A Solution for Chicken Watering Issues

An Interactive Qualifying Project
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Austin Brothers Valley Farm

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Abstract

This project addressed some of the issues associated with watering systems for small chicken operations in New England. Interviews with New England extension agents and local farms, as well as a review of scholarly literature, extension websites, and other farming resources, highlighted both the importance of plentiful and quality water for the health and productivity of a flock, as well as the issues associated with maintaining a watering system. Our system reduces the labor associated with maintaining a watering system, while ensuring a plentiful and high-quality supply of water for a flock. The reduction in labor and water quality improvements that our system provides can help improve the productivity and profitability of small chicken operations in New England.

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Executive Summary

In the United States, there are over 137,000 farms that use poultry and egg production as a source of revenue (USDA, 2015). New England has thousands of these small chicken operations (Maine Farm Bureau, 2018). These small farms give consumers access to fresh meat and eggs, can foster community interaction, and benefit local economies by providing jobs and recirculating money (Farming Solutions, 2016; Schilling *et al.* 2012; Grubinger, 2010). However, running a small chicken operation in New England is expensive (Anderson, 2014), and the harsh and varied climates that occur in New England provide additional challenges. The labor for maintaining a flock of chickens is a significant expense, especially for operations that are small enough not to have automated systems. Maintaining an adequate water supply is particularly labor-intensive: water freezes, spills, leaks, can become contaminated, and can run out (Extension Agent C, personal communication, December 13th, 2017), and all these issues involve hands-on labor to correct. Also the water supply is of critical importance: “water is regarded as the most important nutrient” for raising chickens (Brake and Hess, 2001).

Many small chicken operations in New England rely on either a bell drinker (an inverted storage tank over a bowl) or a simple dish of water to provide water for their chickens (Extension Agent C, personal communication, December 13th, 2017). These systems require significant maintenance: they hold a limited amount of water, they become contaminated quickly, and they are prone to spilling and freezing (Frame, 2010; Wieland & Nolden, N.D.; Extension Agent C, personal communication, December 13th, 2017). A lack of water has been shown to reduce productivity in laying hens, and reduce weight gain in broilers (Frame, 2010). Also, contaminated water can cause disease outbreaks and other health issues for the flock (Frame, 2010; Houldcroft *et al.*, 2008).

This project involved the design of a water storage and delivery system for small chicken operations in New England, that will not freeze, maintains sanitation, and that consistently provides sufficient water regardless of any regularly occurring environmental factors. The goal was to create a template-type solution that can be scaled to meet the diverse needs of small chicken operations across New England. The project had six objectives: identifying the target audience, understanding the current state of technology, designing a system for the target audience, developing resources to share the design, verifying the resources and design, and publishing the resources and this report.

The first two objectives were completed through data collection and analysis of secondary sources, as well as semi-structured interviews with experts in the field of small scale chicken production. The team conducted extensive secondary research to gain a general background understanding of chickens, chicken farming, and current technology by reviewing relevant scholarly literature, how-to guides and manuals, and farming organization websites and forums. The team also conducted primary research through interviews with extension agents and local farms. The interviews with extension agents provided information on current problems and technologies in the industry, as well as expert advice on what features are of most importance in a watering system. The interviews with the owners of small chicken operations provided qualitative data on problems small chicken operations face, the problems of watering systems specifically, and what features are most important to a chicken watering system, from the perspectives of the farmers themselves. The data from the interviews, supplemented with secondary research, was sufficient for the team to define their target audience, small chicken operations in New England, as: chicken operations (including operations with either layers, broilers, or both) with flocks of ten to 500 birds. We selected this range of flock sizes because small chicken operations falling within this range tend to face the same difficulties: smaller flocks than ten birds often are “pet” chickens (Extension Agent C, personal communication, December 13th, 2017), while larger flocks are likely to have automated systems already (Extension Agent A, personal communication, December 14th, 2017).

The extension agents were selected through purposive sampling: the team researched extension agents in every New England state, and selected the two agents from each state with the most poultry experience to contact. Experience was determined from publications and the agents’ profiles on farming and governmental websites. Only three agents responded to requests for interviews. The information the team received from the third participant repeated and confirmed what we heard from the first two agents. Therefore, we concluded that we had reached saturation and further interviews with New England extension agents was unnecessary. Farms were selected based on convenience sampling, specifically location and connections with WPI. The team collected significant qualitative data from conversations with their sponsor, and then reached out to one other local farm for a farm visit. The information received from the three extension agents and two farms that we contacted provided us with a broad and comprehensive understanding of the issues chicken farmers face with providing water for their chickens. The extension agents each represent dozens to hundreds of farmers, and the two local farms gave us unique, contextualized insights.

With the information gathered from primary and secondary sources, the team proceeded to begin designing a watering system for small chicken operations in New England. The team initially considered several formal design processes, focusing on a traditional five-step approach and Axiomatic Design, and found that a formal design process was not appropriate for this situation. A design process is intended to create a single robust design, but the team’s goal for creating a watering system for small chicken operations in New England was not to create a single system, but instead to create a template for a flexible system based off of a series of preexisting parts that, when combined, would meet the varying needs of small chicken operations in New England.

To create the watering system template, the team reviewed research on current technology, as well as the data from interviews. Various recommended components were analyzed for cost and functionality through secondary research that verified their suitability for our project. The team selected the optimal set of components based on the interview data and research.

The final design comprised the following components: a barrel with a heater and a drinker line made from hybrid drinker cups and PVC pipe, all connected with a hose and valve, with heat cable preventing the pipes and hose from freezing. This system is scalable because the number of drinkers can be increased to accommodate a range of flock sizes by increasing the length of the drinker line, and the capacity of the storage tank can be adjusted by selecting a barrel that is suitable for the watering needs of the flock.

The team worked with their sponsor, Austin Farms, to tailor the general model to meet the farm's specific needs and to implement the tailored system at the farm as a verification of the functionality of the concept. Austin Farms is a small farm in Belchertown, MA, that primarily raises cattle for beef, but also has a flock of chickens and runs agritourist events. Their flock comprised about twenty layers at the time of building, but their flock fluctuated between twenty and fifty birds.

Approximately one week after implementation of the system, the team conducted a formal interview with Austin Farms to receive feedback on the success of the system. The sponsor, Austin Farms, thought that the system was successful in reducing the labor time behind providing water to their chickens. When asked how they felt about the system, they said, “I like how simple it is. It is very easy to do and adding additional components do not seem challenging” (Austin Brother’s Valley Farm, personal communication, April 25th, 2018). They also noted that the chickens appeared to have adjusted to the new system quickly. Through the evaluation we were able to better conclude that our designed watering system was both effective and comprehensible

In completion of this project, we were able to complete all of our goals and objectives with success. While our project’s mission was able to help minimize issues related to extensive labor on small chicken operations, many further projects would better improve these issues. One potential means of remediating this would be to research more efficient interior coop set-up to allow for more egg production in laying-hens. Also, we recommend a study on various agricultural marketing techniques. This would be helpful to small farm operations because it would allow for increased. It is important that the topic of small farming operations in New England are supported because they are pivotal components to Northeast agriculture.

Figure 1. The Chickens Using the System. This picture shows the chickens acclimating to their new system.

1. Introduction

Small farms give consumers access to fresh food, and benefit local economies, as most small businesses do, by providing jobs and recirculating money (Farming Solutions, 2016). New England has many locally owned farms, including thousands of small chicken operations (Maine Farm Bureau, 2018). These small chicken operations provide their communities access to fresh meat and eggs, and can indirectly provide localized environmental benefits, foster community interaction, and can contribute to the economy (Farming Solutions, 2016; Schilling *et al.* 2012; Grubinger, 2010). However, running a small chicken operation in New England is not easy: there are many costs to raising chickens (Anderson, 2014), and the harsh and varied climates that occur in New England provide additional challenges. Aside from food, the labor for maintaining a flock of chickens is a major expense (Anderson, 2014), especially for operations that are small enough not to have automated systems. Chickens need quality food, a clean and safe shelter, and access to sanitary liquid water (Frame, 2010; Wieland & Nolden, N.D.). Of those requirements, an adequate supply of water is one of the hardest to maintain: water freezes, spills, leaks, can become contaminated, and can run out. Many small chicken operations in New England rely on basic systems for providing water to their chickens: the most common systems are a bowl of water or a slightly more sophisticated bell drinker (a watering system that has a small inverted storage tank over a tray of water). These systems require significant maintenance: they become contaminated quickly, they are prone to spilling, and they are likely to freeze (Extension Agent A, personal communication, December 14th, 2017; Extension Agent C, personal communication, December 13th, 2017; Farm A, personal communication, December 8th, 201; Austin Brother's

Valley Farm, personal communication, October 22nd, 2017). They also hold a limited amount of water, and require frequent refilling, especially for a bigger flock (Extension Agent C, personal communication, December 13th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017).

Our goal is to design a water storage and delivery system for small chicken operations in New England that will not freeze, maintains sanitation, and that consistently provides sufficient water regardless of any regularly occurring environmental factors. The system will be designed to reduce the labor required for maintaining chickens by preventing the issues that require maintenance in bell drinkers, a bowl of water, or other simple systems. If the labor required to maintain the watering system is reduced with a more reliable and higher quality system, the cost of labor will be reduced. Labor is a significant expense for small chicken operations, so by reducing this cost the productivity, the profitability of an operation may increase (Anderson, 2014).

We are focusing on chicken operations in New England that have ten to 500 birds, a stationary structure, and electrical access to the chicken area. Chicken operations outside these parameters may benefit from our system, but we have limited our focus to make it possible for a singular (albeit scalable) design to satisfy the needs for our entire target population.

We will achieve our goal by completing six distinct objectives: 1) defining target audience and identifying system priorities; 2) understanding the current state of technology; 3) design a system for our target audience; 4) developing resources to share system design; 5) verifying the resources and design; 6) publishing resources and report. Our primary deliverables will be our report and a packet of resources that will enable the small chicken operations in New

England to scale our system to their situation and implement it on their coop, without any engineering background or specialized training.

In the report that follows, we first review the literature on the benefits and challenges of small chicken operations in New England, chicken health and care, watering systems, New England climates, and design processes. We then discuss our methodological approach, followed by our results. Both these sections are organized around the six fundamental objectives of our project; the methodology details the process we followed throughout this project, and the results discuss our major findings. These sections are followed by our conclusions and recommendations, in which we discuss what we have inferred from our project and what we suggest be done in future with respect to our work.

2. Literature Review

2.1 Introduction

In the United States, there are over 137,000 farms that use poultry and egg production as a source of revenue (USDA, 2015). New England is home to thousands of these chicken operations (Maine Farm Bureau, 2018). These operations can vary in flock size and purpose from farms with ten pet chickens to many-thousand bird commercial operations, producing and selling eggs or meat (Extension Agent A, personal communication, December 14th, 2017; Extension Agent C, personal communication, December 13th, 2017). Many small New England operations also follow free-range practices (Anderson, 2010). Free-range chickens need access to a coop that provides shelter from the weather and predators as well as outdoor space where they can move, dig, and eat. Most chicken operations in New England manually care for their chickens, requiring daily refilling of feeders and waterers (Extension Agent C, personal communication, December 13th, 2017). New England chicken operations have benefits to both the economy and environment but also face challenges in the labor required to maintain a healthy flock (Bare, 2012).

In this review of the literature, we will examine the water needs of small-scale chicken operations in New England that specialize in raising both broilers and egg-laying hens. We will also review the current literature on the needs and benefits of chicken operations. Properly maintaining a watering system at such an operation is time consuming and labor intensive, and an improperly maintained system jeopardizes the health and productivity of a flock. Waterers can freeze, spill, leak, and be contaminated with feces, food, and other debris (Anderson, 2010). Most operations that rely on manual labor to mitigate these problems are insufficient, and therefore many of these operations do not provide the adequate quantity and quality of water to their chickens.

Our goal is to design a lost-cost water storage and delivery system for chickens that will maintain adequate sanitation, consistently provides sufficient water regardless of any regularly occurring environmental factors, and will not freeze, leak, or spill. The system will reduce the labor required to maintain water on a small chicken operations and in turn will increase the productivity and profitability of such operations.

This literature review is comprised of four sections: benefits and challenges associated with small chicken operations, hen health and care, water systems, and site environment. Understanding the importance and complexities of small chicken operations will contextualize the water needs of small-scale chicken operations in New England. Literature focusing on hen health and care will ensure our system does not introduce other problems to a coop, endanger a flock, or negatively impact production. Literature on common poultry watering systems enabled us to understand what is “normal” for small chicken operations today, and understanding existing solutions and the current technology will allow us to create an improved system. Lastly, research on environmental conditions in New England ensures that we understand yearly climate variations so we can properly design a system to function year round.

2.2 Benefits Associated With Small Chicken Operations in New England

Small chicken operations provide many benefits to their communities, including access to fresh meat and eggs, indirect localized environmental benefits, fostering community interaction, and can contributing to the economy (Farming Solutions, 2016; Schilling *et al.* 2012; Grubinger, 2010). However, the two most significant benefits of small chicken operations in New England are their economic and environmental benefits.

Small chicken operations in New England bolster communities through their localized economic impacts. New England produces more than $250 million worth of poultry and eggs annually, in part through many small chicken operations (Darnton, 2012). These small chicken operations often purchase supplies locally, supporting other businesses (Cannella and Smith, 2015). In addition, small chicken operations help circulate money locally. Small chicken operations often sell their products at local markets (Cannella and Smith, 2015), and these markets can produce economic multiplier effects because the money circulates directly into the region (Darnton, 2012).

In addition to the economic benefits, many small chicken operations in New England have minimal environmental impacts, and sometimes even environmental benefits, due to the prevalence of free-range practices. Free-range chickens provide environmental benefits by reducing the need for harmful forms of pest control and fertilization. Chickens are natural foragers and will eat insects that are harmful to plants (Murtoff, 2015). They also produce manure rich in nitrates that can be used as an effective fertilizer (Murtoff, 2015), and chickens that have space to roam are able to act as manure spreaders that fertilize soil (Murtoff, 2015). The pest control and fertilization provided by free range chickens can replace environmentally damaging pesticides and fertilizers. Also, products from free range chickens may help reduce the demand for mass-produced poultry products (United Poultry Concerns, 2009, Environmental Impacts). Large-scale farms are often associated with practices that are detrimental to the local environment because of soil and water pollution causing large-scale infertility of local soil (United Poultry Concerns, 2009, Environmental Impacts).

2.3 Challenges Associated With Small Chicken Operations in New England

Running a small chicken operation in New England is neither easy nor cheap: chickens have many needs, resulting in many costs (Anderson, 2014). Chickens need quality food, a clean and safe shelter, and access to sanitary liquid water (Frame, 2010; Wieland & Nolden, N.D.). This is a particular challenge for small chicken operations because they tend to lack automated systems, so the labor required to meet these needs becomes a major expense (Anderson, 2014).

Out of the requirements for raising chickens, an adequate supply of water is one of the most labor-intensive needs for small chicken operations in New England to meet (Frame, 2010; Wieland & Nolden, N.D.; Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017). Water freezes, spills, leaks, can become contaminated, and can run out (Frame, 2010; Wieland & Nolden, N.D.; Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017). Also, the harsh and varied climates that occur in New England provide additional complications, such as dramatic temperature fluctuations and freezing (Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017; Farm A, personal communication, December 8th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017). However, maintaining an adequate water supply is critical to the productivity of a small chicken operation: flocks that have plentiful water, among other things, are healthier and more productive than those that do not (Frame, 2010; Wieland & Nolden, N.D; Poindexter, 2016; Maharjan *et al.*, 2016).

Many small chicken operations in New England rely on rudimentary systems for providing water to their chickens: the most common systems for small operations are a bowl of water or a slightly-more-sophisticated bell drinker (a watering system that has a small inverted storage tank over a tray of water) (Extension Agent C, personal communication, December 13th, 2017). These systems require significant maintenance: they become contaminated quickly, they are prone to spilling, and they are likely to freeze (Extension Agent A, personal communication, December 14th, 2017; Extension Agent C, personal communication, December 13th, 2017). They also hold a limited amount of water, and require frequent refilling, especially for a bigger flock (Extension Agent C, personal communication, December 13th, 2017, farmers). The high level of maintenance required by these watering systems significantly contributes to the challenges of managing a small chicken operation.

Sanitation is another major concern for any small chicken operation (Extension Agent A, personal communication, December 14th, 2017; Extension Agent C, personal communication, December 13th, 2017). Insufficient cleaning of any part of the coop can lead to the spread of disease and allow harmful microorganisms to thrive (Frame, 2010, Wieland & Nolden, N.D, Extension Agent A, personal communication, December 14th, 2017). A sanitary watering system is of particular importance because clean and safe water is necessary for a healthy and productive chicken operation: poor water quality has been linked to health problems and a loss of productivity in flocks (Maharjan *et al.*, 2016). However, the sanitation of a watering system is difficult to maintain because chickens are likely to contaminate any system in their coop with litter, feces, and food (Extension Agent A, personal communication, December 14th, 2017, sponsor/farmers). Smaller chicken operations tend to have less sophisticated watering systems, such as bowls or bell drinkers (Extension Agent B, personal communication, December 20th, 2017, Extension Agent C, personal communication, December 13th, 2017). Open bowls and bell drinkers are particularly difficult to maintain because the tray of drinking water is often close to ground level and constantly exposed to contaminants from the chicken coop (Extension Agent B, personal communication, December 20th, 2017, Extension Agent C, personal communication, December 13th, 2017).

Another significant challenge faced by small chicken operations is preventing excessive moisture in the coop. Chickens do best in a dry environment; excessive moisture can reduce the air quality and can cause a variety of health problems in the chickens, such as such as foot problems (Donald and Simpson, 2006). Maintaining a reasonable level of humidity involves many considerations, such as ventilation (Donald and Simpson, 2006), but preventing leaks and spills of the watering system is also an important factor (Extension Agent C, personal communication, December 13th, 2017). Bowls and bell drinkers are particularly prone to spilling because they not only lack valves and shut offs that might be present in more sophisticated systems, but they are also lower to the ground, and are generally less securely mounted than automated systems, resulting in a higher chance of spillage (Extension Agent B, personal communication, December 20th, 2017, Extension Agent C, personal communication, December 13th, 2017 sources: farm visits, extension agents, pull a manual for setting up bell drinkers and drinker lines).

Freezing is also a major challenge for chicken farms in New England: the extremely cold temperatures in winter make maintaining liquid water difficult (Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017; Frame, 2010; Farm A, personal communication, December 8th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017). Also, this issue can be compounded because the increase in feed consumption during the winter can lead to an increase in water intake (Larson, 2016). Providing consistent liquid water is a challenge for any New England chicken operation, especially smaller operations that typically do not heat their watering systems (Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017). One of the most common methods of preventing water systems from freezing is regularly adding hot water to bowls or bell drinkers during cold spells (Extension Agent A, personal communication, December 14th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017), but this system is labor-intensive, wasteful, and inconsistent: bowls and bell drinkers must be manually filled multiple times per day, the water that is added must be heated, the cold or frozen water that is being replaced must be reheated or discarded, and any lapse in the refilling schedule results in the chickens lacking a water source (Extension Agent C, personal communication, December 13th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017). Although large chicken farms with thousands of birds often have heated water systems, small chicken operations in New England tend to have no heat and, therefore preventing freezing is a major challenge (Extension Agent A, personal communication, December 14th, 2017; Extension Agent C, personal communication, December 13th, 2017; Farm A, personal communication, December 8th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017).

2.4 Water Systems

An adequate water supply is one of the most important resources that must be maintained in chicken coops (Frame, 2010; Wieland & Nolden, N.D, Poindexter, 2016, Maharjan *et al.*, 2016; Extension Agent C, personal communication, December 13th, 2017). There is a direct relationship between feed and water intake: chickens tend to eat less when they lack sufficient water (Frame, 2010). Therefore, proper water consumption promotes good health and increases egg production or, in the case of meat birds, weight gain (Frame, 2010; Wieland & Nolden, N.D; Poindexter, 2016, Maharjan *et al.*, 2016). The exact water needs of chickens vary for a number of reasons including type of bird (broiler vs layer), age, and environment temperature (Frame, 2010; Wieland & Nolden, N.D; Extension Agent A, personal communication, December 14th, 2017). On average however, in cold weather chickens consume 6 to 11 ounces of water per day, and in hot weather they can consume twice that (Frame, 2010).

In order to meet the watering needs of their birds, small chicken operations need a watering system that provides consistent water and addresses the challenges outlined in section 2.3. Any watering system, regardless of sophistication, has two main components: a water source (or a storage container), and a delivery system. We will focus on systems with storage tanks here, because most small chicken operations do not attach their watering systems directly to their water supply (Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017). Also, it must be noted that some watering systems do not have separate storage tanks because the drinking system and the storage system are integrated: a bowl or dish of water holds the water and provides a place for chickens to drink from, while bell drinkers have integrated storage tanks.

For systems with a separate storage tank, there are two basic variables that relate to the function of the storage tank: volume and material. The necessary volume of the tank can be found through the following equation:

$$Tank\ Size\ =\ Number\ of\ Birds\ *\ 22\ oz\ *\ Desired\ Days\ Between\ Fills\ *\ 0.0078125\ (Gal/oz)$$

This equation is an intentionally generous estimate, based on the maximum average water consumption per bird (Frame, 2010), and a Gallon-Ounce conversion factor. As the equation indicates, there is no one "correct" size for any given operation. There is also not a single "correct" material for a storage tank: any material that will hold water and will not leach harmful chemicals into the water is acceptable. Not leaching chemicals is an important consideration because some materials pose a risk of contaminating the water (Collentro, 2012). Based on a review of products that are available online and example systems documented on blogs and forums, two common storage tank materials for large systems are plastic and metal. A price comparison for these components indicates that plastic containers tend to be cheaper, but many farms will choose to use whatever container they have readily available (Extension Agent C, personal communication, December 13th, 2017; Farm A, personal communication, December 8th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017).

Aside from the storage tank, the other main component of a chicken watering system is the water delivery system. A review of forums, blogs, farming organization websites, as well as conversations with extension agents identified the three most common delivery systems as nipple rings drinkers, bell drinkers, and dishes of water.

Nipple drinkers are the most common water delivery system in large chicken operations, but are also used by some smaller operations (Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017). Nipple drinkers distribute water through tiny spouts positioned above the chickens' heads. The chickens peck at the spouts to drink: their pecking releases water which flows down their throats (Houldcroft et al, 2008). This system eliminates spills, but it forces chickens to drink in an unnatural position (Houldcroft et al, 2008). Naturally, chickens drink by scooping water with their beaks, and the unnatural drinking position required by nipple drinkers reduces chickens' water consumption which is a key factor in both chicken health and egg production (Houldcroft et al, 2008).

Bell drinkers, figure 2, are one of the most common delivery systems used by small chicken operations (Extension Agent C, personal communication, December 13th, 2017). Bell drinkers comprise a trough encircling a bell-shaped dome. The dome holds water that replenishes the trough, reducing the frequency of refills. The trough is close to the ground, so chickens can drink naturally (Houldcroft et al, 2008). However, because of the trough height, bell drinkers are easily contaminated with feed or bedding. The system can also spill easily leading to unsanitary conditions which can cause health problems (Houldcraft et al, 2008).

Figure 2.

Amazon. (2018). Bell-Matic Poultry Waterer. Retrieved from: www.amazon.com

The most basic of the common watering systems is an open container of water (typically a bowl or trough). A container of water functions similarly to the bell drinker, without the advantage of being self-replenishing: it allows chickens to drink in a natural position, but it spills and is easily contaminated in the same ways as the bell drinker (Extension Agent C, personal communication, December 13th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017). However, despite the disadvantages, this system is relatively common with small chicken operations (Extension Agent C, personal communication, December 13th, 2017).

Although the three most common systems are the nipple drinker, the bell drinker, and a dish of water, there is a new system that has been recently developed that incorporates elements of both a nipple drinker and a bowl (Zen Cart® Team, 2018). Similarly to a nipple drinker, the system requires chickens to peck to release water (Zen Cart® Team, 2018). However, instead of releasing water into the chicken's throat, the water is released into a dish (Zen Cart® Team, 2018). This hybrid drinker reduces spillage, water waste, and chances of contamination common with open containers and bell drinkers while allowing chickens to drink water naturally (Zen Cart® Team, 2018).

2.5 Environment of Our Research Site/Case Study

Environmental conditions plays a major role in the design of a chicken coop and the watering system within it. With our focus being on operations in New England we must take into account the large climate range experienced annually. In the summer, temperatures average over 65 degrees F, which increases water consumption. This increase must be taken into account when looking at storage capacities and rate of delivery. In the winter temperatures average 30 degrees F and can get as low as -10 degrees F (Current Results, 2018). This requires that our system can resist freezing temperatures and maintain operation year round. With the case study being located in Massachusetts, our system can expect to be exposed to 45 inches of rainfall (U.S. Climate Data, 2017).

3. Methods

Our goal for this project was to design a complete chicken watering system that helps small New England farms with chickens increase productivity and profitability by decreasing the labor required for maintaining their chickens. To achieve this goal, we had the following six objectives: 1. define the target audience and identify the challenges they face, 2. understand the current state of technology, 3. design a system for our target audience, 4. develop resources that enable system implementation, and 5. verify the design and, 6. publish resources and report. Throughout this project we conducted secondary research through a review of scholarly literature, governmental data sets, and other less technical resources such as how-to manuals and blogs. We also conducted primary research in the form of interviews, both with farmers and extension agents. These interviews fell under the scope of human research as defined by the WPI Institutional Review Board. Therefore, our interview template was examined by the WPI Institutional Review Board to ensure proper research ethics. During our interviews we utilized a semi-structured format with a set of standard questions but allowed for the interview to go beyond the set of questions. Anonymity has been granted to those interviewed as a confidentiality measurement.

3.1 Defining the target audience and identifying system priorities

To complete the first objective, we needed to identify common characteristics of small New England farms with chickens. We used that information to define our target audience. Once defined, the needs and concerns of our target audience that affect a chicken watering system were used to define the priorities of our system.

3.1.1 Identifying common characteristics

To identify common characteristics of small New England farms with chickens, we first conducted secondary research on chicken farms and chicken farming. We reviewed scholarly articles, how-to guides, and farming-related discussion boards and forums to gain a general understanding of practices, characteristics, and concerns of small farms. This background knowledge allowed us to identify reasonable interview questions and define data-collection categories. We then identified characteristics of small farms with chickens in New England consulting extension agents, interviewing two locally-owned farms and conducting additional secondary research.

We selected extension agents using purposive sampling: two extension agents were found for each New England state through Google searches and a review of university, governmental, and farming-organization websites. When more than two agents were found for a state, two agents were selected based on the relevancy of their specializations and publications. We contacted the selected agents and asked for interviews. Out of the ten agents contacted, four responded. We decided to interview the extension agents who had responded to the interview requests, and only pursue contacting additional agents if we needed more information.

The interviews with the selected agents were conducted by phone, and lasted about forty-five minutes. The interview questions were relatively broad, focusing on regional trends in poultry farming, common problems, approximate distributions of farm sizes, levels of sophistication of various categories of poultry farms, and the most common watering systems in use (see Appendix A). We also asked the extension agents for recommendations for how to define a target audience for our project, and we asked for contact information for local farms who might be willing to speak with us.

In addition to the interviews with extension agents, we spoke with two farms: our sponsor, and one other local farm. We chose our sponsor and the other local farm out of convenience as we had previously contacted them. In both cases we visited the farms for other aspects of our project and we did not conduct a formal interview. However, through informal conversation about chickens and watering systems, we learned about the similarities and differences between the farms, and how farms of their respective scales might be categorized. Many of the characteristics talked about at the farms aligned with what we had found through interviews with the extension agents.

3.1.2 Defining target audience

After we had completed interviews and defined common characteristics among small scale chicken operations we began defining our target audience. To define this audience, we created a set of criteria that encompassed the largest possible portion of small farms in New England that have chickens, while maintaining enough consistency within that group to have a single, scalable design.

The criteria was based on our conclusions from analyzing the data collected from research and interviews. We analyzed the quantitative data through statistical analyses and graphs, quantified the qualitative data by counting themes and topics across the interviews, and reviewed any un-quantifiable data though meetings and discussions.

3.1.3 Determining the priorities for our system

Once we determined our target audience, we isolated all of our data that was relevant to farms that fall within the defined target audience. We then analyzed that data to determine the concerns and needs of our target audience that directly relate to a chicken watering system. We prioritized the concerns and needs and analyzed each based on how common the concern or need was within our target audience, and how important farmers or experts in the field felt the concern or need was. The concerns and needs were then translated into physical features of the watering system. The features identified were recorded and organized in a list that capture both the function of the feature and its relative importance.

3.2 Understanding the current state of technology

To efficiently produce the best design possible, we needed to understand existing watering system technologies including catchment, storage, and delivery systems, as well as understand the current technology for chicken coops, such as building materials and heating systems. The team gathered information from journal articles, owner's manuals, supplier websites, product reviews, blogs, forums, and patents to learn what components are currently available and what their features are. Through interviews with farmers and extension agents, the team learned what technologies are most commonly used and the advantages and disadvantages of various technologies.

We also researched general methods of connecting pipes and other relevant components by reviewing supplier websites, online reviews, and how-to manuals and videos.

3.3 Design a system for our target audience

To design a system for our target audience, we first needed to select a design process for our project. We evaluated two primary design processes, a traditional engineering design process and Axiomatic Design, based on their suitability for our situation. The traditional design process we looked at incorporated the use of a design matrix and followed a sequential path of design, prototype, test and reiterate if needed. The Axiomatic Design process took a different approach where we looked at functional requirements (the system priorities) and the associated design parameters of each; creating a detailed web of features and components.

Unlike many design situations that have a single objective or deliverable, our project's goal was to create a model for a system that can be applied to a variety of situations (i.e. any member of our target audience). This meant that our design process needed to create a design that encompassed a variety of needs while still being flexible. Our design also needed to be sufficiently detailed to allow our audience to reproduce our model, without providing overwhelming amounts of technical information.

We compared the advantages and disadvantages of the two design processes including the ability of the process to achieve a flexible design, its overall efficiency, and the familiarity the team had with each. All members of the team had experience with traditional design processes, while only one member had experience with the Axiomatic Process. However, the structured approach of the Axiomatic Design process appealed to the team: the structure demanded by the Axiomatic Design process results in all design decisions being traceable, which was essential for creating a flexible design. Axiomatic Design is also considered to be an efficient process by design experts (Brown, personal communication, 15th February 2018).

After opting to use Axiomatic Design for the project, the team began a Design Decomposition (decomposition) for the project using Acclaro software. The decomposition is a central part of the Axiomatic Design process (see results section for details). The team created 4 levels of the decomposition (see Appendix B) over the course of several meetings. However, the decomposition did not go smoothly: after the first few levels, the team got stuck on how to proceed with the decomposition.

The team arranged a meeting with Dr. Chris Brown, a Professor of Mechanical Engineering at WPI and an expert in the field of Axiomatic Design. In the meeting, the issues with the decomposition were exposed: the team had not correctly decomposed some of the higher-level parameters, and most importantly, the team was not approaching the decomposition with a solution-neutral mindset (see Lit review).

Although the feedback from Professor Brown provided a path for the team to correct the decomposition, the team opted to abandon the Axiomatic design process altogether. The team chose to move forward with a design process driven by stakeholder and expert knowledge obtained through interviews with farmers and extension agents, and through the team's methodological process of determining the priorities of the system, and understanding existing technologies (see 3.1 and 3.2). Through this design process driven by stakeholder and expert-driven knowledge, the team had determined the best components for the system already. Because the components were predetermined, a design process to determine the best components was redundant.

After this revelation, the team transitioned into a research-based design approach. The team reviewed their research and determined the best base components for their solution. The team then reviewed shopping websites and customer reviews to determine the exact products (or more specific categories of products) to recommend to the target audience. Once all the components were selected, the team reviewed examples of systems and commonly available materials to find an efficient methods of connecting the components together in a system.

These decisions were recorded through minutes and other shared documents, but not documented officially or following any set process (as often happens in a formal design process). The team converted the unformatted design notes into publishable documentation while creating materials (see 3.4).

3.4 Develop resources to share system design with other farmers that enable system implementation

Our main deliverable will be a resource that allows farms within our target audience to tailor our design to their specific needs, and comprehensive enough to allow users to build our design. To produce a useful resource, we must determine the most effective method of conveying our information and the most effective medium for publishing our resource. To determine the most effective structure, we considered appearance, relevancy of information, and information presentation.

We will approached determining the structure through primary and secondary research. Primary research with experts in the field of small farming guided us to choose the appropriate structure because they are aware of effective structures of conveying information. Secondary research conducted by viewing several examples of informative material that are popular gave us insight into proper structure and methods of conveying information Possible structures we determined for our resources include charts and tables, a descriptive manual, and an infographic.

Once the team had determined the most effective method of conveying information, a meeting was set up with a graphic design professional, Jessica Baer. In this meeting we learned about programs available to create graphics as well as proper structure and styles. The team then conducted secondary research looking at similar graphics to obtain inspiration. A draft was created and reviewed by both the graphic design professional and our advising professor. Comments from these reviews were taken into account and a final draft was created. This was reviewed once more by the graphic professional before the final graphic was completed.

At the end of the resource we created a section that prompts the individual viewing to find more information at an external link. This link directs the individual to a PDF document that is a summary of our report which contains the executive summary and details on the final system we built for our sponsor including pictures, issues we encountered, further recommendations, and information on where we purchased our supplies.

With the completed resource graphic we looked to determine the best medium to publish it to. To find out which medium is best for our audience, we consulted experts in the field who have worked with small scale farms. Experts in the field were able to give us a broad, generalized medium that most of our demographic is accustomed to. Once we decided on an appropriate medium for our resource, we published it ensuring that the publication is convenient and efficient.

3.5 Verifying the System Design

Once we created the design, we verified its effectiveness by implementing the system at our sponsor's farm. This validated our design, and provided us with information about areas of our resources that need to be improved, modified, or removed. The successful implementation of the system provided validation of the design, and the few sticking points we encountered during construction indicated areas of the resource documents that should include extra detail.

Before we began construction, we discussed the system options with Austin Farms to ensure that our project stayed within the budget and met the needs of the farm. This interview took the place of using the resources to tailor the system to the farm, and provided the specifications needed to tailor the general design to Austin Farm's situation.

We will construct the system at Austin Farms in mid-April. The physical construction process will validate our design by making obvious any overlooked design issues. It will also highlight areas of our resource document that may need extra detail for clarity, such as less-obvious required features of components, or particularly difficult steps of construction.

After building the system, we will ask Austin Farms to monitor the system and note how the system affects the amount of time and labor they must put toward their flock. We will also ask them to keep track of how frequently the system needs to be refilled, and to record any problems, such as leaks or spills. We will return to Austin Farms in late April to interview them about how the system worked, and to collect any quantitative data they have on water use or issues that arose.

The final interview will provide the data that validates our design: it will be obvious that our solution is feasible if the system runs without issue. The interview will also provide an opportunity for us to learn of any other concerns or considerations that Austin Farms had that should be reflected in our design or resources.

3.6 Publishing resources and report

Our research was automatically published as a part of WPI's IQP process. However, to increase the impact of our project, we chose to share our research with New England farming organizations who will publish and distribute our resource. We found organizations by asking farmers what organizations they are affiliated with or get information from, by obtaining recommendations from extension agents, and by searching for organizations online. We narrowed our selection based on the potential impact of the organization and whether they have a history of publishing guest papers or research. We then provided our report and the companion resources we created to organizations that were willing to publish our work.

4. Results

4.1 Defining the target audience and identifying system priorities

Our defined target audience dictated the priorities of our system; the requirements of a watering system vary with operation size. Drawing on the insights of extension experts, farmers, and scholarly literature, we created our own term and definition for our target audience because no pre-existing terms adequately described our situation. We titled our target audience "small chicken operations" and defined them as chicken operations with ten to 500 birds. We did not differentiate between layers and broilers because both types of birds require water and have similar needs in terms of a watering system. However, we did limit the scope of our project to New England because regional climate variations do have a significant impact on the requirements of a chicken watering system, for example, freezing is less of a concern in southern regions. Once we identified our audience, we determined the needs and characteristics of farms within that population through farm visits, interviews with extension agents, and secondary research. We used that information to identify the priorities of our watering our system.

4.1.1 Identifying and defining target audience

Defining our target audience was fundamental to our project because the needs of our target audience determined the requirements of our system. Although we considered preexisting terms and investigated several methods for characterizing a reasonably-sized group of chicken operations, ultimately we defined our target audience based on flock size. We focused directly on flock size because although all chickens have the same basic needs such as food, shelter, and water (Jacob, 2015), the way those needs are met, and therefore the requirements of an applicable watering system, will vary most with operation size (relative to other parameters) (Extension Agent A, personal communication, December 14th, 2017; Extension Agent C, personal communication, December 13th, 2017; Farm A, personal communication, December 8th, 2017; Austin Brother's Valley Farm, personal communication, October 22nd, 2017) .We titled our target audience "small chicken operations", and defined it as a chicken operation with ten to 500 birds. We opted to create our own definition because through secondary research, we found that there was not a preexisting term that would fit our project's needs. Therefore, we had to create our own definition, which we did after interviewing extension agents across New England, requesting advice and information regarding what a good target audience would be and how to identify that target audience.

We had initially hoped to use a variation of "small chicken farms" to define our target audience. However, we found that this was an impractical approach because the only official definition we found was irrelevant, and otherwise interpretations of the phrase vary widely across literature. The only official definition that we found for "small farms" was from the USDA census: "small farms [are] farms with $250,000 or less in sales of agricultural commodities" (USDA, 2007). This definition was irrelevant to our project, because the finances of farms are outside of the scope of our research. Also, the definition also does not specifically consider chickens, and overall farm profits are a poor way to define the size of a chicken operation because a farm whose primary focus was poultry and a farm with a few chickens on the side might both fall under the census definition of small farms, but would have vastly different requirements for their watering systems. Beyond the USDA definition, we did not find other formal definitions, and we found that the term "small farm" is rarely used in accordance to any standardized definition.

We also investigated other terms associated with chicken farming, such as “free range” and “pasture based”, hoping that they would help characterize our target situation. Unlike “small farms”, both of these terms almost-universal definitions, and are directly applicable to chicken farms (Certified Humane, 2014). However, including these terms would not improve our definition: our definition needed to set bounds on the characteristics of a chicken operation that would affect a watering system, and the level of outdoor access the chickens have is largely irrelevant to watering system requirements.

We decided it would be better to create our own definition and term rather than use an unclear and inaccurate preexisting term. We approached three extension agents across New England for advice on characterizing and defining our audience. An extension agent works as a researcher with an agricultural focus that brings scientific discoveries and knowledge to educate farmers. These agents are reliable sources because they are professionals in the field of agriculture. The extension agents recommended three parameters that we could use to build a definition: flock size, feeding system, and sales (Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017). The flock size was the most-recommended parameter for our target audience, and is what we ended up using in our definition. However, the range extension agents suggested looking at varied. Two agents suggested considering a range of fifty to a few hundred chickens; one agent said that an operation with at least fifty chickens was “in business” (Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017). Another agent indirectly suggested we consider flocks of over ten birds by stating that a flock of less than ten birds were “pet chickens” (Extension Agent C, personal communication, December 13th, 2017).

The other parameters suggested by the extension agents effectively formed indirect ways of quantifying a “small” chicken operation. One agent suggested using the feeding system as a parameter that would result in a reasonable flock size. This agent explained that any operations that had more than 1000 birds would use bulk feeding systems, and therefore enough birds to warrant a bulk feeding system defined a “serious” business (Extension Agent A, personal communication, December 14th, 2017). Another agent recommended that we characterize farms was based on where they sold their products: smaller operations tend sell their products at farm stands or farmers markets (Extension Agent B, personal communication, December 20th, 2017).

We considered all the suggestions for how to characterize our target audience, and decided to set our definition on a number of birds because indirect parameters, such as feeding systems or sales, would lead to an unnecessarily complicated definition. We used what the extension agents told us about flock sizes as a baseline: we initially set our range to ten to 1000 chickens. We set the lower bound to ten because flocks of less than ten birds are generally pets (Extension Agent C, personal communication, December 13th, 2017), and owners of pet chickens likely have different priorities than people trying to make a profit (for example, people with pet chickens might have more money to spend on their flock) (Extension Agent C, personal communication, December 13th, 2017). We set the initial upper bound of our target audience to 1000, because, based on our interviews with extension agents, we decided it was reasonable to assume that larger operations would already have automated watering systems (Extension Agent A, personal communication, December 14th, 2017).

We considered shifting our lower bound to 50 chickens because two extension agents had said that 50 chickens was a good number to characterize a business. However, some of the local farms we researched, including one we visited, had smaller flocks--the farm we visited had a flock of 25--but they still showed interest in an improved watering system. We decided that most designs that would work for ten chickens could reasonably be scaled to work 50, and therefore there was no reason to exclude operations with ten to fifty chickens from our target audience.

We did shift our initial upper bound of 1000 chickens to 500 chickens to ensure that our target audience did not include farms that already had sophisticated watering systems. This was because some of the farms we researched including one we visited, had more sophisticated systems with less than 500 birds, and we felt that a cutoff of 1000 birds would include too many farms with already-sophisticated systems.

4.1.2 Determining the priorities for our system

All coops must provide drinking water, food, a consistent light source, and adequate, clean, dry, and draft-free space for their chickens (Frame, 2010; Wieland & Nolden, N.D; Extension Agent A, personal communication, December 14th, 2017; Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017). Through interviews with extension agents, we learned that larger operations meet these requirements with automated systems, whereas smaller operations meet these needs with manual labor (Extension Agent A, personal communication, December 14th, 2017; Extension Agent C, personal communication, December 13th, 2017). For example, large operations tend to have bulk feeding systems and automated watering, as well as a climate-controlled environment (Extension Agent A, personal communication, December 14th, 2017), whereas small operations have containers or simple systems for feed and water, that must be manually replenished regularly (Extension Agent A, personal communication, December 14th, 2017). Because we defined our target audience as small chicken operations, the priorities of our system assume an audience that does not already have automated systems. Also, because our project focused on watering systems, our system priorities had little to do with coop requirements other than providing drinking water: our overarching priorities were to provide an improved watering system, and to not negatively impact other requirements of the coop.

Through interviews, we determined two primary functions of a watering system: storing water and delivering water (Austin Brother’s Valley Farm, personal communication, October 22nd, 2017). From this, our priorities became completing each of these functions efficiently, and preventing failures that would compromise these systems or the other requirements of the coop, such as leaks, structural degradation of the coop, introduction of rodent holes, and introducing stress to the flock.

Storing water is one of the key components that our system needs to include. Within the storage system there are also priorities that need to be accounted for. One priority is that is the water inside the tank remaining liquid, which is a significant issue for farmers in New England who are managing freezing weather. In New England, weather can reach -10 degrees (Current Results, 2018), so our storage system must have a heating system to ensure water will flow even on the coldest winter days. Another priority of the storage system is that the water remains sanitary: there must be a sanitation system built in to the watering system, or the watering system must be easy to clean. One way to eliminate bacteria is to use UV Radiation (2.4.4 Water Sanitation). The storage tank must also have sufficient volume: reducing the frequency the system needs to be refilled is a major priority in order to save on time and labor (Austin Brother’s Valley Farm, personal communication, October 22nd, 2017; Extension Agent C, personal communication, December 13th, 2017). Also, to avoid damaging or weakening other features of the coop, the tank must not spill or leak (Extension Agent C, personal communication, December 13th, 2017).

The water delivery system has several priorities, too. One priority of the delivery system is that it has an appropriate number of drinkers. This number will vary depending on the flock size. Another priority is that the drinkers are something the chickens can adapt to, and that the water delivery method does not result in decreased water consumption. Also, similarly to the storage tank, the delivery system must not spill or leak because it could compromise other features of the coop (Extension Agent C, personal communication, December 13th, 2017).

Aside from technical design constraints, there are also a few priorities for the system that are imposed by logistics and the realistic situation of our target audience. Aside from safety, the most important priority for the watering system is that it is cost efficient (Extension Agent B, personal communication, December 20th, 2017; Farm A, personal communication, December 8th, 2017; Austin Brother’s Valley Farm, personal communication, October 22nd, 2017). Our target audience comprises of mostly for-profit operations, and a system that is not cost-efficient would therefore be of little use. Also, our system must comprise standard parts: although we have the ability to design and fabricate custom parts if necessary, our audience is realistically limited to parts available through hardware stores, farm supply stores, and online retailers. In addition, the system design must be flexible and scalable, because farms are likely to opt to use materials they already have when possible, and as our audience encompasses a wide range of flock sizes, the needs of various members of our target audience could vary greatly.

4.2 Understanding the current state of technology

In order to understand the current state of watering technology used by small scale chicken operations, we interviewed extension agents to get a baseline of information and reinforce that information with secondary research. With thorough research of the topic, we learned that there is “no one system for watering chickens” (Extension Agent C, personal communication, December 13th, 2017).

In order to define the current technology of watering systems, we had to learn about the current technology of the chicken coops that the watering systems attach to. From this secondary research we were able to determine that the two styles of chicken coops are stationary and mobile (Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017).

From our interviews with extension agents, we learned that while no one watering system is exclusively used, the entire industry is *saturated* with just a few different methods. The most common types of watering systems are bell drinkers, nipple drinkers, and standard bowls of water (Extension Agent B, personal communication, December 20th, 2017; Extension Agent C, personal communication, December 13th, 2017). While these are the most common they all have similar drawbacks. All of the three systems have issues with leaking that can lead to contamination.

We also learned about the storage and sourcing of water. From a field visit with a small scale chicken operation, we learned that one method of water storage is using a 40-gallon plastic drum. We learned from this visit that a difficulty faced with 40-gallon plastic drums is that, depending on the flock size, it needs to be refilled often. Home wells are the primary source of water for some small scale chicken operations. This is due to the rural setting of most of the target audience and because the ground well is already in place, requiring no extra implementations (Farm A, personal communication, December 8th, 2017). Rainwater harvesting is another source of water for our target audience as well as ponds that collect water to feed livestock, but it is rare for our target audience to rely on these methods because of labor requirements and cost (Innovative Water Solutions, 2015).

Lastly, we needed to research one of the most important parts of our designing process: how to keep water from freezing. Since our target audience is located in New England, winter can be particularly challenging when attempting to keep water from freezing in sub-zero temperatures (Current Results, 2018). From our interviews with extension agents, we learned that heated ribbon tape is a commonly used method in preventing water from freezing. Another method of heating are heat lamp bulbs. While the latter is a common method, there is an inherent fire hazard. Secondary research highlighted heated storage tanks utilizing electrical heaters submerged at the bottom of the tanks to keep the water from freezing. This method is advantageous because it requires no external heating source but can cost significantly more than other methods (Drovers, 2013).

4.3 Design a system for our target audience

The team initially selected the Axiomatic Design process (see 4.3.1), and began to implement it. However, the team transitioned to a research-based approach after determining that the Axiomatic Design approach was not applicable to the project’s needs. Throughout this transition, however, the team had many revelations about the applicability of the Axiomatic Design process to situations outside of a traditional design setting.

4.3.1 An overview of Axiomatic Design

Most traditional design processes involve some variation of the following steps: define the problem; research; brainstorm or generate ideas; develop, analyze, and select the best idea; prototype; test and analyze the solution; and improve the solution. Traditional design is algorithmically based, and a good design is considered such because it was the result of a good procedure (Brown, 2011). Axiomatic Design is still an algorithmic process, but it provides certain rules to follow and judge designs by (Brown, 2011).

Unlike traditional design, Axiomatic Design focuses on two rules, called “axioms,” which are universally applicable criteria for a “good” design (Brown, 2011). The first axiom is to “maximize the independence of the functional elements” (Brown, 2011); this axiom provides control and adjustability in the result (Brown, 2011). The second axiom is to “minimize the information content” (Brown, 2011); this axiom ensures that the solution that is most likely to succeed is selected (Brown, 2011). Axiomatic Design also has an unusual but highly systematic process associated with it, comprising mapping “Functional Requirements” to “Design Parameters” by way of a “zig-zag decomposition”. Functional Requirements (FRs) are, as the name implies, what the required function is. FRs describe the action that needs to be completed and start with verbs. Design Parameters (DPs) are the things that satisfy the functional requirements; they are nouns, and usually describe physical components or systems. For example, a FR might be “secure bolt” and the corresponding DP would be “nut”.

The zig-zag decomposition is the process that generates the FRs, DPs, and ultimately, the solution (Brown, personal communication, 15th February 2018). The process starts from broad, general ideas (the function of the thing being designed as a whole, instead of a specific piece), and branches downward until every component needed to achieve the initial goal is documented.

The first step of the decomposition process is to define the highest level FR, and the corresponding DP: this should be the overall function of the design (Brown, personal communication, 15th February 2018). For example, for our project, our initial FR (FR0) is “Provide water to chickens”. Every FR has one DP related to it, and after defining FR0, DP0 is created. To continue the example with our project, the DP0 is “Chicken watering system”.

The zig zag decomposition gets its name from the literal zig-zagging between FRs and DPs (Brown, personal communication, 15th February 2018). After DP0 is defined, the FRs required to satisfy that initial DP0 are created: for us this includes FRs such as “Store water” or “Transport water to chickens”. These FRs become the next level of FRs (labeled 1, 2, 3 etc.). Each of those FRs has a corresponding DP: if FR1 was to “store water”, DP1 might be “water storage system”. The process then continues: for every DP created, the designer must ask what are the FRs necessary to satisfy that DP. Those FRs are documented, answering DPs are created, and the cycle starts over again.

At the high level, the process may seem obvious, redundant, or unnecessary. One is effectively writing “to store water, we will use a water storage system” in chart form. However, the decomposition ultimately results in documentation of every object needed for the design, clearly and visually mapped to the function it is associated with.

The axioms influence the zig-zag decomposition by guiding how the FRs are created. The first (information) axiom is apparent because each FR maps to exactly one DP (Brown, 2011). If two FRs mapped to one DP, then if that DP were to be adjusted to better satisfy one of the FRs, there would be potentially unintended consequences to the other FR. The one-to-one mapping alleviates this issue.

4.3.2 Findings about Axiomatic Design

Initially, the team settled on the Axiomatic Design process because of its efficiency and structured approach (Brown, 2011). Later in the project, the team abandoned the Axiomatic Design Process because they realized that the project did not call for a technical design process: the system was able to be designed using the data collected from the team's interviews and secondary sources. However, although the team did not finish the Axiomatic Design Process, there were several findings regarding how the process could be applied outside of the traditional design setting.

A primary step of the Axiomatic Design process is the decomposition (Brown, 2011). The decomposition involves zig-zagging between requirements ("Functional Requirements" or FRs) and the "Design Parameters" (which are processes, systems, anything that satisfies the FRs; also called DPs) (Brown, 2011). The zig-zag decomposition involves breaking every design parameter into a set of requirements that are "Collectively Exhaustive and Mutually Exclusive" (CEME) (Brown, 2011). The decomposition begins with a high level FR and a high-level DP, and then is continued--decomposed--until the solution is obvious (Brown, 2011). A full decomposition can proceed to the point that individual nuts and bolts are spec'd out (Brown, 2011). (See Results 4.3.1 for details.)

The Axiomatic Design process requires users to approach the design situation in a solution-neutral mindset (Brown, personal communication, 15th February 2018). The process is meant for a design situation in which, theoretically, the best solution is not known (Brown, 2011). Because the team had determined what design would be optimal based on expert interviews and secondary research, the design decomposition process was not approached with an open mind, and the result was a decomposition that was written specifically to result in a predetermined solution (Brown, personal communication, 15th February 2018). From a design standpoint, this resulted in a useless decomposition (Brown, personal communication, 15th February 2018). This is not surprising, nor is it a new finding; years of scholarly work warn against approaching Axiomatic Design (or any design process) with a predetermined solution (Brown, personal communication, 15th February 2018).

However, although the decomposition was not functional for generating a design, the team found it was a very useful documentation tool. Through what many experts would consider a complete abuse of the design process, the team found an alternative application for the decomposition. The team found that the decomposition helps both with ensuring that no features are overlooked, and directly links features to requirements, which is beneficial when creating a template-type design.

Since the requirements of the zig-zag decomposition must be collectively exhaustive (Brown, 2011), this breakdown ensures that important features are not forgotten. The team found this “check” to be particularly useful because the team members were not experts in the field of chicken watering systems. The CEME requirement for the branches of the decomposition helped the team substitute experience with process: although the team did not have significant experience with chicken watering systems (realistically not enough experience to instinctively know what features were essential), the decomposition ensured all required features were considered.

The team also found that the connections formed between FRs and DPs in the decomposition provided traceability that made creating a template-type design easier. The team wanted to avoid a design that required exact parts, because the broadness of the intended audience made it unlikely that all users would want to use the same components. Also, the very nature of farming made it likely that members of the target audience may have existing systems they would want to modify, or scrap materials that they could use, which made the flexibility of design components even more essential. The relationships between FRs and DPs connected a requirement to every physical component, so although the team suggested a specific component in the design, they could also provide the reasoning why that product was best, which resulted in the ability to provide alternative components with similar functions, and a set of requirements for a component if a user wished to use a material that the team had not considered.

4.3.3 The Design

With the research-based design approach, we completed a model of an ideal watering system for small chicken operations. This system comprised of three main components that contained distinct functional requirements. The three components were: water storage, connection, and delivery.

For storing the water, we needed to ensure that the tank was a safe material, was easy to fill, had a removable cap (inside needs to be able to be accessed to be cleaned) (Severson, 2015), and decided to leave the volume and the material of the tank variable, with recommendations depending on budget and number of birds. For a low budget farm consisting of 10-500 birds, our research showed that a plastic drum with a removable lid was the best option (CDC, 2014). Plastic drums are great for storing water for chickens because it is safe, recyclable, and cost efficient (CDC, 2014). Another feature to the storage system was a heating source. For this, we recommend using a reflective outer coating of insulation, secured to the outside of the tank. This ensures that the water temperature inside the tank is resistant to fluctuation. Another component of the heating system is the internal water heater. This water heater is needed during the winter to prevent the water from freezing. The tank also needs a spout towards the bottom of the tank (approximately 10 inches above the base of the tank). This will allow for water to exit the tank into a connected hose. This spout should contain a shut-off mechanism to allow for easy maintenance on the system (Sevenson, 2015). Lastly, it is important that the water tank rests on has a structurally sound foundation to prevent tipping. The specific design for a stand for the tank is outside the scope of our resource because resources and landscapes on farms vary so greatly and there are many adequate designs.

For the connection portion of the water system, we had to ensure that there were no leaks, the connection was flexible, and that water inside the connection system remained liquid. Through visits to hardware stores and examining various components, we concluded that a hose was the best choice for connection between the water storage and water delivery systems. This choice is both flexible and contains male and female threaded ends that would allow for leak-proof connection. We also decided that heating tape was the best method of keeping the water inside the hose from freezing because it easily wraps around the hose and will not cause any damage to the hose due to overheating. These design specifications fit the overall functional requirements of the component while ensuring the cost is minimized.

To deliver water to the chickens, we had to analyze different drinkers, drinker line components, and heating system. Priorities of this component were that it was leak-proof, simple for chickens to use, prevented freezing, and was contamination resistant (Literature Review 2.4). Through research, we concluded that chicken drinker cups were the best choice. These cups must be separated by 10-12 inches so the chickens do not overcrowd each other and 8-12 inches off the ground to allow the chickens to peck downward at the drinkers (Extension Agent A, personal communication, December 14th, 2017). Research says that each coop needs one drinker per four chickens. To best connect the drinkers onto a “drinker line”, ½” PVC piping is required. The user must cut the PVC into several segments and connect them using the drinkers with T-joints. The line needs a cap at one end and a male threaded connection on the other to connect to the garden hose. For heating, the same heat tape line should be used as in the connection component. To secure the drinker line, ½” pipe fasteners are needed and should be screwed into the wall of the coop.

Figure 3. The Drinker Line. This image shows the set-up of the drinker line in the coop.

Figure 4. The Barrel outside the Coop. This image shows the set-up of the water storage system outside the coop. The spout, hose connection, insulation, and base of the system are displayed.

4.4 Develop Resources to share system design with other farmers that enable system implementation

4.4.1 Determining the Most Effective Deliverable

From primary research conducted by speaking to graphic design professionals and our project advisor, and second research of effective graphic resources we determined that an infographic is the most effective medium for conveying information to our target audience. During the research process we also looked at creating a manual that included a number of charts and tables that would break down the system into great detail and provide the reader the ability to design a system specifically for their situation based off of specific constraints they would provide. Through discussions with our advisor and the team we found that going with this type of medium would end up being too word heavy, un-appealing visually, and ultimately too intimidating for our target audience. An infographic is visually appealing, more direct in conveying exactly the information we felt is most important, and still allows for us to prompt the reader to find more information through an additional document if they so wish.

4.4.2 Creating the Infographic

Once we determined that an infographic is the best medium for our resource we first met with a graphic design professional, Jessica Baer. In this meeting we gained information on ways to format our content, how to guide the reader’s attention, emphasize certain portions, and make the most visually appealing graphic possible. We also gained further confirmation that a program called Piktochart, a free to use infographic design program that was also recommended by our advisor, would be the best way to create the infographic.

After the first meeting with Jessica we began brainstorming possible layouts of the graphic, gaining inspiration from other graphics found through simple google searches. We had a previously created 3D image of a basic watering system (see Appendix C) that we intended to use as the centerpiece on our graphic which directed much of the design process.

With a layout in mind we began drafting the graphic, sending our progress to Jessica and showing our advisor for feedback. The infographic included a top section outlining the difficulties faced by our target audience and the shortcomings of traditional manual watering systems. Following is a complete image of the watering system, the 3D image, showing the audience the various components of the system in an understandable and visually appealing manner as well as the benefits our system has compared to traditional systems. It was important that we included enough information in the image that the audience would have a general understanding of every component in the watering system (Jessica Baer, personal communication, March 20, 2018). Following the image are descriptions of each component of the system, referenced by a numbering system that outlines the recommended component, estimates of an average cost of that component, and relevant notes about that specific component. At the end of the document is a small banner with the WPI logo and text prompting the reader to seek out more information by accessing a provided link (bit.ly/2FeOlWD). The full infographic can be found in Appendix D.

4.5 Verifying the Resource and Design

4.5.1 Sponsor's Component Selection

Based on our background research, as well as interviews with extension agents, and conversations with our sponsor, we determined that cost and safety are the primary concerns of our sponsor and other farms when selecting system components. Minimizing costs included considering low cost components as well as the ability to use and/or modify existing materials on the farm. Safety concerns, particularly for our sponsor, included fire hazards associated with any heating components (e.g. water heaters, heat tape, heat lamps) (Austin Brother's Valley Farm, personal communication, April 15th, 2018). We approached our sponsor with a system diagram, a budget, and a description of the system components (see Appendix E). The design we presented involved two heating elements, and our preliminary estimates were that the system would cost $100 +/- $20 (see 4.3.2 for design). We expected the farm would request we remove at least one heating element because of their reluctance to incorporate electronic heating elements when working with past student projects (Stoddard, personal communication, November 20, 2017). We also expected them to request we cut costs somewhat, as our predicted budget was up to $120. However, they approved the design using all recommended components. Through the discussions that occurred during our farm visit on which we were selecting components, we learned that they were willing to pay extra for a system that would not freeze during the winter. The reliability that would be provided by two heating systems (heat cables and a pail de-icer, see section 4.3.2) was worth the expense to our sponsor. The concerns about fire hazards did not come up.

4.5.2 Costs and Budgeting

We created two budgets for our system prior to construction: one estimated price for preliminary approval from our sponsor, and one final budget that included all costs of the final system. We reviewed our spending on the project after construction to determine how close to the preliminary budget we were and found that we were more than double over the original budget.

Our initial budget set the cost of the system at approximately $100. This budget was a rough estimate, including only major components and using average prices. We ignored sale values and we included a +/- $20 range to account for the looseness of the budget. We calculated price averages from online stores such as amazon, and websites for hardware retailers, such as Home Depot. Our target for the system was under $100, so our initial estimates were reasonable.

Our second budget involved the exact components we were purchasing. We planned to order the drinker cups and the water heater online, and purchase the remaining components at home depot. Because our sponsor was able to provide a water tank, and we found several components on sale, we estimated the final cost of the system at $80. This was the final budget that we sent to our sponsor for approval. The budget was approved, and we proceeded to purchase parts.

Although the costs included in our budget were accurate, the budget did not account for everything: the budget did not include the insulation, fasteners, platform for the storage tank, or system to secure the water tank. Part of this was due to a miscommunication between the sponsor, as we believed that our sponsor would provide materials to build a platform for the storage tank. Others were due to certain parts being overlooked, such as fasteners and other small hardware that added up the cost in the end. After having to purchase additional items for the system, we ended up at almost double our anticipated budget. Instead of asking our sponsor for additional funds, we chose to divide and incur the additional costs ourselves. According to the WPI IQP handbook, students are expected to pay $75 each towards the project, as they are not paying for books or other supplies. Therefore, the additional costs fell within, even below, that expectation.

4.5.3 Construction and Functionality

We verified the functionality of our design by constructing and implementing the system at our sponsor’s farm. The construction process highlighted several oversights in our design, specifically the requirements for the storage barrel and the importance of hardware, a stand for the tank, and a method of mounting the drinker line in the coop. Overall, however, our design was easy to construct, and the few design flaws we found, we rectified by updating our infographic and documentation.

Construction took two visits because we had to obtain additional materials after our first attempt at construction: the barrel our sponsor provided was not sufficient for the project, and we did not have enough materials to build a stand of sufficient height.

Our primary difficulty was with the barrel: our sponsor provided us with a 55 gallon barrel, which appeared to have been repurposed from some other application. The barrel had a lid, as per requirements, but the lid was fused to the barrel. The lid must come off the storage tank because there is hardware for the spigot that must be mounted on the inside of the storage tank, and the heater must be inserted into the tank. However, we had neglected to mention that the lid had to come off the barrel in our documentation. During our first day of construction, we attempted to cut the lid off the barrel: we found instructional videos online that depicted a method of removing the lid of a 55 gallon barrel, flipping it over, and using the cut off top as a lid (https://www.youtube.com/watch?v=9m7a4QuPZME). We had limited tools available, and attempted to remove the lid with a hand saw.

It was impossible to keep the cut straight with the hand saw, so one major finding was that any modifications that are to be done to the barrel should be done with appropriate tools, such as a jigsaw or other powered cutting device. We also found, after removing the top, that the rim on a typical 55 gallon barrel is a structural component of the barrel. Therefore, another important finding was that any modifications to the barrel should not affect the rim: if the top must be cut off, the cut should be made on the top face of the barrel. Because of the direction of the cut, another consideration is that a separate lid will have to be fabricated for the barrel if a piece of the lid is removed in construction. Ultimately, we had to scrap the original barrel, and we removed the top surface of a new barrel, and replaced the plastic panel with a slightly-larger metal lid. Further construction details and images can be found in the recommendations section below.

Aside from the difficulties with the barrel, construction uncovered a few other issues with our design. We were attempting to build a stand for the barrel out of cinder blocks, but we did not account for the height difference between the coop and where the stand was set: the stand was to be built on an area that sloped away from the coop, resulting in a several-inch height difference from the base of the coop and the base of the stand. Consequently, our stand was too short, and we had to return with cinder blocks to create an additional layer on the stand. Although stand-design is mostly outside the scope of the project, we found that calculations determining the height of the stand should factor in height differences in the ground, and allow several inches for setting the base into the ground. Being generous with the height estimates is preferable to being conservative.

We also had neglected fasteners in our original design (although this was resolved before we began construction, see 4.5.1) and we had not factored in methods of attaching the insulation to the tank. Attaching the insulation to the tank was resolved with all-weather Duct Tape.

Over a week after the installation and implementation of the watering system, the team visited the farm to conduct a formal interview regarding the results of the system. Austin said that she had filled the tank only once since the installation. Upon examining the height of the water in the tank, one-third of the tank appeared to remain filled. This means that with the 50 birds she has in the coop, she only needs to fill the tank 8-12 days (with such little evaluation time, it is difficult to provide a concrete number). Austin seemed pleased with the reduction in labor required, as her old system required daily refilling. When asked about how she felt about the system design, she said “I like how simple it is. It is very easy to do and adding additional components do not seem challenging” (Austin Brother’s Valley Farm, personal communication, April 25, 2018). It was also noted that after twelve days, the water inside the tank had remained clean and clear of any debris, showing that the system has proper concealment from external contamination. Lastly, Austin shared that the chickens had been acclimating to the new drinker line very well. This shows that the water system we showed was not invasive to the productivity inside the coop. From this evaluation, we were able to gain further justification that our design for a chicken watering system is beneficial to small chicken operations.

4.6 Publishing Resources and Report

The entirety of our report was published through the WPI IQP process and is available for review by anyone who seeks it out. In addition, the infographic resource we created was distributed to our sponsor, extension agents, and farming associations including Farm Aid, Northeast Organic Farming Association (NOFA), and Northeast Sustainable Agriculture Research and Education. The infographic included a link at the end that when accessed leads you to a summarized document of our report that includes our executive summary, the building process of our sponsor’s system, and recommendations on components.

To create the link on the resource we utilized one of our team members WPI hosted user space that is allotted to each student. The user space was set up to direct the reader to a PDF document located in the user’s network folder. The user space link was then put through a URL shortener so that the final link on the resource is one that does not contain a team members name and can be easily typed into a browser. The end result of this is a reference link that does not itself have any relevance to the document it links to and a PDF that has the potential to be lost if the students user space is shut down after graduation. We chose to use this process however, as it allowed us to host the document without needing to purchase a domain name. The link that we ended up using is the following: bit.ly/2FeOlWD

Recommendations

Over the course of this project our methodological approach and subsequent results have provided sufficient information to give informed recommendations on the design process, implementation, and evaluation of the chicken watering system.

Design Process

Although our project was based around designing an improved watering system for chickens at small chicken operations in New England, we inadvertently came across several significant findings about design processes throughout our project. We began our project conducting research, and through that research we received enough recommendations from experts in the field that allowed us to generate a complete design. After amassing those recommendations, we attempted a traditional engineering design process. However, we found that we could not conduct an engineering design process for our project because, while a design process is generally intended to foster creativity, we simply needed a method of putting together the pieces we had been given through experts with interviews and secondary research. Creativity was not relevant to this stage of our project. From this experience, we learned when to use a "research-based" design approach, and we learned ways that a traditional design process can be used to validate designs created through nontraditional processes.

We attempted to use Axiomatic Design as our design process before we transitioned to a research based approach. (For a full description of Axiomatic Design and how the process is implemented, see section 2.6.) Although Axiomatic Design was not a good choice for our design situation, we inadvertently found other ways the process could be used, and how parts of the process could be used to supplement non-traditional design situations. Axiomatic design is a design process that revolves around ensuring designs adhere to two “axioms”, which are effectively principles of good designs (see section 2.6). There is a process associated with Axiomatic Design, called the design decomposition that, in theory, will lead to a good solution. We attempted to follow Axiomatic Design for our project, but we ran into difficulty partway through the decomposition. The decomposition is supposed to be conducted in a solution-neutral mindset, and we were approaching our design process having a solution already in mind. From this we learned that a design process is sometimes unnecessary: in some cases research makes the design obvious, and from there, generating a design is redundant.

The importance of solution-neutral thinking, and the redundancy of using a design process in our situation was not surprising, and could have been pointed out by almost any design expert. However, through attempting to force our design through the Axiomatic Design Decomposition, we had several findings about the process itself, and how it can be applied to situations that do not need a design process.

The Axiomatic Decomposition involves relating Functional Requirements (the things that must be done) to Design Parameters (the way those things that must be done will be accomplished). The decomposition zig-zags between the Functional Requirements and the Design Parameters (see section 2.6), getting progressively more specific with each iteration. Each level of the decomposition must also be CEME (collectively exhaustive and mutually exclusive).

The decomposition process is intended to be conducted with a solution-neutral mindset--no preconceptions of designs, or trying to guide the process to a certain outcome. This was, of course, our failure in using Axiomatic Design: when we approached the decomposition, we had already decided on the best solution. However, as we worked through our decomposition, we found that the process of breaking down every requirement into design parameters to be a good way to verify we had not forgotten important considerations in our design. Because the “parent” of each branch of the decomposition is supposed to be the sum of its “children” (alternatively stated as each branch is CEME), if important features are missing in the final design, those features will become obvious through the decomposition.

We did not spend significant time investigating the merits of applying the Axiomatic Design Decomposition to other design situations, but from our brief attempt at the design process, that occurred before we moved to a fully research-based approach, we found that the decomposition was a good way to expose potential oversights in a design. We recommend any design team that is stuck on their design problem and suspects that they have forgotten parts or are overlooking important features, considers using the decomposition to attempt to show the missing connections or features of their design.

Building the System

The chicken watering system that we designed can be easily replicated. For someone attempting to build a system based off of our design, we have many recommendations. Our first recommendation is that the manufacturing instructions of each component are followed. The manufacturing instructions will give specific instructions regarding safety, operations, and characteristics of the material being used. Our recommendations to people trying to replicate our design include building recommendations, component recommendations, and safety recommendations.

Our first major recommendation for the building process has to do with the plastic water barrel. We recommend that you use an electric jigsaw to cut the top off of the barrel. Using a handsaw can result in sloppy craftsmanship and can take a long time to complete. Also, when cutting the top off of the barrel, one must cut above the top lip on the barrel. This top lip keeps the barrel rigid and will reduce level of warping when filled with water. Another essential step to this building process is to make the hole for the faucet at the bottom of the tank as tight as possible. With this, appropriate sized O-rings, and a nut, the faucet should not leak.

The second major recommendation we have for the building process is in reference to the assembly of the drinker line. We recommend that a ruler, a marker, and a handsaw are used to cut 8-12 inch segments of PVC pipe. It is extremely essential that the user understands that the PVC cement sets very quickly. When using the PVC cement, use only a little bit and make sure that all the T joints between the PVC segments are facing the same way. To ensure the PVC cement dries fully, you should wait a minimum of two hours before water is run through the piping.

Our last major recommendation for building the system is to ensure that the water tank has a solid foundation to rest on. For the implementation of the system, the ground must not be frozen in order to allow for digging to set up the foundation. This foundation may have to support hundreds of pounds when the tank is filled. Several different materials can be used such as wooden 2x4 beams cut and formed together to make a stand or cinder blocks stacked on top of each other. This structure must be level to ensure no tipping. Another means for securing the water tank that we recommend in addition to a sturdy base is the use of bungee-cords that wrap around the tank and screw into the side of the chicken coop.

System Components

From the process of building an implementing the system for our sponsor we have come up with a list of recommended components to use and retailers where they can be located. Most of the components came from local Home Depot stores but some were purchased online.

The Storage Tank

The overall water storage tank portion of the system consisted of the following components:

- A plastic 55 gallon drum (*Figure 5*) locally sourced by our sponsor. We recommend that the barrel has a removable lid and that you clean the inside to remove any contaminants.

Figure 5.

Home Depot. (2018) 1/2 in. Brass 1/4 Turn MPT x MHT No-Kink Hose Bibb

Retrieved from: www.homedepot.com

- Reflective Insulation (*Figure 6*) purchased at Home Depot used to wrap the 55 gallon drum.

Figure 6.

Home Depot. (2018) 16 in. x 25 ft. Double Reflective Insulation with Staple Tab. Retrieved from: https://www.homedepot.com

- ½" Garden Hose Faucet Valve (*Figure 7*) purchased at Home Depot

Figure 7.

Home Depot. (2018) 1/2 in. Brass 1/4 Turn MPT x MHT No-Kink Hose Bibb. Retrieved from: www.homedepot.com

- Eye bolts (*Figure 8*) purchased at Home Depot

Figure 8.

Home Depot. (2018) 5/16 in. x 4 in. Zinc-Plated Lag Thread Screw Eye.

Retrieved from: www.homedepot.com

- Bungee Cords (*Figure 9*) purchased at Home Depot

Figure 9.

Home Depot. (2018) 48 in. Flat Bungee Cord

Retrieved from: www.homedepot.com

- All Weather tape (*Figure 10*) purchased at Home Depot

Figure 10.

Home Depot. (2018) 2 in. x 50 yds. Aluminum Foil Tape Roll.

Retrieved from: www.homedepot.com

- Submersible Water Heater (*Figure 11*) purchased online at Amazon.com. We recommend the heater has an internal thermometer.

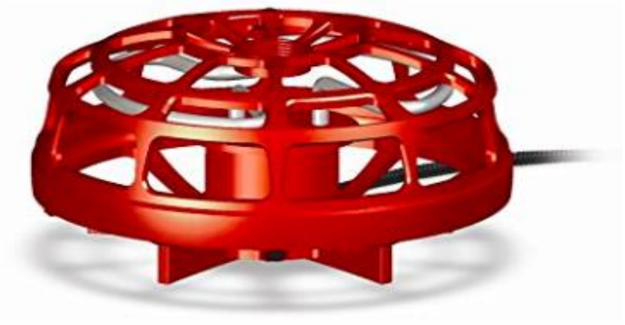

Figure 11.

Amazon. (2018) K&H Pet Products Ultimate Pail Deicer (No Float) w/ Cord Clip Red 250W.

Retrieved from: www.amazon.com

The connection line portion of the system, between the storage tank and drinker line, consisted of the following components:

- ⅝" Diameter, 6' Long Garden Hose (*Figure 12*) purchased at Home Depot

Figure 12.

Home Depot. (2018) 5/8 in. Dia x 6 ft. Leader Water Hose

Retrieved from: www.homedepot.com

- 9' Heat cable (*Figure 13*) purchased at Home Depot

Figure 13.

Home Depot. (2018) 9 ft. Automatic Electric Heat Cable Kit.

Retrieved from: www.homedepot.com

The Drinker Line

The drinker line portion of the system consisted of the following components:

½” Diameter PVC Components, purchased from Home Depot:

- 10’ long pipe (*Figure 14*)
- End cap (*Figure 15*)
- Threaded hose connector (*Figure 16*)

Figure 14.

Home Depot. (2018) 1/2 in. x 10 ft. 600-PSI Schedule 40 PVC Plain End Pipe.

Retrieved from: www.homedepot.com

Figure 15.

Home Depot. (2018) 1/2 in. PVC Sch. 40 Socket Cap.

Retrieved from: www.homedepot.com

Figure 16.

Home Depot. (2018) 1/2 in. PVC Male Terminal Adapter.

Retrieved from: www.homedepot.com

- Drinker cups with a ½” PVC T (*Figure 17*) purchased online at Backyardflock.com. We recommend purchasing the drinker cups that come with the ½” PVC T as it makes assembly and overall configuration of the system very easy.

Figure 17.

Backyard Flock. (2018) Automatic Poultry Drinker Cups with PVC Tee Fittings. Retrieved from:

www.backyardflock.com

- ½" Pipe fasteners (*Figure 18*) purchased at Home Depot.

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Figure 18.

Home Depot. (2018) 1/2 in. Galvanized Tube Strap 2-Hole (10-Pack).

Retrieved from: www.homedepot.com

- Standard PVC cement (*Figure 19*) purchased at Home Depot.

Figure 19.

Home Depot. (2018) 8 oz. PVC Cement.

Retrieved from: www.homedepot.com

Other component recommendations:

The Storage Tank Base

Specifications for the base of the water tank were not included in our design as there are multiple ways of constructing a proper base. However, there are a few requirements that the base must meet. The base must elevate the water tank output to be higher than the drinker line in order to allow for a gravity fed system. The base must also be sturdy and strong enough to support the load of a full water tank. The base should also be constructed in a way that accounts for the shape of the base of the water tank. If the tank has a rim, it is important to support the rim. If the tank is flat bottomed, the entire bottom should be supported in order to distribute the load.

Potential materials the base can be constructed of include: a wooden frame, brick, stone, or cinder block, or by using natural terrain such as hills or slopes.

6. Conclusions

The goal of this project was to design an optimal chicken watering system form our target audience of small chicken operations in New England. We verified the design by implementing a watering system based on our design at our sponsor's farm. In order to share the validated design with other farmers we created an infographic that was distributed to farming extension agents and farming organizations throughout New England. We hope that this distribution will reach a large portion of the 137,000 farms in New England; providing farmers the necessary information to improve or build a new watering system. For those who choose to implement our system design we expect them to see multiple improvements to their chickens and chicken coop. The major benefits include increased sanitation of the water provided to chickens and the coop overall as the system is designed to keep out contaminants and not spill or leak. Farmers can expect to save time while seeing higher egg yield due to reduced regularity of filling and maintenance on the watering system and increases in water sanitation and consumption due to easily accessible drinkers and consistent year round access to water, even during the winter.

In order to properly validate our design and back up the claims of our system we ran a two week test at Austin Farms. Testing our system demonstrated its simplicity and effectiveness, providing a new solution to previous watering system issues including increased time between fillings, improved sanitation, and easier maintenance. The system did not experience any failures during the testing period, further enforcing the robust nature of the design. However, although the test indicates our system is functional, it does not serve as a complete validation of our system because of significant limitations on our testing.

The limitations on the conclusions that can be drawn from the system test are due to the duration and season of the testing period, the scale of the test, and the age and newness of the chickens. Ideally the testing period would have been at least a full year in order to demonstrate the functionality of the system across all four seasons, and to allow the chickens to fully adjust to the new watering system. However, due to our academic schedule the testing period was less than two weeks and occurred in spring. The period was short enough that the time it took for the chickens to adjust to the system may have had a significant effect on our results. Since the testing period fell in a mild part of spring, and the system did not experience any extreme cold temperatures found in the winter. Due to this the test was unable to validate the functionality of the heating components and the systems resilience to freezing. Because of the age and newness of the chickens, our sponsor had recently replaced their flock days before we constructed the system, the chickens had to adjust to a new watering system and coop. This helps validate that our system is good for a new flock of chickens, but it does not indicate how easily an existing flock, used to another watering system, would adjust to our design.

Although we believe our design is sound, there should be future work done to fully verify the system due to the limitations of our testing. We recommend other researchers evaluate the system for a year-long period, and conduct studies involving both chickens new to the farm and chickens who have been on the farm and are used to a different watering system. These studies do not have to be conducted by a dedicated team of researchers; basic observations while implementing the system under various conditions would be sufficient to test these scenarios.

In addition to further validating our system, we feel that our project has exposed several other areas of research that should be investigated by future IQP, MQP or research teams. Reviewing how quickly chickens adapt to changes in their coop is an important consideration when designing systems for chickens, but few comprehensive studies have been conducted. Throughout our research, we found many discussions of how to teach chickens to use various drinkers, and which systems would affect water consumption, but we did not find controlled studies that evaluated how long chickens took to adjust to a new system, and what effects changing the watering system would have on an older flock of chickens. This research would help farmers determine the best time to implement new watering systems with respect to their chicken’s lifecycles.

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42.

Appendix

Appendix A

Extension Agent Interview Questions

Priority Questions

1. What water source/drinker style do most small farms use?
2. What do you think the distribution of farm sizes is in your state/area?
3. Is chicken farming becoming more or less common?
4. What would be a good definition for “small farms”?
5. What are the biggest concerns of small farms with chickens? (Esp. related to watering systems, sanitation, efficiency, cost, etc.)
6. What style of coop is most common (mobile vs stationary)?
7. Do you know of farms we could contact?

Basic Farm Statistics

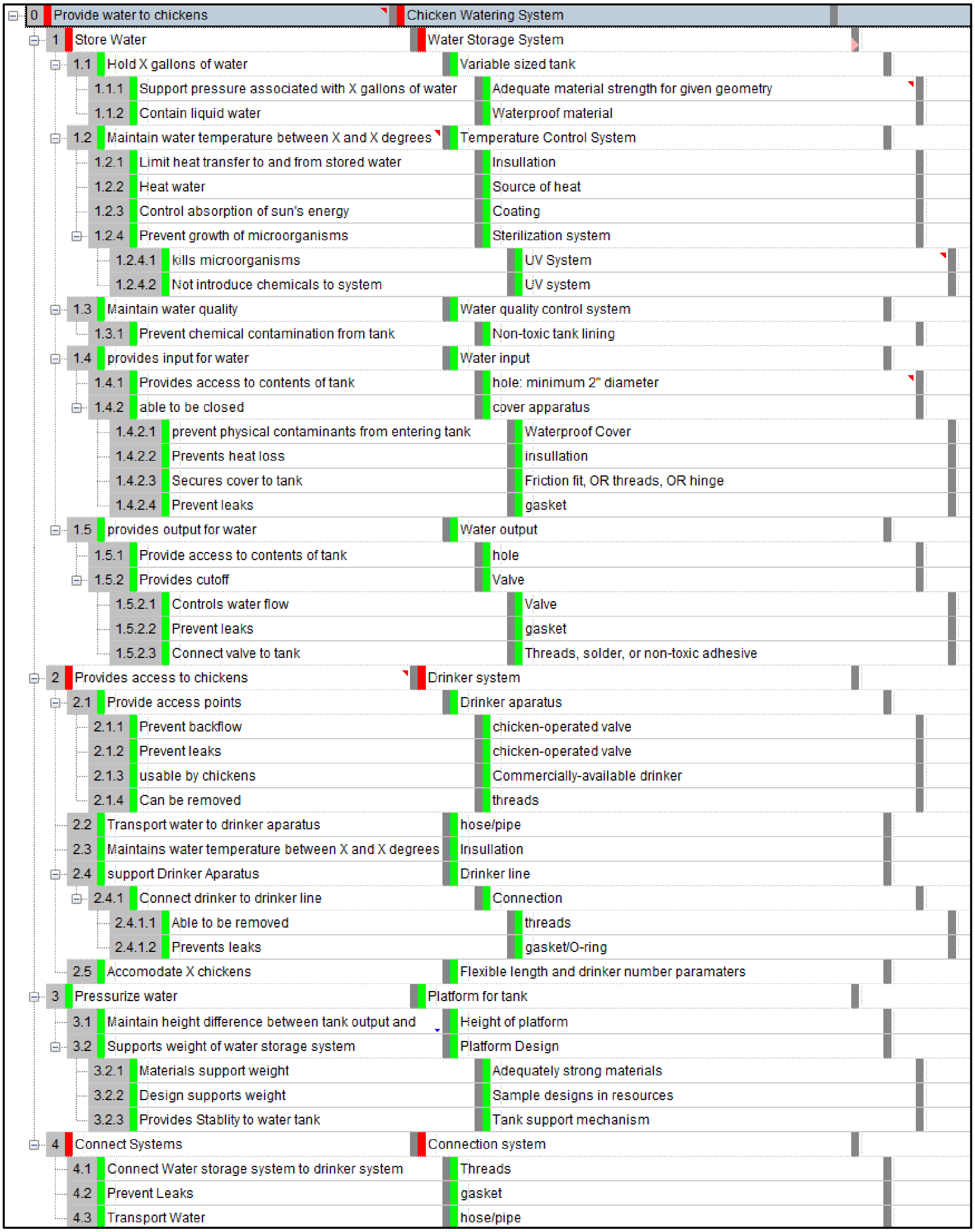
- What are the common types of chicken coops?
    - Stationary or mobile, standalone or connected to barn
    - How do you go about providing them water?
    - Are your chickens primarily for eggs or meat?
- How many employees do most farms have?
    - What would be a good size range for a “small farm”?

Watering Methods

- What are common water sources for chicken coops?
- How many drinkers are recommended per chicken?
- What type of drinker is recommended and why?
    - How often does the system need to be cleaned?
    - What are the disadvantages?
- How much maintenance does this require?
- Biggest concern you have regarding chickens water?
- Do many farms use the hybrid drinker?

Appendix B

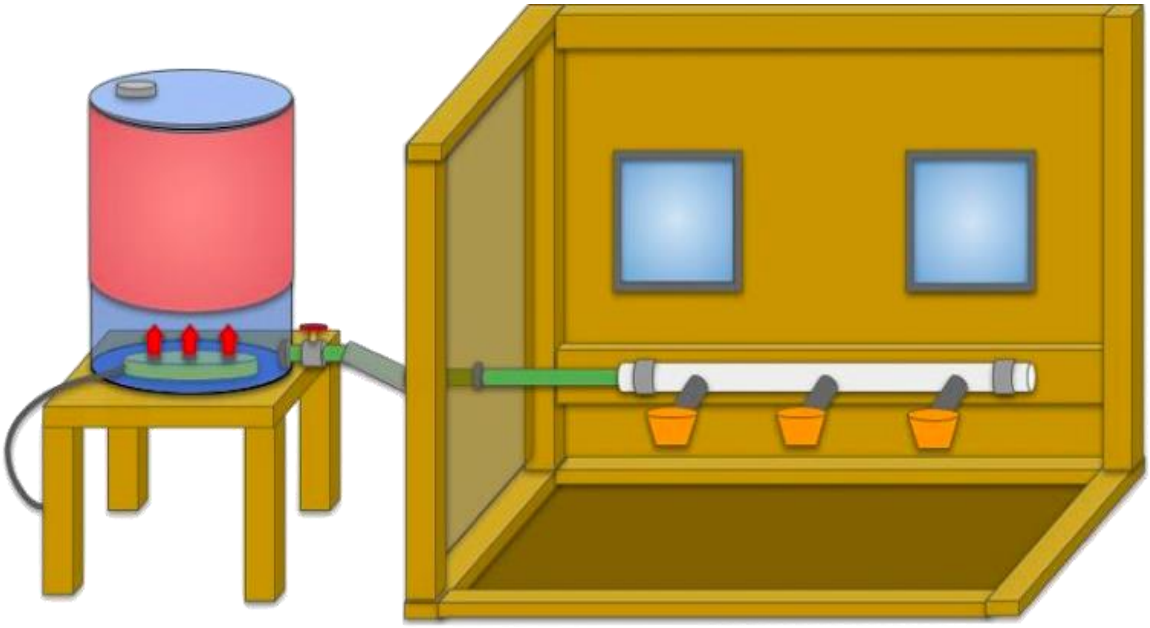
Axiomatic Design Decomposition



0	Provide water to chickens	Chicken Watering System
1	Store Water	Water Storage System
1.1	Hold X gallons of water	Variable sized tank
1.1.1	Support pressure associated with X gallons of water	Adequate material strength for given geometry
1.1.2	Contain liquid water	Waterproof material
1.2	Maintain water temperature between X and X degrees	Temperature Control System
1.2.1	Limit heat transfer to and from stored water	Insullation
1.2.2	Heat water	Source of heat
1.2.3	Control absorption of sun's energy	Coating
1.2.4	Prevent growth of microorganisms	Sterilization system
1.2.4.1	kills microorganisms	UV System
1.2.4.2	Not introduce chemicals to system	UV system
1.3	Maintain water quality	Water quality control system
1.3.1	Prevent chemical contamination from tank	Non-toxic tank lining
1.4	provides input for water	Water input
1.4.1	Provides access to contents of tank	hole: minimum 2" diameter
1.4.2	able to be closed	cover apparatus
1.4.2.1	prevent physical contaminants from entering tank	Waterproof Cover
1.4.2.2	Prevents heat loss	insullation
1.4.2.3	Secures cover to tank	Friction fit, OR threads, OR hinge
1.4.2.4	Prevent leaks	gasket
1.5	provides output for water	Water output
1.5.1	Provide access to contents of tank	hole
1.5.2	Provides cutoff	Valve
1.5.2.1	Controls water flow	Valve
1.5.2.2	Prevent leaks	gasket
1.5.2.3	Connect valve to tank	Threads, solder, or non-toxic adhesive
2	Provides access to chickens	Drinker system
2.1	Provide access points	Drinker aparatus
2.1.1	Prevent backflow	chicken-operated valve
2.1.2	Prevent leaks	chicken-operated valve
2.1.3	usable by chickens	Commercially-available drinker
2.1.4	Can be removed	threads
2.2	Transport water to drinker aparatus	hose/pipe
2.3	Maintains water temperature between X and X degrees	Insullation
2.4	support Drinker Aparatus	Drinker line
2.4.1	Connect drinker to drinker line	Connection
2.4.1.1	Able to be removed	threads
2.4.1.2	Prevents leaks	gasket/O-ring
2.5	Accomodate X chickens	Flexible length and drinker number paramaters
3	Pressurize water	Platform for tank
3.1	Maintain height difference between tank output and	Height of platform
3.2	Supports weight of water storage system	Platform Design
3.2.1	Materials support weight	Adequately strong materials
3.2.2	Design supports weight	Sample designs in resources
3.2.3	Provides Stablity to water tank	Tank support mechanism
4	Connect Systems	Connection system
4.1	Connect Water storage system to drinker system	Threads
4.2	Prevent Leaks	gasket
4.3	Transport Water	hose/pipe

Appendix C

Raw Watering System graphic used to start infographic



Appendix D

Final Infographic Resource

A Solution for Chicken Watering Issues

The Struggles of Small Farms

- Low Staff Numbers
- Inefficient Equipment
- Tight Budgets
- Chicken Health

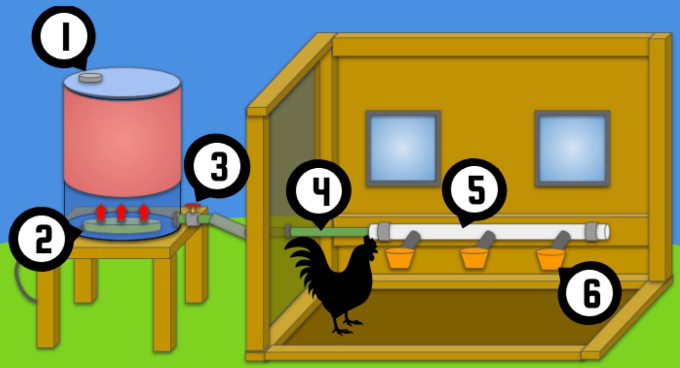
Problems with Traditional Watering Systems

- Excessive Maintenance
- Water Spills
- Contamination
- Freezing Water

Our Solution:

The Optimal Watering System

Saves Time
Lowers Maintenance
Reduces Waste
Saves Money



01 Storage Tank

Component: 55 Gallon drum or similar container
Avg. price: $60.00
Notes: Tank output must be higher than drinker line for gravity fed system. The tank must be adequately supported.

02 Water Heater

Component: Pail deicer with self-regulating temperature.
Avg. price: $25.00
Notes: If heater cannot be used outside of water, the control valve must be above the heater.

03 Control Valve

Component: Standard garden hose valve or PVC ball valve
Avg. price: $2.00
Notes: Provides cutoff for water flow for easy cleaning

04 Connection Line

Component: Flexible garden hose
Avg. price: $32.00
Notes: Line hose with heat cable to prevent freezing in winter.

05 Drinker Line

Component: Schedule 40 PVC pipe with end cap
Avg. price: $2.50/ft
Notes: Drinker line will need to be secured to the coop wall with pipe fasteners or similar hardware.

06 Drinker Cups

Component: Ergonomic Drinker Cups eak proof, does not introduce toxins to system
Avg. price: $2.00/cup
Notes: Cups spaced 1 ft apart on drinker line. 1 cup per 5 chickens

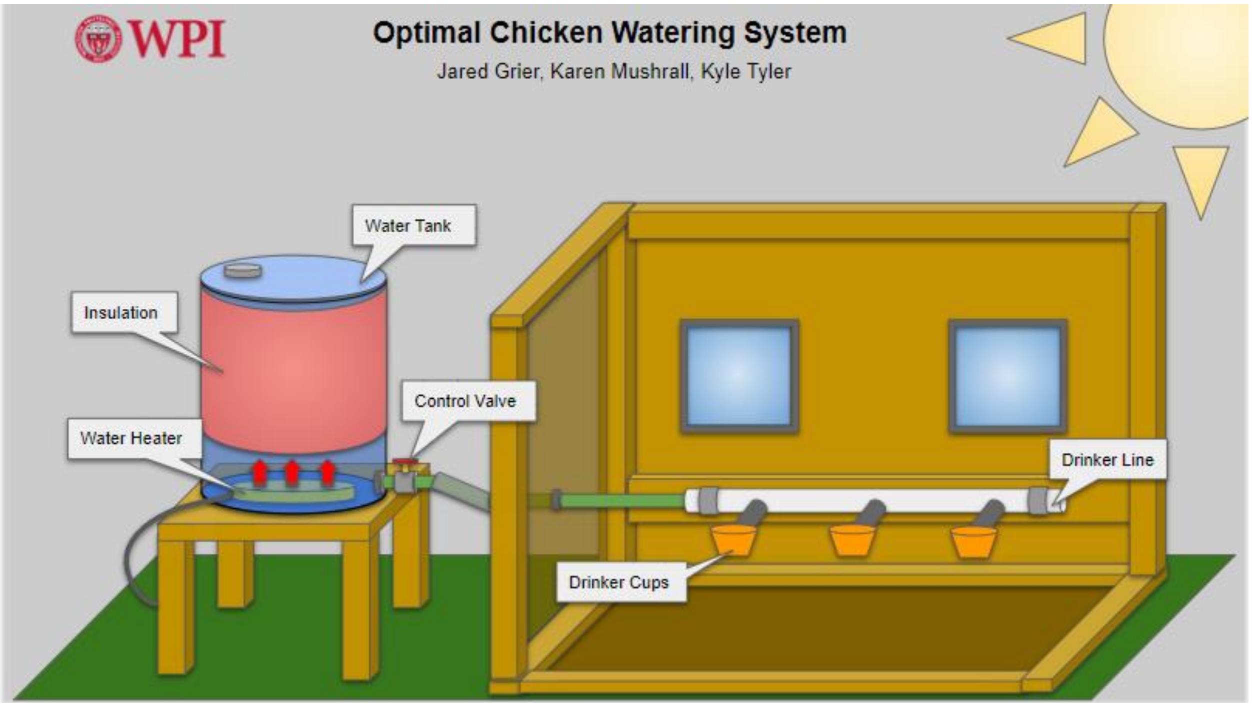
WPI

For more information please visit (case sensitive):

bit.ly/2FeOlWD

Appendix E

Watering System Diagram with annotations



Initial Budget, presented to Sponsor

Submersible Water Heater	$25.99	Amazon
Container (30gal)		
PVC Pipe (1/2"x10ft)	$1.85	Home Depot
PVC Cap (1/2")	$0.49	Home Depot
PVC Ball Valve (1/2")	$2.27	Home Depot
PVC Hose adapter (1/2")	$3.49	Home Depot
Drinker Cups (2pk w/ PVC T)	$9.95	Backyard flock
Garden Hose (5/8" x 6')	$7.97	Home Depot
Heat Cable (6ft)	$22.94	Home Depot
PVC Cement 8oz	$4.94	Home Depot
Total	$79.89	

Component Descriptions

Storage Tank

Tank Size:

Number of Birds X Days Between Fills X 0.2

Water Output:

Use a **bulkhead fitting** to connect pipe to tank. Add a **gasket** or sealant to prevent leaks as needed.

Notes:

Tank output must be higher than drinker line. Tank is heavy and must be adequately supported.

Insulation

Tank Insulation:

Recommended: **R30 Roll Insulation**
Requirements:

Pipe Insulation

Recommended: **Pipe Insulation**
Requirements:

Heat Source

Tank Heat Source:

Recommended: **Pail Deicer**
Requirements: Self-regulating temperature. If heater cannot be used outside of water, water output valve must be above top of heater. Follow manufacturer's installation instructions and warnings.

Pipe Heat Source

Recommended: **Heat Cables**
Requirements: Self-regulating temperature. Follow manufacturer's installation instructions and warnings.Create drip loop before plug if needed. DO NOT DOUBLE WRAP HEAT CORD.

Connection from Tank to Drinker Line

Valve:

Recommended: **PVC Ball Valve**
Requirements: Provide cutoff for water flow.

Waterline:

Recommended: **Hose**
Requirements: Flexible (to allow adjustable height of drinker line)

Drinker Line

Pipe:

Recommended: 3/4 in Thick. 480-PSI Schedule 40 PVC Plain End Pipe

Requirements: Rigid, Strong, Leak proof

Attachment mechanism:

Recommended: Plastic pegboard (screwed to coop) with spring clips to hold pipe

Requirements: support drinker line, adjustable height, chicken-proof

Drinker Cups

Recommended:

Chicken Drinker Cups. Cups spaced 1 ft apart on drinker line. 1 cup per 5 chickens minimum. Follow manufacturers instructions for installation; apply sealant, glue, or thread seal tape to connections to avoid leaks.

Requirements:

Ergonomic for chickens, leak proof, does not introduce toxins to system