmet vending solution and does not want to partner with us at this time. By quickly taking control of the market as an independent solution however, we could force Bixi into licensing our product, and perhaps resulting in higher revenue.
A third, smaller, bike share company in the US market is SandVault, who are also developing their own helmet vending solution. However, based on unofficial conversations with bike share operators, they do not have great quality of product or service. We do not consider them a major competitor to us, or other bike share companies at the moment in time. Bike share in North America

Figure 3-4: Bike Share Systems in the US, 2010 (F&S, 09/2010)

The above chart shows that the potential for bike share system success in the US. It is predominantly heavy on the East Coast, in liberal areas that have a high density of the user group defined above. However, as with most cultural aspects and technology that emanate from Europe, I expect it to expand to the West Coast after succeeding in the East.

3.7 Bike share vs Car (share)

Bike share systems are slowly starting to overtake motor vehicle use and urban car share systems especially for short-distance commutes. In most cases this is due to gas prices or traffic and over-crowding on streets, with more than 2/3 of the public transport respondents of a study conducted by Kumar and Vaidya in 2011 reported
frustration, except in a few countries such as France/Denmark/Spain and some cities in North America, where bike shares exist.

With population density in urban areas constantly increasing, and the nature of current urban transportation being very slow to respond to an increase in usage in the form of more buses, rail cars and wider roads, it is probable that the usage of bikes and bike share will increase greatly in the near future in the US.

3.8 The Financing

Bike share systems operations costs are mainly funded through user fees and advertisement space, while the majority of the capital investment is government subsidized. This creates an opportunity for public-private-partnerships (PPPs), wherein the governmentally backed company pays for the system, but also gets control of the advertisement space (Midgley, 2011). The business model for gathering fees from the users are constantly advancing, with several systems now based on a combination of subscription charges and usage fees, which grow exponentially with the time the bike has been in use without returning it.
3.9 The Next Generation

The technological development of bike share systems is constantly advancing, integrating with smartphones for real-time information and the upcoming introduction of electrically power assisted bicycles, and constantly advancing solutions to simplifying payment. The faster and easier a user can rent a bike, the more feasible of a commuting option it will be, especially across age boundaries, as the technological barrier (i.e. users communicating or interfacing with the payment technology) decreases.

3.10 Bike Sharing and Helmets

According to Frost and Sullivan, competition in the bike-share market will come result from features added to bike-shares systems that enhance usage and convenience (F&S, 09/2010). One of these areas of development is the addition of helmets. Several bike-share systems have shown interest in pursuing this area of development.

The self-serve nature of bike-share programs limits their ability to provide helmets to users. Most jurisdictions with bike-share systems do not require cyclists to wear helmets. Not having to wear a helmet simplifies the use of bike-share systems for one way trips or trips combined with public transport, since the user does not have to carry a bulky helmet before and after using the system. However, for many people this poses a safety risk. There is a considerable body of research about the benefits about the usage bicycle helmets for bicycle commuters, but there is hardly any research on the issue with regard to bike-share users. It is an issue that receives much public attention from government officials.

The main deterrent in some regions to the implementation of bicycle-sharing programs is helmet laws. For many years, it had been assumed that no Australian city would install a bike-share system because of national mandatory helmet laws. Melbourne launched its system in June 2010 and later opened a pilot program whereby users can purchase helmets for $5.00 from vending machines and either keep them, or return them to a convenience store for recycling and receive a cash back refund.
(VicRoads, 2010). Officials in Mexico City took a different approach, repealing the helmet law to make way for a bike-share system (MetroBike, LLC., 2010). In Boston Hubway offers helmets through CVS/Walgreens stores, however these are often located at an inconvenient distance from bike stations, and are therefore looking for a self-service on-station solution.
Chapter 4

Sales and Marketing

4.1 Sales

4.1.1 Distribution Channels

Our sales plan has two different components:

- Selling directly to bikeshare operators
- Licensing our technology to bikeshare manufacturers

During the first two years our sales approach will be heavily focused on the direct sales tactic. We will focus our sales efforts on North American markets with already existing, or newly developing bikeshare programs. An emphasis will be put on markets where public and road safety are major issues in the community, and the government is very involved not only enforcing road laws, but very concerned about the well-being of its citizens. Markets with these characteristics will most likely be our first customers and willing to try out a novel system.

After creating a dominant market position and proving our technology to be top quality in the market, we will move to license our product to a competitor or bikeshare manufacturer as an exit strategy from the market.
Direct sales

In the direct sales approach we will sell the machine as a turnkey solution directly to bikeshare operators. The customer pays a single per machine cost, after which they become the owner of the machine, thus releasing us of all legal liability pertaining to the selling of the helmets. We will provide training for maintenance personnel and troubleshooting assistance when necessary.

The benefit of directing sales towards bikeshare operators is that our customer group is well defined as there is only one operator per city and the market is well documented. Therefore we can bypass large scale marketing approaches and contact our customers directly.

In addition, by selling directly to the operator, it gives us and the customer freedom to match our product with the specific bikeshare system they are using.

Once our system is in position, we will help maintain the operational side of the system with our software back-end and small number of dedicated technical personnel. We will split the revenue from the rental and sales of helmets 25-75 between us and the bikeshare, respectively, to cover our operational costs. The revenue from selling the ad space from the machines will also be split between us and bikeshare operator, and will be one of our main sources of continuous revenue.

One of the main criteria we will use to identify new cities to approach is the ratio between overall helmet use for cyclists in the city compared to the helmet use rate of only bikeshare users. Bicycle helmet use statistics are generally well documented by governmental organizations or by the operator itself, making the information readily available. Also as operators tend to be financed with government money they tend to be very upfront and open about helmet use as they are keen to maintain road safety.

Our initial markets will consist of municipalities that have a heavy focus on green transport, and an overall community awareness for road and public safety, and a very involved government concerned about the safety of its citizens. We believe that these markets will be most willing to trial with a novel solution for providing another aspect of safety to public commuting and promote the adaption of bikeshare programs in
cities who are concerned with the dangers of helmetless biking.

Licensing

Our other sales approach is licensing our technology to an existing bikeshare system manufacturer. Due to customer interest in a solution for helmet distribution, competing development of a helmet vending machine has begun between bikeshare manufacturers.

We are currently in the forefront of this development competition as we are the only company with an existing prototype. By using this advantage we can be the first to enter the market and prove the feasibility of our concept and its superior engineering and user experience. This will require fast growth and a significant portion of the market in the first two years of operation to force a competitor to discard their own R&D work to implement a helmet vending solution faster by licensing our product.

By licensing our technology to a major player in the market, we will be able to offer our technology as an integrated solution to our customers as well as allow the bikeshare manufacturer to compete in the helmet vending market immediately without spending time and money developing their own product. This is a win-win situation for both us, and the bikeshare manufacturer.

Under a licensing agreement the licensee will pay us a lump sum of money for the right to be the sole proprietor of your technology, and will also pay a royalty to us for the sale of each machine. In turn they will also take over all the operating costs of the system, and be able to collect the revenue from both the rental operations and ad space from the machine.

4.1.2 Pricing

Our revenue will come both from the sale of the machines, and the sale of ad space from the machine. We will take the necessary portion of revenue from the sale and rental of helmets will be used to cover the operational costs of maintaining the system
from our end.

The Machine

Manufacturing costs of one machine in full production are estimated at $2200 and retail price at $9000. Manufacturing costs of initial models, which are intended for the trial period with Hubway, are expected to be $3500. The increased cost is due to fabrication occurring in-house.

General capital investment costs for a bikeshare system are $3000-$5000/bicycle, and therefore our price level is in correlation with the current costs of bikeshare systems.

If our technology is licensed to a bikeshare manufacturer, they would have the right to sell our machine under the HelmetHub name as an integrated bike/helmetshare system. By having them do the sales work we would split the profit per HelmetHub machine that they sell 80-20 between us and the licensee, respectively.

Helmets

Pricing of the helmets is left to the client depending on the quality and cost of the helmets they are providing. We are currently attempting to develop a relationship with a helmet manufacturer to offer low-cost helmets that fit in the design of our machine.

Our suggested pricing method is for the user to make a deposit by credit card for a helmet, which is then partially refunded when the helmet is returned. This allows the users of the machine the option to keep the helmet at retail price. Initial discussions with Hubway in Boston suggest that their pricing scheme would be $8 initial payment with $6 refund upon return, making the rental price of a helmet $2.
4.2 Marketing

4.2.1 To our Customers

Our marketing approach will consist of directly contacting possible customers and utilizing the media exposure we get by launching a novel technology in our trial market of Boston. Bikeshare programs are naturally in the spotlight due to their visibility in the city streets, novelty and use of public funds for financing. There is also great public interest for new safety solutions, especially in North America where safety and corporate liability are major issues. Within a month of the public disclosure of our alpha prototype we have already been featured in The Boston Globe, BostInno and on NPR. We will utilize the past, and future public exposure to attract interest from new markets and operators. They will either be directed to our website or we will use the press interest as a reference during sales calls to prove the existing public interest in our product.

As the helmet vending market is new, our marketing efforts will initially be focused on contacting existing bike operators directly and trying to partner with someone who has an interest in our product to use as a trial and reference customer. Currently we have identified and have been in conversation with Hubway from Boston as a possible launching partner. Using Hubway as our reference customer we would prove the feasibility and effectiveness of our technology and concept by showing its effect on both bike and helmet usage rates in the bikeshare system.

In addition to spreading information about our product through traditional and social media outlets, we will also generate word of mouth and buzz simply due to the size and visibility of our product in the urban environment. This will provide indirect market exposure through social media and blogs commenting on the new attractions on the city streets. The extra media exposure would encourage possible future customers off of our radar to contact our organization directly instead of having us reach out to them.

When marketing our product to public entities we will place an emphasis on the benefits that our product has on public health: increased safety for bicyclists, decrease
in city congestion and availability of safe and healthy exercise. We will also place an emphasis on how our product will allow the implementation of mandatory helmet usage laws for cyclists, which several cities have shown interest, to be more feasible.

4.2.2 To our Customers’ Customers

Based on the description of bike share users in the Market section, the average user is independent and prefers to make their own choices. Therefore helmet use with bike shares cannot be forced upon them or marketed with the use of a fear factor. Instead we prefer to consider we are giving them the option of choosing for themselves whether they want to use a helmet or not. We are eliminating the need whether to use a helmet or not, by providing them at convenient location and price and suggesting they make the smart choice. However, the specific marketing tactic will be completely at the discretion of the bike share manufacturer.
5.1 Technology

5.1.1 The Machine

The machine is designed to dispense helmets and accept returns, each of which is accomplished on opposing sides of the machine. The dispensing actuation and the return door are manually operated while the electronics are solar powered and have a battery life of 7 days. The helmet capacity on the dispensing side is 36. The return side capacity is 20.

The dispensing side of the machine features a credit card reader, a large touch screen, a receipt printer and a handle that operates the dispensing mechanism. The user can purchase a helmet by swiping their credit card, choosing the amount of helmets they want, whether or not they want a receipt and then dispensing a helmet by pulling, on the handle.

The return side of the machine is a collection unit for used helmets. The return panel has a credit card reader, an LCD screen for instructions and a receipt printer. The door for deposits is unlocked by swiping a credit card that has been previously used to purchase a helmet. The helmet is then placed in the door and RFID technology is used to identify whether the object returned is a HelmetHub system helmet before return is accepted.
The two large sides of the machine can function as advertisement or map panels at the discretion of the operator.

5.1.2 How to Purchase a helmet

The payment system of the machines can work in two different ways depending on the implementation of the machine in the bikeshare system:

- Independent of existing bikeshare system
- Integrated with existing bikeshare system

In the independent implementation the payment information is entered at the HelmetHub machine by swiping a credit card. In the integrated approach, in addition to the option of paying at the HelmetHub machine, payment for the helmet can be made simultaneously while paying for bike rental at the bikestand kiosk. The kiosk would then supply the user with a numerical code to enter into the HelmetHub machine.

5.1.3 Service and Maintenance

The HelmetHub machine will not dispense a helmet that hasn't been sanitized after the last user has returned it. However, the machine does not sanitize the helmet in an automated fashion. Due to liability issues, all of the returned helmets have to be removed from the machine after each use and inspected manually for cracks or damage. This is a necessary procedure as there are no reliable, automated methods to check the structural integrity of a helmet, and we refuse to vend helmets that might not be up to standards. To help streamline this process we are in the process of looking into technology that will allow us to determine if a helmet has received an impact large enough to cause damage, and thus decrease the pool of helmets that need to be removed from the machine. As the helmets get inspected, they will be thoroughly cleansed and marked with a sticker so that the user can visually recognize that the helmet has been processed.
The maintenance process for the helmets demand that large numbers of helmets be collected from machines, and then these machines restocked. This requires dedicated maintenance personnel to collect and reload machines. Bikeshare systems already employ trained maintenance personnel to repair bikestands and bikes, as well as reallocate the bikes to fill empty stations. Ideally the same maintenance personnel would perform the function of collecting helmets and reloading machines. We would also train the maintenance personnel to maintain and repair broken machines.

5.1.4 Consultation

At the request of the client we can also perform analysis to determine the required amount of machines for their bikeshare system and the machines optimal placement in their grid.

5.1.5 Development Status

As a group we have already developed a functional alpha prototype of the product. Our design and technology were both proven in the prototype. However, the product still needs development work to reach a state where it is fully marketable and robust. We believe that a beta version of the product, which could be implemented in the streets, could be designed and manufactured by July 15th, 2012. Since our founding group is formed of students who will not be taking pay, our costs will be solely in capital and materials. The cost of the beta prototype is expected to be $5000. Subsequent machines could be manufactured for $3500 a unit.

5.1.6 Future Development

In order to develop a model of the machine that will be used to push company expansion internationally and to be manufactured in a larger scale there are three key requirements in the human resources and business structure:

Qualified Software Engineer

Although there are two founding members of HelmetHub who are capable soft-
ware engineers, they are both Mechanical Engineers by expertise, training and at heart. In order for the future models of the machine to have robust, integrated software it would be in the best interest of the company to hire a qualified software engineer to lead the electronic aspect of technology development.

Experienced, dedicated business & marketing professional

None of the four founding members have experience or training with entrepreneurship, marketing or start-ups in general. In addition, the founders main interest in the business side of the company is the engineering and R&D of the product. To complement our founding team it would be necessary to bring on a person who is driven to execute our business plan and drive company growth and exposure.

Move into large-scale manufacturing

To accommodate the change from small-scale in-house fabrication to large-scale production a large initial capital investment is required to cover materials cost for a large number of machines to be manufactured, cover the costs of outsourcing component manufacturing and for appropriate office and machining workspace for assembly of the final product. Production cost of the machine in large-scale manufacturing is estimated at $2200 per unit.

5.1.7 Intellectual Property

HelmetHub will be seeking to file a patent on the dispensing mechanism of the machine. The mechanism was publically disclosed on December 13th, 2011 and is protected under U.S. copyright law for one year. We are planning to file a provisional patent on the technology by March 1st, 2012. The company name HelmetHub will be trademarked.
5.2 Roadmap

The chart below outlines the product development schedule for HelmetHub during the first 3 years of development.

Year 1

Technology development & testing: small-scale implementation in Boston

- File Provisional patent for all patentable intellectual property March 1st, 2012
- Development and manufacturing of first beta prototype July 15th, 2012
- Manufacture 1-3 units for deployment in Boston August 1st, 2012

Year 2

Expansion of coverage in Boston, and into other North American markets

- Development of next generation design February 1st, 2013
- Implementation of large-scale manufacturing process March 1st, 2013
- Production of machines for Summer complete May 1st, 2013

Year 3

Expanded coverage of North America, possible expansion in to Europe and Exit

5.2.1 Year 1 (2012)

The first half of year 1 will be spent developing a beta prototype of the machine that will be ready for launch in the Summer of 2012. We desire to build 2-4 units of this model to test in Boston and Cambridge. Our initial stations will be either the two upcoming MIT stations in respect of our alma mater or/and heavy traffic stations in downtown Boston. In addition to focusing heavily on developing a product for launch in Summer 2012, the beginning of the year will be spent setting up the corporate infrastructure of our group; incorporating, establishing a business structure,
searching for funding, developing a working relationship with Hubway in Boston and patenting our technology.

The specific goal for the Spring is to agree on terms with Hubway to use their bikeshare system as a trial grounds for our technology. Ideally we would be able to install 2-4 machines at high usage stations in Boston and Cambridge in addition to our home at MIT. These machines would then be used to troubleshoot and test the technology in the field, and to develop an efficient infrastructure for maintaining an adequate operating capacity of helmets in the machines. Also, the trial system would be used to gather data on how our product effects the usage rates not only of helmets, but the bikeshare system in general.

After proving the feasibility of our product with Hubway, we will use the collected data and positive reference from Hubway to push our product into other North American markets, the largest and most interesting ones being New York, Washington D.C. and Montreal.

During the initial phases of operation the development and manufacturing of the machines would mainly be performed in house. Since the founding members are not taking pay, and are all capable machinists, this would be a more cost-efficient method of production. The design of the machine will most probably be in slight flux throughout the Spring, and modifications in the design are easier to compensate for in-house.

The Fall of 2012 will be used to focus on developing a final model of the machine based on the results of the trial period. Work done during this period will allow us to finalize the design of a model that is suitable for both large-scale, outsourced manufacturing and robust enough for a high-traffic urban environment allowing the company to shift its main focus away from the research and development phase.

5.2.2 Year 2 (2013)

By the beginning of year 2 we hope to have solidified interest from at least two other North American markets and a desire from Hubway to expand our coverage to the majority of their network in Boston and Cambridge. Our goal is to install 50 machines
in the greater Boston area.

Manufacturing would move from small-scale in-house to large-scale factory production to accommodate for the production of ca. 50 machines for the Summer of 2013. Of these 50 machines, 20 would go to Boston, with the remaining 30 split between 3-5 other markets for trial use. All applicable component and sub-assembly manufacturing would be outsourced to decrease manufacturing costs. Assembly of the system would be kept in-house to maintain stringent quality control over the product.

Since our new target markets are in the Northeast and the largest number of units will be placed in Boston, all manufacturing will be centralized around Boston and machines shipped via ground transport to their final locations.

Two of the founding members of HelmetHub would relocate to the new cities we introduce our product to in order to have a dedicated, knowledgeable contact to watch over operations and planning.

5.2.3 Year 3 (2014)

In year 3 we plan to have some level of coverage in all major North American markets in the Northeast as well as expanding towards the West Coast (Seattle, Portland and San Francisco). We will have expanded our coverage in the markets we entered in for trial purposes during year 2 to have a HelmetHub station at ca. 20% of the bikeshare stations in the city. We don't expect to enter a city immediately with full coverage, and are prepared to go through a few months or year trial run with a smaller number of machines to prove the market for helmet use in the city.

Helmet use in Europe has trended to be lower than in the USA, but we also hope to push expansion into Europe by identifying the European cities most inclined toward helmet use.

In year 3 we also hope to have put ourselves in a market situation where we dominate the helmet vending industry. By showing the technical upperhand and quality of service of our system we desire to push a bikeshare manufacturer, or one of our competitors to either buy us out or license our product for their system.
Chapter 6

Manufacturing

6.1 Initial Manufacturing Operations

In the first year of operations, the expected number of machines to be manufactured is small. The trial run in Boston will use 2-4 machines. Manufacturing of these machines will take place in-house, at a centralized machine shop, and the fabrication work will be done by either the founding members of HelmetHub or by workers we hire. This approach will allow us to maintain low labor costs, while maintaining stringent supervision over the quality of our product.

Storage of the small number of machines should be possible within our lab/workspace. Transport and installation of the machines can be coordinated with Hubway in Boston using their equipment and crew.

6.2 Future Manufacturing Operations

Moving past the trial phase, we will shift manufacturing to larger scale production, and we will move production to a factory or outsource fabrication of the major components to separate manufacturers. Final assembly and quality assurance would remain under the company’s supervision and be completed in our own workspace. Fabrication will be centralized in the Northeast region, which has the infrastructure and industry in place locally to supply for small-scale start-ups. The scale of manufacturing makes
outsourcing most of the fabrication more cost effective in comparison to in-house pro-
duction. However, this will require us to relocate to a more sizeable office space, or
obtain space in a warehouse to accommodate for the larger number of machines.

Shipping can be accomplished relatively cost effectively by the use of ground
transport (moving trucks, shipping contractors) as the size of the machine is conducive
to containers/trucks. Installation would be done in conjunction with the bikeshare
operator utilizing their maintenance and installation crew, eliminating costs related
with hiring outside contractors/crew.
Chapter 7

Management Team Bios

The founding partners of HelmetHub are four core members of the original student team that developed the alpha prototype. These four members will form the core of the company and the rest of the team will remain available for consultation or freelance projects as the workload of the founding members varies.

7.1 Founding Members

Danielle Hicks, CEO, President
Dani will graduate MIT in June 2012 with a degree in Mechanical Engineering with a concentration in Sustainable Product Design. Dani has experience in graphic and industrial design, and will lead the company in aesthetic, exterior and UI design.

Charles Mills, COO, Vice President
Chris will graduate from MIT in June 2012 with a degree in Mechanical Engineering with a focus in Computer Science and Electrical Engineering. Chris is highly interested in project management, and product design. His experience with other start-ups will help the team in its initial stages of development.

Arni Lehto, CFO, Treasurer
Originating from Helsinki, Finland, Arni will graduate MIT in June 2012 with
a degree in Mechanical Engineering with a minor in Economics. Arnis focus and experience in robotics and product design will be utilized in developing the core technology and electronics systems of the machine.

**Breanna Berry, CIO, Secretary**

Breanna will graduate from MIT in June 2012 with a degree in Mechanical Engineering with a concentration in Civil Engineering and Design. Her interests lie in the development and optimization of urban, public transportation systems.
Appendix B

ZU-1890M Credit Card Reader
SPECIFICATION
FOR
MAGNETIC CARD READER
(Manual Insertion type)

ZU-1890M

MAR. 2001

MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.

MATSUSHITA INDUSTRIAL EQUIPMENT CO., LTD.
OSAKA JAPAN
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1. INTRODUCTION

This specification describes about manual insertion type magnetic card reader, featuring small size, lightweight and high performance, which enable to read card data, encoded by following ISO 1,2 standards.

2. PRODUCT NAME

2.1 Product Name : Manual insertion type magnetic card reader
2.2 Model No. : ZU-1890M

3. FUNCTION

3.1 Card operation : One way (Refer to Appearance)
3.2 Read/Write : Read only
3.3 Installation of the transport : Horizontal direction

4. EQUIPMENT SPECIFICATION

4.1 Out dimension : (W) 101.6 mm × (D) 112.6 mm × (H) 76.2 mm
4.2 Weight : Approximately 115 g
4.3 Supplied voltage
   (1)Supplied voltage : DC 5 V (tolerance ±10%) / Ripple (Less than 50 mV p-p)
   (2)Current consumption : TYP. 20 mA, MAX. 25 mA
   (3)Maximum applied voltage : DC 7 V
4.4 Connector : FFC-9TLAW2B (HONDA) Equivalent
4.5 Environment requirements : At indoor

5. BASIC FEATURES

5.1 Card operating speed : 10 cm/s ~ 120 cm/s
5.2 Magnetic head
   (1)Numbers of channel : 2
   (2)Core width : 1.4 mm
   (3)Core material : Permalloy
5.3 Insulation resistance : More than 10 MΩ at DC 250V
   (Measured between P.C.B. ground terminal and frame)
Appendix C

RFID Readers, ID-12 and ID-20
**ID SERIES DATASHEET Mar 01, 2005**

**ID-2/ID-12 Brief Data**

The ID2, ID12 and ID20 are similar to the obsolete ID0, ID10 and ID15 MK(ii) series devices, but they have extra pins that allow Magnetic Emulation output to be included in the functionality. The ID-12 and ID-20 come with internal antennas, and have read ranges of 12+ cm and 16+ cm, respectively. With an external antenna, the ID-2 can deliver read ranges of up to 25 cm. All three readers support ASCII, Wiegand26 and Magnetic ABA Track2 data formats.

---

### ID2 / ID12 / ID20 PIN-OUT

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Description</th>
<th>ASCII</th>
<th>Magnet Emulation</th>
<th>Wiegand26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin 1</td>
<td>Zero Volts and Tuning Capacitor Ground</td>
<td>GND 0V</td>
<td>GND 0V</td>
<td>GND 0V</td>
</tr>
<tr>
<td>Pin 2</td>
<td>Strap to +5V</td>
<td>Reset Bar</td>
<td>Reset Bar</td>
<td>Reset Bar</td>
</tr>
<tr>
<td>Pin 3</td>
<td>To External Antenna and Tuning Capacitor</td>
<td>Antenna</td>
<td>Antenna</td>
<td>Antenna</td>
</tr>
<tr>
<td>Pin 4</td>
<td>To External Antenna</td>
<td>Antenna</td>
<td>Antenna</td>
<td>Antenna</td>
</tr>
<tr>
<td>Pin 5</td>
<td>Card Present</td>
<td>No function</td>
<td>Card Present *</td>
<td>No function</td>
</tr>
</tbody>
</table>

---

### Operational and Physical Characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ID-2</th>
<th>ID-12</th>
<th>ID-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Range</td>
<td>N/A (no internal antenna)</td>
<td>12+ cm</td>
<td>16+ cm</td>
</tr>
<tr>
<td>Dimensions</td>
<td>21 mm x 19 mm x 6 mm</td>
<td>26 mm x 25 mm x 7 mm</td>
<td>40 mm x 40 mm x 9 mm</td>
</tr>
<tr>
<td>Frequency</td>
<td>125 kHz</td>
<td>125 kHz</td>
<td>125 kHz</td>
</tr>
<tr>
<td>Card Format</td>
<td>EM 4001 or compatible</td>
<td>EM 4001 or compatible</td>
<td>EM 4001 or compatible</td>
</tr>
<tr>
<td>Encoding</td>
<td>Manchester 64-bit, modulus 64</td>
<td>Manchester 64-bit, modulus 64</td>
<td>Manchester 64-bit, modulus 64</td>
</tr>
<tr>
<td>Power Requirement</td>
<td>5 VDC @ 13mA nominal</td>
<td>5 VDC @ 30mA nominal</td>
<td>5 VDC @ 65mA nominal</td>
</tr>
<tr>
<td>I/O Output Current</td>
<td>+/−200mA PK</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Voltage Supply Range</td>
<td>+4.6V through +5.4V</td>
<td>+4.6V through +5.4V</td>
<td>+4.6V through +5.4V</td>
</tr>
</tbody>
</table>

---

### Pin Description & Output Data Formats

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Description</th>
<th>ASCII</th>
<th>Magnet Emulation</th>
<th>Wiegand26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pin 1</td>
<td>Zero Volts and Tuning Capacitor Ground</td>
<td>GND 0V</td>
<td>GND 0V</td>
<td>GND 0V</td>
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<td>Pin 2</td>
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<td>Antenna</td>
<td>Antenna</td>
<td>Antenna</td>
</tr>
<tr>
<td>Pin 4</td>
<td>To External Antenna</td>
<td>Antenna</td>
<td>Antenna</td>
<td>Antenna</td>
</tr>
<tr>
<td>Pin 5</td>
<td>Card Present</td>
<td>No function</td>
<td>Card Present *</td>
<td>No function</td>
</tr>
</tbody>
</table>
Appendix D

Arduino processor
Features

- High Performance, Low Power Atmel® AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 135 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16MHz
  - On-Chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 64K/128K/256K Bytes of In-System Self-Programmable Flash
  - 4Kbytes EEPROM
  - 8Kbytes Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
    - Programming Lock for Software Security
- Atmel® QTouch® library support
  - Capacitive touch buttons, sliders and wheels
  - QTouch and QMatrix® acquisition
  - Up to 64 sense channels
- JTAG (IEEE std. 1149.1 compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - Four 16-bit Timer/Counter with Separate Prescaler, Compare- and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four 8-bit PWM Channels
  - Six/Twelve PWM Channels with Programmable Resolution from 2 to 16 Bits
  - Output Compare Modulator
  - B/16-channel, 10-bit ADC (ATmega1281/2561, ATmega640/1280/2560)
  - Two/Four Programmable Serial USART (ATmega1281/2561, ATmega640/1280/2560)
  - Master/Slave SPI Serial Interface
  - Byte Oriented 2-wire Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 54/68 Programmable I/O Lines (ATmega1281/2561, ATmega640/1280/2560)
  - 64-pad QFN/MLF, 64-lead TQFP (ATmega1281/2561)
  - 100-lead TQFP, 100-ball CBGA (ATmega640/1280/2560)
- Temperature Range:
  - -40°C to 85°C industrial
- Ultra-Low Power Consumption
  - Active Mode: 1MHz, 1.8V: 500μA
  - Power-down Mode: 0.1μA at 1.8V
- Speed Grade:
  - ATmega640V/ATmega1280V/ATmega1281V:
    - 0 - 4MHz @ 1.8V - 5.5V, 0 - 8MHz @ 2.7V - 5.5V
  - ATmega2560V/ATmega2561V:
    - 0 - 2MHz @ 1.8V - 5.5V, 0 - 8MHz @ 2.7V - 5.5V
  - ATmega640/ATmega1280/ATmega1281:
    - 0 - 8MHz @ 2.7V - 5.5V, 0 - 16MHz @ 4.5V - 5.5V
  - ATmega2560/ATmega2561:
    - 0 - 16MHz @ 4.5V - 5.5V
\[ T_A = -40^\circ \text{C} \text{ to } 85^\circ \text{C}, \ V_{CC} = 1.8 \text{V} \text{ to } 5.5 \text{V} \] (unless otherwise noted) (Continued)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Condition</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{CC} )</td>
<td>Power Supply Current(^{(s)})</td>
<td>Active 1MHz, ( V_{CC} = 2V ) (ATmega640/1280/2560/1V)</td>
<td>0.5</td>
<td>0.8</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>( I_{CC} )</td>
<td>Power Supply Current(^{(s)})</td>
<td>Active 4MHz, ( V_{CC} = 3V ) (ATmega640/1280/2560/1L)</td>
<td>3.2</td>
<td>5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>( I_{CC} )</td>
<td>Power Supply Current(^{(s)})</td>
<td>Active 8MHz, ( V_{CC} = 5V ) (ATmega640/1280/2560)</td>
<td>10</td>
<td>14</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>( I_{CC} )</td>
<td>Power Supply Current(^{(s)})</td>
<td>Idle 1MHz, ( V_{CC} = 2V ) (ATmega640/1280/2560/1V)</td>
<td>0.14</td>
<td>0.22</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>( I_{CC} )</td>
<td>Power Supply Current(^{(s)})</td>
<td>Idle 4MHz, ( V_{CC} = 3V ) (ATmega640/1280/2560/1L)</td>
<td>0.7</td>
<td>1.1</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>( I_{CC} )</td>
<td>Power Supply Current(^{(s)})</td>
<td>Idle 8MHz, ( V_{CC} = 5V ) (ATmega640/1280/1281/2560/2561)</td>
<td>2.7</td>
<td>4</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>( V_{ACIO} )</td>
<td>Analog Comparator Input Offset Voltage</td>
<td>( V_{CC} = 5V ) ( V_{IN} = V_{CC}/2 )</td>
<td>&lt;10</td>
<td>40</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>( I_{ACLK} )</td>
<td>Analog Comparator Input Leakage Current</td>
<td>( V_{CC} = 5V ) ( V_{IN} = V_{CC}/2 )</td>
<td>&lt;50</td>
<td>50</td>
<td></td>
<td>nA</td>
</tr>
<tr>
<td>( t_{ACID} )</td>
<td>Analog Comparator Propagation Delay</td>
<td>( V_{CC} = 2.7V ) ( V_{CC} = 4.0V )</td>
<td>750</td>
<td>500</td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>

Notes:
1. "Max" means the highest value where the pin is guaranteed to be read as low.
2. "Min" means the lowest value where the pin is guaranteed to be read as high.
3. Although each I/O port can sink more than the test conditions (20mA at \( V_{CC} = 5V \), 10mA at \( V_{CC} = 3V \)) under steady state conditions (non-transient), the following must be observed:
   ATmega1281/2561:
   1) The sum of all \( IO_L \), for ports A0-A7, G2, C4-C7 should not exceed 100mA.
   2) The sum of all \( IO_L \), for ports C0-C3, G0-G1, D0-D7 should not exceed 100mA.
   3) The sum of all \( IO_L \), for ports G3-G5, B0-B7, E0-E7 should not exceed 100mA.
   4) The sum of all \( IO_L \), for ports F0-F7 should not exceed 100mA.
   ATmega640/1280/2560:
   1) The sum of all \( IO_L \), for ports J0-J7, A0-A7, G2 should not exceed 200mA.
   2) The sum of all \( IO_L \), for ports C0-C7, G0-G1, D0-D7, L0-L7 should not exceed 200mA.
   3) The sum of all \( IO_L \), for ports G3-G4, B0-B7, H0-H7 should not exceed 200mA.
   4) The sum of all \( IO_L \), for ports E0-E7, G5 should not exceed 100mA.
   5) The sum of all \( IO_L \), for ports F0-F7, K0-K7 should not exceed 100mA.
   If IOL exceeds the test condition, VOL may exceed the related specification. Pins are not guaranteed to sink current greater than the listed test condition.
4. Although each I/O port can source more than the test conditions (20mA at \( V_{CC} = 5V \), 10mA at \( V_{CC} = 3V \)) under steady state conditions (non-transient), the following must be observed:
   ATmega1281/2561:
   1) The sum of all \( IO_H \), for ports A0-A7, G2, C4-C7 should not exceed 100mA.
   2) The sum of all \( IO_H \), for ports C0-C3, G0-G1, D0-D7 should not exceed 100mA.
   3) The sum of all \( IO_H \), for ports G3-G5, B0-B7, E0-E7 should not exceed 100mA.
   4) The sum of all \( IO_H \), for ports F0-F7 should not exceed 100mA.
   ATmega640/1280/2560:
   1) The sum of all \( IO_H \), for ports J0-J7, A0-A7 should not exceed 200mA.
   2) The sum of all \( IO_H \), for ports C0-C7, G0-G1, D0-D7, L0-L7 should not exceed 200mA.
   3) The sum of all \( IO_H \), for ports G3-G4, B0-B7, H0-H7 should not exceed 200mA.
   4) The sum of all \( IO_H \), for ports E0-E7, G5 should not exceed 100mA.
Appendix E

Wireless Router
ConnectCore® 3G
Embedded 3G Cellular Gateway Module

Future-proof, pre-certified embedded module with unrestricted cellular connectivity, Ethernet, GPS support and unique software and hardware design integration flexibility.

Overview

The ConnectCore 3G embedded module allows you to instantly add intelligent cellular communication to your products, resulting in quick time-to-market and significantly reduced design risk.

Built on leading Qualcomm Gobi 3000 technology, the module delivers a pre-certified embedded cellular connectivity solution without the traditional carrier/network limitations. Selecting cellular network technology and carriers is now a matter of software configuration and service provisioning, any time.

The ConnectCore 3G offers the development and operational benefits of the iDigi® platform. This secure, highly-scalable platform seamlessly ties enterprise applications and remote devices together. Users can easily configure, upgrade and manage remote devices, regardless of location or network.

Its unique combination of features makes the ConnectCore 3G the ideal choice for wireless M2M applications in a wide variety of target markets such as energy, utilities, transportation, industrial/building automation, digital signage, security/access control and many more.

Features/Benefits

- Embedded M2M gateway module with universal 2G/3G cellular connectivity, GPS option and Ethernet
- Unique pre-certified “any network, anywhere” solution offering unrestricted communication
- iDigi-enabled solution with Digi plug-and-play firmware and Python based product customization
- Design and integration flexibility through rich set of peripherals and off-module connector options
- High-speed USB host interface for integration of memory cards, cameras and other devices
- Extended operating temperature and low emissions
- Future-proof design with 4G upgrade path

Related Items

Design Services  Accessory Kits  Support

www.digi.com
<table>
<thead>
<tr>
<th>Specifications</th>
<th>ConnectCore® 3G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td>Digi NS9215 (ARM926EJ-S @ 150 MHz), 8 MB NOR Flash (System), 128 MB NAND Flash (System/User), 32 MB SDRAM</td>
</tr>
<tr>
<td><strong>Software</strong></td>
<td>Digi plug-and-play firmware with support for IPv4/IPv6, IPv (IPsec with IKE/ISAKMP, multiple tunnels, DES/3DES/AES encryption, VPN pass-through, GRE forwarding), SSL/SSH, SMS, iDigi®, XBee® RF modules</td>
</tr>
<tr>
<td><strong>Configuration and Management</strong></td>
<td>iDigi, Web User Interface (HTTP/HTTPS), Command Line Interface (CLI)</td>
</tr>
<tr>
<td><strong>Custom Application Development</strong></td>
<td>Eclipse-based Digi ESP™ for Python development environment for Windows XP/Vista and Mac OS X, with support for Python and iDigi Dia</td>
</tr>
<tr>
<td><strong>Hardware Interfaces/Peripherals</strong></td>
<td>3 x UART (up to 921 kbps), USB 2.0 Host, GPIO (5V-tolerant inputs), 1 x UART (up to 460 kbps), CAN 2.0, RIC</td>
</tr>
<tr>
<td><strong>Integrated GPS Option</strong></td>
<td>Standalone, AGPS, gsp0neXTRA</td>
</tr>
<tr>
<td><strong>Network Interface - Cellular</strong></td>
<td>2G: GPRS/EDGE, 3G: HSDPA/HSUPA, 4G: LTE</td>
</tr>
<tr>
<td><strong>Technology/Bands</strong></td>
<td>HSPA/UMTS (800/900/1900/2100 MHz), EDGE/GPRS/GSM (850/900/1800/1900 MHz), EV-DO/CDMA (800/1900 MHz)</td>
</tr>
<tr>
<td><strong>Data Rate (Downlink/UpLink)</strong></td>
<td>HSDPA/HSUPA: 7.2 Mbps or 14.4 Mbps, WCDMA: 384 kbps</td>
</tr>
<tr>
<td><strong>Power Requirements (3.3V)</strong></td>
<td>0.75A (max)</td>
</tr>
<tr>
<td><strong>Power Management</strong></td>
<td>Telephone Link enable/disable, Ethernet enable/disable, Power-up on EIRP</td>
</tr>
<tr>
<td><strong>Environmental/Mechanical</strong></td>
<td>70 mm x 50 mm x 15.4 mm (Footprint compatible with ConnectCore 9P9215 family)</td>
</tr>
<tr>
<td><strong>Board-to-Board Connector</strong></td>
<td>2 x 80-pin connector (PCI P/N 61082-081409LF) (Pinout compatible with ConnectCore 9P9215 family)</td>
</tr>
</tbody>
</table>

Visit www.digiembedded.com for part numbers.

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Appendix F

Large LCD (Dispense)
SPECIFICATIONS FOR LCD MODULE

DS-G160128STBWW

PIXELS: 160 X 128 DOTS
OUTLINE DIMENSION: 129.0 X 102.0 MM
VIEWING AREA: 101.0 X 82.0 MM
DOT SIZE: 0.54 X 0.54 MM
DOT PITCH: 0.58 X 0.58 MM

REVISION RECORD

<table>
<thead>
<tr>
<th>REV.</th>
<th>DATE</th>
<th>PAGE</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2007-3-15</td>
<td></td>
<td>NEW RELEASE</td>
</tr>
</tbody>
</table>
### 4.2 Enviromental Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>ITEM</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temp</td>
<td>Topr</td>
<td>-Normal temp. version-</td>
<td>-20</td>
<td>70</td>
<td>deg C</td>
</tr>
<tr>
<td>Storage Temp</td>
<td>Ttsg</td>
<td></td>
<td>-30</td>
<td>80</td>
<td>deg C</td>
</tr>
<tr>
<td>Humidity Endurance</td>
<td>RH</td>
<td>no ondensation Ta&lt;=40 deg</td>
<td>-</td>
<td>95</td>
<td>%</td>
</tr>
<tr>
<td>Vibration</td>
<td>-</td>
<td>100-300Hz, X/Y/Z directions, 1 hour</td>
<td>-</td>
<td>4.9m/ss 0.5g</td>
<td></td>
</tr>
<tr>
<td>Shock</td>
<td>-</td>
<td>10 mS X/Y/Z direction 1 time each</td>
<td>29.4m/ss 3.0g</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

### 5. ELECTRICAL CHARACTERISTICS

#### 5.1 DC Characteristics

Electrical Characteristics at Ta=25 deg C, Vdd = 5V + / - 5%

<table>
<thead>
<tr>
<th>ITEM</th>
<th>SYMBOL</th>
<th>CONDITION</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage (logic)</td>
<td>Vdd-Vss</td>
<td>-</td>
<td>4.5</td>
<td>5.0</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Supply Voltage (LCD)</td>
<td>Vdd-V0</td>
<td>Vdd = 5V</td>
<td>-</td>
<td>18</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>Input signal Voltage</td>
<td>V-ih</td>
<td>“H” level</td>
<td>2.2</td>
<td>-</td>
<td>Vdd</td>
<td>V</td>
</tr>
<tr>
<td>(for CD, DBO-7, WR, R/ CS)</td>
<td>V-il</td>
<td>“L” level</td>
<td>0</td>
<td>-</td>
<td>0.6</td>
<td>V</td>
</tr>
<tr>
<td>Supply Current (logic)</td>
<td>Icc</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1.2</td>
<td>mA</td>
</tr>
<tr>
<td>Supply Current</td>
<td>Io</td>
<td>-</td>
<td>0.15</td>
<td>0.22</td>
<td>0.27</td>
<td>mA</td>
</tr>
</tbody>
</table>
Appendix G

Small LCD (Return)

Matrix Orbital LK162-12-WB-C166
Serial LCD Displays & LED Replacement Lamps

Multi-Chip and Cluster-Based LED Replacement Lamps

- Low current draw - less energy than incandescent. No heat dissipation.
- Long life up to 10,000 hours. Standard socket.
- Available in both RoHS and non-RoHS versions.

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Color</th>
<th>Wavelength</th>
<th>Voltage</th>
<th>Current</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>2118686</td>
<td>Red</td>
<td>625 nm</td>
<td>3.3 V</td>
<td>20 mA</td>
<td>50 mA</td>
</tr>
<tr>
<td>2118687</td>
<td>Yellow/Green</td>
<td>550 nm</td>
<td>2.5 V</td>
<td>15 mA</td>
<td>40 mA</td>
</tr>
<tr>
<td>2118688</td>
<td>Blue</td>
<td>470 nm</td>
<td>4.2 V</td>
<td>50 mA</td>
<td>50 mA</td>
</tr>
<tr>
<td>2118689</td>
<td>White</td>
<td>540 nm</td>
<td>4.5 V</td>
<td>20 mA</td>
<td>50 mA</td>
</tr>
</tbody>
</table>

Wedge Base LEDs & Holders

- Wedge LEDs can be applied to both push-in and adhesive backside for easy installation.
- Resistor and replacement switch can be used to adjust current.

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Color</th>
<th>Dimensions (W x H x T)</th>
<th>Resistor Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2123346</td>
<td>Blue</td>
<td>0.8 x 0.6 x 0.3 cm</td>
<td>10 kΩ</td>
</tr>
<tr>
<td>2123347</td>
<td>Yellow/Green</td>
<td>1.0 x 0.8 x 0.4 cm</td>
<td>15 kΩ</td>
</tr>
<tr>
<td>2123348</td>
<td>Blue-Green</td>
<td>0.9 x 0.7 x 0.4 cm</td>
<td>20 kΩ</td>
</tr>
</tbody>
</table>

LED Displays

- Available in various sizes and colors.
- Use with appropriate power supply and controller for optimal performance.

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Display Size</th>
<th>Resolution</th>
<th>Power Supply</th>
<th>Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>164101</td>
<td>16 x 2</td>
<td>7 x 8</td>
<td>3.3 V</td>
<td>5 V</td>
</tr>
<tr>
<td>164102</td>
<td>16 x 4</td>
<td>7 x 16</td>
<td>5.0 V</td>
<td>5 V</td>
</tr>
</tbody>
</table>

For detailed specification sheets, please visit www.jameco.com.
One-year warranty.
Appendix H

Resistive Touchscreen
Bergquist Part Number: 400427

Description: 6.400" 4-wire Resistive Touch Screen

Mechanical Dimensions and Construction.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Dimensions</td>
<td>5.760&quot; x 4.510&quot;, 146.30mm x 114.55mm +/- .020&quot;, +/- .50mm</td>
</tr>
<tr>
<td>Overall Thickness</td>
<td>.055&quot;, 1.4mm +/- .008&quot;, +/- .20mm</td>
</tr>
<tr>
<td>Viewable Area</td>
<td>5.236&quot; x 3.976&quot;, 133.00mm x 101.00mm +/- .020&quot;, +/- .50mm</td>
</tr>
<tr>
<td>Active Area</td>
<td>5.118&quot; x 3.839&quot;, 130.00mm x 97.50mm +/- .020&quot;, +/- .50mm</td>
</tr>
<tr>
<td>Nominal Glass Thickness</td>
<td>.043&quot;, 1.1mm</td>
</tr>
</tbody>
</table>

*See mechanical drawing for additional specification

Environmental Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature</td>
<td>-10°C ~ +60°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-40°C ~ +80°C</td>
</tr>
<tr>
<td>Constant Temperature/ Humidity</td>
<td>70°C / 80% RH / 500 Hrs. Tested at ambient temperature after cycle</td>
</tr>
<tr>
<td>Thermal Shock</td>
<td>-40°C ~ +80°C 60 min/cycle/10 times Tested at ambient temperature after cycle</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>Acetone, methylene chloride, methyl ethyl ketone, isopropyl alcohol, mineral spirits, unleaded gasoline, diesel fuel, antifreeze, vinegar, coffee, tea, cooking oil, most commercial cleaners including laundry detergent, and ammonia based glass cleaners 10 minutes at room temperature</td>
</tr>
</tbody>
</table>

Optical Characteristics

<table>
<thead>
<tr>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Transmission</td>
<td>&gt;75%</td>
</tr>
<tr>
<td>Haze</td>
<td>&lt;5%</td>
</tr>
</tbody>
</table>

Linearity Characteristics

<table>
<thead>
<tr>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction X</td>
<td>&lt;1.5% Linearity is the value of the max. error voltage</td>
</tr>
<tr>
<td>Direction Y</td>
<td>&lt;1.5% Linearity is the value of the max. error voltage</td>
</tr>
</tbody>
</table>
### Durability

<table>
<thead>
<tr>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activations</strong></td>
<td>10 Million</td>
</tr>
<tr>
<td><strong>Activation Force</strong></td>
<td>≤82g Stylus</td>
</tr>
<tr>
<td><strong>Top Film Hardness</strong></td>
<td>3H</td>
</tr>
<tr>
<td><strong>Tail Bond Strength</strong></td>
<td>&gt;13 lbs</td>
</tr>
</tbody>
</table>

### Electrical Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operating Voltage</strong></td>
<td>5.5V or Less</td>
</tr>
<tr>
<td><strong>Insulation Resistance</strong></td>
<td>≥ 10 MΩ at 25 V(DC)</td>
</tr>
<tr>
<td><strong>Electrostatic Protection</strong></td>
<td>Withstands 15KV air discharge</td>
</tr>
</tbody>
</table>

### Warranty

1-year limited warranty

### Mechanical Drawing

**See attached drawing**
Appendix I

Thermal Receipt Printer
**Feature:**
- Smart appearance
- Easy paper loading
- Low noise thermal printing
- Different interfaces optional
- Front panel make paper replacement easily
- Easily embedded to any kinds of instruments and meters

**Application:**
- Oiling Machine print proposal
- Queue machine Print proposal
- Recording Meter print proposal
- Self-service Print proposal
- Ticket Machine print proposal
- Medical instrument print proposal
- Weight Machine Print proposal
- Electric Instrument Print proposal
- Test Instrument Print proposal

**Specification:**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printing Method</td>
<td>Thermal Dot Line</td>
</tr>
<tr>
<td>Printing Speed</td>
<td>50-80mm/s</td>
</tr>
<tr>
<td>Resolution</td>
<td>8 dots/mm, 384 dots/line</td>
</tr>
<tr>
<td>Effective Printing Width</td>
<td>48mm</td>
</tr>
<tr>
<td>Character Set</td>
<td>ASCII, GB2312-80 (Chinese)</td>
</tr>
<tr>
<td>Print Font</td>
<td>ANK: 5x7, Chinese: 12x24, 24x24</td>
</tr>
<tr>
<td>Paper Type</td>
<td>Thermal paper</td>
</tr>
<tr>
<td>Paper Width</td>
<td>57.5±0.5mm</td>
</tr>
<tr>
<td>Paper Roll Diameter</td>
<td>Max: 39mm</td>
</tr>
<tr>
<td>MCBF</td>
<td>5 million lines</td>
</tr>
<tr>
<td>Interface</td>
<td>Serial (RS-232, TTL), Parallel</td>
</tr>
<tr>
<td>Insert Depth</td>
<td>50mm</td>
</tr>
<tr>
<td>Power Supply (Adapter)</td>
<td>DC5V-9V</td>
</tr>
<tr>
<td>Outline Dimension (WxDxH)</td>
<td>111x65x57mm</td>
</tr>
<tr>
<td>Installation Port Size</td>
<td>103 x 57mm</td>
</tr>
<tr>
<td>Color</td>
<td>Beige/Black</td>
</tr>
<tr>
<td>Operating Temp</td>
<td>5°C ~ 50°C</td>
</tr>
<tr>
<td>Operating Humidity</td>
<td>10% ~ 80%</td>
</tr>
<tr>
<td>Storage Temp</td>
<td>-20°C ~ 60°C</td>
</tr>
<tr>
<td>Storage Humidity</td>
<td>10% ~ 90%</td>
</tr>
</tbody>
</table>

Model No.: A2 Micro Panel Thermal Printer
Bibliography


