Raspberry Harvesting Efficiency Improvement

Sponsored by Driscoll’s

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Executive Summary

This report was commissioned to clearly define the objective of the project as requested by Driscoll’s. The document serves as an agreement between the mechanical engineering project team and the sponsor. Initially, the document addresses the root causes of the problem, benchmarks other solutions, includes observations and interview results from the sponsor, and investigates industry standards and codes. The second half of the document describes the project team operations. This includes a formal definition of the problem from the perspective of the team, a list of customer needs and wants with attached priorities and weights, a Quality Function Deployment (QFD) analysis, and engineering specifications. On the project management side, the project schedule is outlined, the design process is described, and key techniques that will be used to solve the problem are listed. While the report’s main objective is to fully define the problem and solution process, it also aims to obtain the sponsor’s agreement on the scope of the project.

Chapter 1. Introduction

In 2016, the state of California passed legislation to increase the minimum wage from $10/hour to $15/hour by the year 2022, and to lower the agricultural work week overtime exemption from 60 hours/week to 40 hours/week by the year 2022. With both of these laws taking effect in the near future, Driscoll’s is expecting a 65% increase in harvesting cost over the next five years. According to the company, 50% of its California growing costs comes from raspberry harvesting.

Driscoll’s has investigated increasing the price of raspberries, but this cannot absorb total cost. Raspberries are already expensive in the eyes of the consumer, and while increasing prices is being explored as an option, prices cannot be raised as fast as growing and harvesting costs are increasing. Further, Driscoll’s relies on selling large volumes of raspberries for low profit. Therefore, there is not a large enough profit margin for the company and the growers to absorb the increased cost.

As a result, the company is determined to find a solution to decrease the cost of raspberry harvesting in order to maintain production in California and keep the company profitable. Driscoll’s has determined that if a solution can be found that will increase the efficiency of harvesting raspberries by 6% this year, and closer to 30% by the time legislation is in full effect, the company will be able to stay profitable without needing to rapidly increase the price to the consumer.

While Driscoll’s has enlisted the help of professional companies before, their recommendations have been difficult to implement. Therefore, the company has come to the senior project groups at Cal Poly as part of the solution to increase efficiency. Multiple teams, including the Poly Pickers (mechanical engineering team), an interdisciplinary team, and an agricultural engineering team have been put to the task.

Chapter 2. Background

Customer Summaries

The first meeting with Toby, the sponsor contact, was useful to get a gauge on the process as a whole and better understand what the sponsor is looking for. Efficiency, measured in kg of raspberries harvested per person-hour, needs to increase by 6% by any means, including waste elimination, a mechanical device, and/or
process improvement. Initial improvement ideas expressed by Toby focused on reducing damage to the raspberries that occurs in the harvesting process and on reducing waste and making the process leaner.

At the Reiter Brother's field in Camarillo, the field supervisor, Luis, shared some insight on improvements to be made to the harvesting process. He expressed that many current employees have been working for at least a decade in the field and have seen various changes towards process improvements with little results. Therefore, they may not be as receptive to a process improvement without extremely conclusive data coupled with exceptional benefits. To this end, a mechanical device may have a higher potential to be accepted by the growers and harvesters because it is tangible and novel.

**Existing Designs**

There are two primary aids currently used in Driscoll's harvesting of raspberries. The first harvesting aid is the plastic bucket that pickers carry into the field and fill with raspberries. In Camarillo, approximately 7-9 buckets are carried into the field, and then hung onto a guy wire once filled until the picker is ready to return to clamshell packaging. A picture of the bucket on a guy wire is shown below in Figure 1. Note that the hook on the bucket is used to hold the bucket onto the belt of the picker while they are picking, and then is placed on the wire to be collected later.

![Picking bucket used by pickers.](image)

In most other locations, the picker will take 3-4 buckets into the field at a time and hang the buckets on their waist. Once the buckets are filled, the picker returns to the table to pack the raspberries.
The clamshell packing takes place at a table that holds unfolded trays, folded trays, and clamshells. The table is portable, stable and provides room to fill the clamshells and load them into trays. A picture one type of table design is shown below.

![Packing table, holding clamshells and folded trays.](image)

Another current raspberry harvester is a complete harvesting machine that goes down the rows of raspberry plants and shakes and collects the raspberries to the trays. These machines are intended for either frozen or processed berries, but are existing products that are useful to consider and benchmark. A leading manufacturer of a machine raspberry harvester is Oxbo. They have four models available for raspberry harvesting that vary in cost, size, and harvesting capacity. The 9120 model harvester is shown below.

![Oxbo 9120 Harvester](image)

This machine relies heavily on high raspberry harvest quantity. Delicate raspberries can sustain damage under very little force and small impacts, and going through a machine that hits or shakes the raspberries of the plants
and drops them to a conveyor belt greatly increases damage likelihood and decreases expected quality. While this machine is very suitable for its intended use, it does not fulfill the fresh berry quality requirements.

Another mechanical harvester is the Pluk-O-Trak harvester, produced by the company Munckhof, which is based in the Netherlands. This harvester is designed to be an apple harvester, with focus on reducing labor and keeping quality high. Apples are more durable than raspberries, but when tree-shaker harvesters are used to drop and collect the apples, a significant degree of fall damage is sustained, and some apples are harvested prematurely. With the Oxbo harvesting machines, raspberries undergo a similar process that increases damage and premature harvesting likelihood. The Pluk-O-Trak makes a compromise between hand picking fruit and harvesting. The fruit is picked by hand, and then placed on extended arms with a conveyor system, which transports the fruit into a large collection bin. An image of the Pluk-O-Trak is shown below.

![Figure 4. Pluk-O-Trak Apple Harvester](image)

As shown in the image above, the harvester has multiple conveyor arms, and the harvesters place picked fruit on them. The conveyor arms draw the apples up and store them into a bin. The system is self-propelled, and follows the pickers at a steady pace. Keeping the hand-picking aspect of harvesting ensures better quality fruit compared to current machine harvesters, while automating the harvesting process reduces labor needs.

The above existing designs have been benchmarked across several performance criteria to determine how well they meet the design constraints.

**Patent Search Results**

Table 1 below shows the various patents related to raspberry harvesting that were researched for benchmarking.
Table 1. Search Results for Relatable or Similar Patents

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Date</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9,469,458</td>
<td>10/18/2016</td>
<td>Clamshell raspberry container</td>
<td>Driscoll’s patent for current raspberry containers</td>
</tr>
<tr>
<td>4,286,426</td>
<td>9/1/1981</td>
<td>Vibratory fruit harvester</td>
<td>Inverted U-shape grape harvester with oscillatory striker bars and a conveyance system</td>
</tr>
<tr>
<td>5,076,047</td>
<td>12/31/1991</td>
<td>Fruit Harvester</td>
<td>Cranberry harvester with vertically oscillating tines over a ground roller that pulls up vines and strips berries, and fruit is suctioned into a storage bin</td>
</tr>
</tbody>
</table>

**Technical Literature**

The technical literature is a report investigating the implementation of harvest aids. Aids discussed range from heavy machinery, personal machine assistance, and full automation. Heavy machinery typically is a self-driven machine with mechanisms for collecting, sorting, and or storing fruit. This is typically referred to as mechanical bulk-harvesting. Heavy machinery that directly harvests the fruit typically compromises quality, rendering this option as inappropriate for the fresh berry industry due to high occurrence of damaged or under-ripe berries. Driscoll’s quality standards do not allow damaged or under-ripe fruit to be packed, so this solution is inappropriate. For applications that are not focused on top quality, these machines are a good choice because they can dramatically increase quantity efficiency. Robotic harvesting systems are selective, using detection and recognition features, combined with robotic motion control. Robotic solutions will likely be the long-term harvesting efficiency solution, but will overall take longer to develop and implement than other solutions. Lastly, mechanical harvesting aids are the most ubiquitous aid used for fresh fruit harvesting. They are typically used in close quarters with human labor, aiming to reduce motion or work by the laborers. They have some initial cost but yield consistent results due to minimal system changes while increasing labor productivity.

**Industry Codes, Standards, and Regulations**

The FDA regulates anybody who grows, harvests, and stores produce that is meant for human consumption. These regulations ensure that the necessary measures are taken to reduce or eliminate the likelihood of produce becoming unfit for human consumption. For example, anything that touches food needs to be sanitized every day.

The FDA is relevant to this raspberry harvesting improvement because any solution taken must adhere to FDA regulations. A solution would be unacceptable if it caused a higher rate of harmful bacteria to be present in the
produce, for example. If the solution results in harmful debris passing onto the customer, this would also be restricted by the FDA. Precise care must be taken to ensure that any changes to the current process does not result in FDA noncompliance.

Chapter 3. Objectives

The following section includes the precise scope of the project.

Problem Statement:

The problem statement provides a description of the problem and attempts to provide a direction for the project to go in. It is designed to expand the solution space and motivate creativity. It is important to note that the problem statement is a living component of the document; that is, it can be updated to reflect any new findings that are discovered later on.

To remain profitable through the implementation of recent labor legislation, Driscoll’s harvest efficiency needs to be improved. Driscoll’s needs to increase the raspberry harvesting efficiency by at least 6% this year to keep business in California profitable. The solution must be easy to implement and readily acceptable by both contracted farm owners and the raspberry pickers. The solution must be low-cost and cannot change the fundamental layout of the raspberry field. The efficiency will be measured as the weight of the raspberries harvested per hour, with the reference measurement coming from an initial field visit in Oxnard, CA.

Boundary Diagram

A boundary diagram highlights the aspects of the process that our solution can modify, which are contained within the dashed lines. Figures 5 and 6 depict the boundary diagram for the raspberry harvesting.

Figure 5. Boundary diagrams around picker, bucket, and packing table.
Customer Needs/Wants

In order to fully understand the problem, a complete list of customer “needs and wants” was created. It is important to note the difference between these criteria. A customer “need” is a criterion that must be completed in order for the problem to be solved. That is, without addressing the “need” in the solution, the customer will not consider the solution adequate. A customer “want” is a criterion that does not need to be completed in order to solve a problem. In other words, they are requirements that would make the customer happy but are not crucial to solving the problem. In many cases, customers will confuse “needs” and “wants,” often not seeing the difference in the two. As a result, a comprehensive list is outlined of these two criteria clearly. Table 2 summarizes the “needs” and “wants” that are among the most important.

Table 2. Important Customer Needs & Wants

<table>
<thead>
<tr>
<th>Needs</th>
<th>Wants</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Increased harvesting efficiency, defined as the weight of raspberries harvested per hour, by 6%</td>
<td>- Increased quality of berries picked, such as preventing damage</td>
</tr>
<tr>
<td>- Cost per worker less than $100</td>
<td>- Little to no training for workers to fully utilize solution</td>
</tr>
<tr>
<td>- Solution is widely and willingly accepted by farm owners and pickers</td>
<td></td>
</tr>
</tbody>
</table>

QFD House of Quality

QFD (Quality Function Deployment) House of Quality is a tool that is used to help ensure that the design solution is solving the correct problem. It works by scoring customer needs and wants against engineering feasibility. The scoring system is weighted based on the importance of each component. When the QFD is
complete, the idea with the highest score will probably prove to have the most promise. A House of Quality was created based on the customer needs and wants that was developed in the section above. To see a record of this document, please refer to Appendix A: QFD House of Quality.

**Engineering Specifications Table**

Table 3 shows the engineering specifications that that solution must meet to solve the problem.

Table 3. Engineering Specifications

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Parameter Description</th>
<th>Requirement/Target</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Harvesting Speed</td>
<td>6%</td>
<td>Min.</td>
<td>H</td>
<td>A, T, I</td>
</tr>
<tr>
<td>2</td>
<td>Cost</td>
<td>$100 per worker</td>
<td>Max.</td>
<td>H</td>
<td>I</td>
</tr>
<tr>
<td>3</td>
<td>Manufacturability</td>
<td>Practical and reasonable</td>
<td>N/A</td>
<td>M</td>
<td>A, I</td>
</tr>
<tr>
<td>4</td>
<td>Parts/Components</td>
<td>Use off the shelf components</td>
<td>N/A</td>
<td>L</td>
<td>I</td>
</tr>
<tr>
<td>5</td>
<td>Noise</td>
<td>Less than 65 dB</td>
<td>Max.</td>
<td>L</td>
<td>T</td>
</tr>
</tbody>
</table>

* (A) Analysis (T) Test (S) Similarity to Existing Designs (I) Inspection

**High Risk Specifications**

- **Harvesting Speed** - The point of this project is to increase the efficiency of raspberry production. Therefore, if this spec is not met, the project will fail.
- **Cost** - This is a requirement that was set by Driscoll’s in order to make the solution feasible for the short term. If this can’t be hit, then the solution will not be able to be implemented.

**Chapter 4. Concept Design Development**

In order to develop a wide range of concepts, multiple brainstorming methods were used. The methods and results are summarized in the following sections.
Ideation Phase 1

During the first round of ideation, each member was given a dry erase marker and started writing ideas simultaneously on the same whiteboard. This promoted a rich environment of brainstorming, where ideas were formed, combined, and modified, as can be denoted by the many arrows and lines. As a result of this first round of ideation, a total of 26 unique solutions were developed. Figure 6 depicts a scan of the whiteboard used during this phase of ideation. For a complete list of the ideas developed, please refer to Appendix D.

![Figure 7. Whiteboard used during ideation phase 1.](image)

Ideation Phase 2

During this phase of ideation, solution space boundaries were pushed to their limits and explored. To motivate ‘out of the box’ thinking, each member was asked various questions, such as “How could we solve the problem with water?” or “What if the pickers didn’t have to carry their packing tables?” Asking questions in this manner forces solutions to be developed in a certain manner that may not have occurred through general brainstorming. Phase 2 of ideation generated three more ideas. For a complete summary of these ideas, please refer to Appendix D.

Ideation Phase 3

Phase 3 of ideation involved refining the ideas that had been developed thus far. Up until this point, no ideas had been rejected, no matter how ridiculous or far-fetched they seemed to be. During this phase, however, the physical and monetary constraints, as well as the feasibility, were considered. In total, eight ideas were further developed during this phase. A complete account of these ideas and their development can be found in Appendix D.
Concept Selection Process & Results

During the ideation phase of the design process, the goal is to learn as much as possible about the problem and explore the broadest solution space possible to solve the problem. Through interviews, experiments, and first-hand experiences, the designer tries to gain as much information about the problem. The “anything goes” mentality maintained in the first phases of ideation heavily reflects. As a result, up to this point, the process can be seen as a diverging cone representing the ever-increasing solution space that is developed. Figure 7 depicts this process.

![Figure 7](image)

Figure 7. Graphical representation of the ideation process.

In order to narrow the scope and focus on one or two concepts, three different techniques were utilized, and are described as follows.

Pugh Matrix

The Pugh Matrix is a method for quantitatively comparing many concepts simultaneously against a common reference point. A matrix is formed where each column represents a different concept, and each row represents the various criteria that the solution must fulfill. One of the ideas (typically the one most representative of the current solution) is chosen to be the datum, and is assigned a value of zero for each row. The other ideas are then evaluated one at a time, going over each criteria and assigning a (+) if it satisfies the criteria better than the datum or a (-) if it does a worse job. An (S) is placed in the column if it is the same as the datum. When this has been done for each concept, the (+)’s, (-)’s and (S)’s are all added up separately (they are not summed up in one lump sum). These numbers, called the Pugh Matrix score, are then evaluated against each other to see which concept is the best. After completing the Pugh Matrix, there was no clear winning idea. Rather, all the concepts seemed to get relatively the same score. As a result, another concept selection method was used.
Decision Matrix

In order to analyze the concepts from a different viewpoint, a weighted decision matrix was used. A weighted decision matrix involves analyzing concepts against a list of weighted criteria. A matrix is setup very similar to the Pugh Matrix, where the concepts are listed at the top of each column, and the criteria are to the far left of each row. With the decision matrix, however, each criteria is assigned a different weight. Each concept is then analyzed against the criteria and assigned a value between 1-3 (inclusive), where 1 means the concept failed to meet the criteria, and 3 means that it exceeded it. These scores are multiplied by the weight and then added together to get a final score. Please see Appendix B to see the decision matrix used to analyze the concepts.

After completing the decision matrix, it was found that the packing cart and passive sorter concepts had the two highest scores.

“Concept Shootin’ Gallery”

At this point in the concept selection process, there was not much hope motivation to carry on. A wide variety of solutions had been explored and discussed during ideation, but there was never an “Aha” moment where the light bulb clicked on a pointed to one fantastic, clever, and sleek idea. Rather, as each concept was discussed and developed further, it became apparent that most of them created more problems than they solved. The problems associated with each of the eight concepts that were developed and analyzed up to this point are discussed below.

Mobile Packing Table

While the mobile packing table allows for more materials to be carried, three are no really apparent savings. The pickers are still packing and still responsible for obtaining their own materials. While the carts could be brought down the rows, this would most likely lead to a decreased efficiency, for now the pickers are burdened with moving this cart every so often while trying to simultaneously pick the fruit. While a “team” system could be devised, where one or two pickers pick fruit and a third follows and packs with the cart, it is believed that this too will lower efficiency. While the pacing process takes a long time for one picker to accomplish, it does not take so much time as to merit the dedication of one packer for every two pickers. There is simply not enough to do, and the packer would end up standing idle most of the time.

Aqueduct

The aqueduct creates the problem of wet raspberries. It was found that the raspberries need to be packed dry. If they are packed wet, this would increase the chances of mold growing on the berries. Therefore, a drying system would have to be developed in order to completely dry the berries in a reasonable amount of time. Further, the aqueduct would require lots of initial cost in order to install this system on every row. Since the rows are picked at most once per day, this would result in a lot of capital that gets rarely used.

Gondola

It was not apparent where the savings were with this system. While it would help the pickers transport many buckets out of the field, it would only be able to do so with limited use. Due to the tents covering the field, there is limited space for an overhead system such as this to be installed. Further, in order to keep it out of the way of other operations, such as pruning, the system would only be able to be installed above the middle row.
This would result in minimal use. Further, similar to the aqueduct, to be effective, one system would need to be set up for each tent, thus resulting in lots of unused capital.

**Automatic Sorter - Passive**

The main issue here lies in the possibility of damaging the fruit. Each time the berries are transported before reaching the clamshell creates a new opportunity to accrue more damage. Since these berries are sold as fresh fruit, damage is not acceptable.

**Automatic Sorter - Active**

While this concept has the same issues as the passive automatic sorter, it would also be very expensive to produce. Creating a truly automated system would require a lot of money spend on motors, encoders, microcontrollers, etc. and would most likely end up far outside the budget. Further, developing a system as complex as this is outside the scope of what can be completed with this project.

**Arm Tubes**

This idea brings up concerns of ergonomics. It is imperative that the pickers are not obstructed while they are working, so developing a system like this that is still comfortable and effective would be very challenging. Further, it is not totally apparent where any actual savings would be.

**Modified Tray Height**

While this idea would save money for each tray, it would require a large initial investment. Further, research would have to be carried out to determine the side effects, such as an increase in vibrations during shipping that would result from the taller stack of clamshells. Finally, this solution would simply not achieve the results required for this project of increasing efficiency as measured in pounds harvested per hour.

**Monorail**

Similar to the aqueduct and the gondola, this solution would require a large initial capital investment and lots of time spent to install properly. Further, not every part of the system is used every day, thus resulting in a lot of the investment sitting “idle” for a majority of the time.

As a result of this analysis, it can be seen that there is no clear solution. While some concepts solve the problem in a clever or effective fashion, they almost all negate this fact by creating more problems elsewhere. Moreover, while the results of the Pugh Matrix and the decision matrix did rank some ideas higher than the others, there were no concepts that greatly stood above the others. Therefore, to narrow down the list, a new approach was taken, affectionately called the “Concept Shootin’ Gallery.” This approach involved taking a more pessimistic approach, where ideas were evaluated on how bad they were. By considering blaring errors such as idle equipment and large setup times, the concepts were narrowed down to two ideas: the mobile packing table (wagon) and passive automatic sorter.

It is important to note that these two values did, although not by much, achieve the highest ratings on the decision matrix, thus confirming that they had the most potential. With this decision, and keeping in mind the weaknesses listed out above, the two ideas were further developed.
Cart

The cart, formerly called the mobile packing cart or wagon, involves creating a wheeled version of the packing tables currently used in the fields. The cart would include two large wheels (could be bike wheels for ease of serviceability) for the cart to roll on. The wheels would be large to allow easy movement over rough terrain and would be limited to two to maintain high maneuverability. A system of shelves would be built up above the wheels for storage of packed trays. This would ensure that the trays are out of the way when packing has been completed and that the majority of the weight is directly over the axis of rotation. The packing materials (empty clamshells and unfolded boxes) would be stored in shelves farther up or out. A packing surface on top would allow ease of packing for the current tray. Further, a scale could be incorporated to help tackle the issue of overpacking. Finally, two handles would extend out the back to allow the cart to be pivoted about the axle and moved. Figure 8 depicts a CAD model of the concept design.

![Figure 8. Concept CAD Model of the Cart (Bike wheel model courtesy of GrabCAD)](image)

The cart could be operated in two configurations. Either each picker or a team of two pickers would have their own cart or a team of two pickers and a packer would share a cart. In the former configuration, every picker would be responsible for packing their own fruit. The decision of creating a team instead of giving every picker their own cart would be motivated by size and cost of the cart. In the latter configuration, the dedicated packer would be responsible for all activities related to the cart. That is, they would pack all the fruit, gather all the packing materials, and deliver the finished trays to the trailer. This method would require some change of pay scale to ensure that everyone received credit for how many berries they picked.
Conveyor

The semi-automatic conveyor system would be placed on the trailer and follow the crew throughout the workday. The system would be driven with a DC motor, best driven by a battery. Possible options for keeping the battery charged include solar cells, a small generator, and using the tractor’s battery. Due to the light weight of the raspberries and the slow projected speed of the conveyor, the motor should use little power.

The conveyor belt operates as a standard conveyor belt typically seen at a store checkout. A concept CAD model is shown below in Figure 10. The conveyor would be loaded with raspberries from the picker’s buckets and carry the raspberries towards the packing area at the end. The conveyor would be split into multiple lanes, each of which would fill a clamshell. The quality inspectors would be at the receiving end visually examining all the raspberries as they move towards the end. The conveyor would be moving slowly enough that the inspectors can remove leaves and bad raspberries while the conveyor is in motion. The conveyor design would take into account the transition between the conveyor and the empty clamshells in order to minimize damage of the raspberries. The conveyor will be easy to turn on and off, so the inspector can halt the conveyor whenever needed, and will include proper safeguards to protect against any pinching action or otherwise harmful consequence when operating around a conveyor belt.

Logistically, all the packing materials, both trays and clamshells, would remain at the trailer so packing supplies would not have to be moved. Scales can be incorporated to weight every clamshell until it is filled and placed in a tray. This would reduce likelihood of overpacking in the clamshells. To preserve the pay system where pickers get incentive pay based on what they harvest, an identifying system would be used to keep track of what the pickers bring to the conveyor belt. One idea would be similar to the dividers used in checkout lines at a store. A picker could have a divider for their own raspberries, so when that picker’s ‘batch’ reaches the end of the conveyor, quality inspection personnel would know which picker to give credit to when they pack that picker’s raspberries. If a picker’s batch does not fill a complete tray, then those excess clamshells could be placed in a designated waiting area. When the picker returns with another batch to be packed, the quality inspector can take those waiting clamshells from before, start filling a tray, then start packing the new batch. While this sounds like a lot to keep track of, especially with crew sizes in the mid-twenties of people, if everything is labeled clearly and properly it should be straightforward to keep track of each picker’s raspberries and they can preserve the current pay system.
Figure 10. Labeled Concept CAD model of Conveyor system (Conveyor belt frame model courtesy of GrabCAD)
Figure 11. Conveyor Overhead Schematic Diagram of Conveyor System.

Achieving Project Goals

Cart

The packing cart functions as a mobile packing station, allowing the workers to consolidate the picking and packing steps into one mobile location. In most harvesting cases, pickers go into the field and collect 3-5 buckets worth of berries, then exit the field and set up the packing tables. Here, the raspberries are packed into the clamshells and then loaded into trays. The cart eliminates excess walking in and out of the field. It allows the pickers to carry a much higher capacity of berries while in the field compared to carrying a few buckets at
a time. The cart is expected to meet the project goals by increasing efficiency via consolidation of the packing and picking steps and allowing the pickers to remain in the field longer and take fewer walking trips.

The cart could incorporate a method to pack raspberries directly into the clamshells. This would greatly reduce raspberry touches and damage because of the elimination of the bucket. The raspberries would no longer have to be compressed at the bottom of the bucket, and would not have to be poured out into clamshells at the packing table.

**Conveyor**

The conveyor system aims to meet the overall project goal of increasing harvesting efficiency through large reduction in packing time and some reduction in walking time, allowing pickers to spend more time in the field picking raspberries. The conveyor achieves this by fully utilizing quality inspector labor, allowing for continuous quality and weight monitoring in a single continuous stage. However, additional personnel will be required to operate the conveyor. All raspberries can be inspected quickly because they are spread out on a conveyor system and can be easily spotted and removed if they do not meet quality standards. With a considerate design, touches on the raspberry are not increased from the current harvesting method and additional likelihood of damage is not introduced. With scales, clamshell overpacking can be greatly reduced, if not eliminated completely because they are getting packed by the actual weight, not by eye only to be rechecked later. Pickers no longer have to carry their tables with them, and they do not have to worry about packing materials, eliminating some of the complaints recorded in the picker survey.

**Preliminary Analysis Discussion**

Once the packing cart and the semi-automatic conveyor were selected, the data collected from the Camarillo field visit was used to create a model of a typical harvest cycle. A typical harvest cycle is characterized by entering the field, collecting berries, exiting the field, packing berries, and taking completed trays to the trailer for QA. This process which takes approximately an hour at the Camarillo farm. At other fields, the harvesting cycle time would be less because of the reduced bucket carrying capacity. To model this, time in the field and packing time would be reduced proportionally, but walking time would stay the same, and potentially increase because of increased trip frequency in/out of the field and to/from the trailer. All data can be found in Appendix C.

Our data model determined that using the semi-automatic conveyor system has the potential to increase harvesting efficiency by approximately 20%. In a complete harvesting cycle recorded from the Camarillo visit, the followed picker spent 46 minutes picking berries, 9 minutes packing, and 5 minutes walking. Figure 11 below helps visualize this distribution.
The semi-automatic conveyor belt solution would not affect the time spent in the field. Once out of the field, instead of worrying about a packing table and packing supplies, the picker would just unload the raspberries and continue picking. This process will be further discussed below. This step was estimated to take no more than 2.5 minutes with 8-9 buckets. The walking time of the pickers was due to several tasks, including walking to gather packing supplies from the trailer, bringing trays to the trailer, and transporting tables to move to the next row. The conveyor solution would allow pickers to proceed with picking in a single trip. Buckets would be brought out of the field and poured and then once empty, pickers would proceed to the next row, with no table or packing materials in tow. Average walking time per harvest cycle was estimated to be cut in half, from 5 minutes to 2.5 minutes. This breakdown of the modified harvest cycle is shown below in Figure 12 below.
Preliminary analysis on the above projection compared to current data helps quantify the efficiency improvement that is possible by using the conveyor system. Picking time stays the same but with the reductions in packing and walking time, a harvest cycle time would be reduced to 51 minutes instead of an hour, which is a 15% reduction in time. For 8 hours of work per day, a worker could complete approximately 8 harvest cycles under the current harvesting process. Time savings from the conveyor would allow a picker to complete approximately 9.4 cycles. Pickers brought an average of 4 trays, or 18 lbs, after a harvest cycle. 8 hours of work, or 8 cycles yields 144 lbs per day currently. An additional 1.4 harvest cycles increases picker yield by 5.6 trays, or 25 lbs of raspberries, to a daily yield of 169 lbs. This is an increase of 17.6%, an efficiency increase which holds for lbs harvested per hour, both for individual pickers and the whole crew.

Currently the picking cart is a more difficult to define quantitatively. The reason for the difficulty is because of the combination of packing and picking steps. For a single picker, bringing a cart with them is going to increase their time in the field, but eliminate the standalone packing step. This increased time in the field is the combination of both picking and packing. In a harvest cycle, the time of the combined step of picking and packing while using the cart must be less than the sum of the time of the distinct packing and picking steps in the current harvesting method. To best determine the whether the cart will increase efficiency by the desired amount, creating a functional prototype of a cart and using it in similar conditions to the raspberry fields will best determine feasibility. A prototype would be valuable to determine cart configurations that are best suited for a single picker or a team of pickers and to establish a proof-of-concept.
Risks and Unknowns

Cart:

The packing cart main challenge will be the ergonomics. While a packing cart may improve harvesting efficiency, the worker approval metric is at risk. The cart must be comfortable to move and use, and must not add excess fatigue to what is already a labor-intensive job. Moving the cart down the row is the first critical action that must be addressed. The cart’s weight and mobility will affect how easy it is to transport the cart. One thing to note about the weight is that both the weight of the cart itself and the weight of all of the raspberries must be accounted for in the design. Each bucket of raspberries that is added to the cart is about three pounds of added weight. With multiple buckets from each picker, and multiple pickers per cart, this weight can quickly add up. The cart’s mobility may be primarily push-driven or pull-driven. If it is push-driven, the picker will need to constantly move the cart down the row as they move. If it is pull-driven, the cart will move as the picker moves via a towline, however, this poses a significant risk to comfort. Additionally, the packing motion from the picker (given no dedicated packer) must be fluid and not pose movement risks. Any twisting motion made by the picker’s body (i.e. filling a clamshell from the bush and turning to add it to the cart) would cause fatigue and potential injury. The senior project team must carefully analyze and develop a solution to prevent this if this concept is chosen.

Another risk with the cart is the pay structure for the pickers/packer. If the cart is just used as a platform for multiple pickers, it would be critical to develop a process so the berries from one picker does not mix with the berries of another picker. Since pickers get paid a commission for how many trays they pack, the tray would have to be kept separate on the cart as well. Another option is to record the weight of the buckets that each picker fills, and use this as a basis for payment.

If the cart is used with a dedicated packer, the pay structure becomes even more of a challenge. One question that would need to be answered is, “does the packer share/have a commission for the berries from the pickers?” If so, would the entire team get the same commission or would it try to be kept separate? The solution to this is still unknown, and could potentially make the difference between worker acceptance or not.

Lastly, a large risk with the cart is the utilization. For each tent of the farm, there are several rows of berries. On the ends, a metal pole used to hold the tent up lines down the middle of the rows. Due to this obstruction, it is not foreseeable that the cart can be used on these rows, and traditional picking methods must be utilized. This lowers the utilization of the cart and therefore increases the cost to increase efficiency.

Conveyor:

The primary challenge with the conveyor is the process change and the effects that it might have. One example is the harvesting surges that may occur. If a large number of pickers come in at once with their berries ready to be dropped off, the conveyor must be able to handle this surge without causing a bottleneck in the picking process. To solve this, the conveyor must be sufficiently large; however, there is a chance that there simply wouldn’t be enough room on the trailer to make the conveyor large enough. The trailers are often used as staging areas for trays before the truck arrives to pick up fruit, and incorporation of a conveyor would take away from this usable space. Preliminary analysis will be performed to ensure that there will be adequate space if this concept is chosen.
Another risk with the conveyor is the power source. The team must find a way to provide power to the conveyor that lasts all day and is reliable. Direct AC power is unlikely due to the location of the packing in the field. Therefore, some sort of stored energy solution is required. Batteries would be sufficient to power the conveyor, but this will drive up the cost overall. This is only a minor concern since this concept targets the entire picker base, so the budget is also much higher.

Another risk the conveyor poses is the workload imposed on the Quality Assurance (QA) inspectors. The concept suggests that two QA inspectors run the conveyor and do the packing. However, there is a chance that this new duty, as well as inspecting the berries and applying stickers, may cause too much work for the QA inspectors to handle. The team will perform a time simulation on this at peak conditions if this concept is chosen. One possible solution to this risk is adding a third QA inspector at the trailer; however, this would increase the operational costs of this solution.

Chapter 5. Final Design

PDR Feedback

The PDR yielded helpful feedback and constructive criticism that enabled a final concept to be selected and developed into a final design. Discussing the PDR with Driscoll’s helped explore and refine the requirements of the project. The conveyor and the cart concepts helped identify new constraints that were previously unknown.

For the conveyor belt, power and serviceability constraints were stricter than envisioned in the preliminary design phase. Using generators would be loud and costly to maintain in the long run, and a large footprint and weight would make transportation cumbersome. Connecting to the tractor’s auxiliary power was not an option as well because of battery drain reducing reliability of transporting the trailer. Solar was explored as a silent, renewable power source, but because of the harsh farm conditions with lots of dirt their efficiency would decrease rapidly and maintenance would be difficult. For hardware, a controlled conveyor belt would take an experienced technician to maintain and repair because such a system would use sensitive and somewhat complicated electronics. These are also difficult to protect from the harsh environmental factors of the raspberry farms. The complexity and power requirements of the conveyor system detracted from its ability to be a complete, easy to implement and maintain solution.

During the review, it was established that the cart design and implementation constraints were more relaxed compared to the constraints used to develop the preliminary design of the cart. One constraint was the ratio of pickers to packers. Initial discussions of a picking and packing team depicted a pair of pickers that would share a cart that would move with them as they progressed down a road. Instead, teams could be larger with a dedicated packer following pickers. This made the cart more efficient by specializing labor; workers would no longer have to alternate tasks. This would require a change in the current setup of workers’ incentive pay. There was reassurance that if a harvesting aid solution seemed promising, then owners would be inclined to alter how the pay structure was configured.

The PDR served to be extremely helpful because it tested boundaries and constraints and helped establish what aspects of the preliminary designs are valid. With all of these considerations, the cart became the design of choice because of its simplicity, efficiency, and likelihood of acceptance.
First Prototype – Overall Description & Layout

The cart is intended to be used in a picking and packing team, in which one designated packer follows a team of pickers, takes their buckets, and packs them into clamshells and trays. Team sizes are expected to be between 4 and 6, or a ratio of 3:1 up to 5:1, depending on the speeds and abilities of the pickers and packers. The cart contains features to maximize the productivity of the dedicated picker. A rendering of the first cart design is shown below in Figure 14 and Figure 15.

![Figure 14: Labeled CAD Render of Empty Cart](image)

- Optimized packing surface for all of Driscoll’s clamshells
- Bucket storage area
- Unfolded tray storage
- Large 16” diameter pneumatic wheels
- Quick release pins
- Adjustable/foldable handles
- Slide out drawer tray storage area
- Swinging gate for sturdy drawer support

Figure 14: Labeled CAD Render of Empty Cart
Going from top to bottom, the cart has a packing surface that is large enough to accommodate the four current clamshell sizes. As shown in Figure 15, clamshells come tightly stacked from the supplier. Packers place this stack on the surface and fill them with raspberries, gradually working with the stack. Empty buckets are stacked and stored on the right side of the cart. Unfolded trays are stored on the left side of the cart, easily accessed for folding by the packer. Figure 14 shows that the cart is maneuvered by adjustable handles with foam grips to enable packers to complete their work more comfortably than with a fixed configuration and bare metal handles. Tray storage is located at the bottom of the cart, and it has a capacity of 21 filled trays. The storage mounted on a drawer slide system, which can be pulled in and out for easy tray access. When the storage surface is empty, there will be little difficulty in accessing the entire surface, but as it fills up towards the top, accessing the back of the storage area will be more difficult. An extendable storage area allows all the trays to be accessed easily, such as when they all need to be unloaded. The high raspberry weight, just under 100 pounds, when the storage is completely filled may cause the cart to become unbalanced when the drawer
is extended. The cart includes a mechanism that swings out and rests on the ground behind the cart. This adds a third leg to the cart that the storage drawer can rest on when fully extended, reducing the probability of tipping over. The tires have an aggressive tread and allow for easy navigation across rough terrain found in the raspberry fields.

**CDR & Field Testing**

The above design was presented to the class as part of the Critical Design Review. The review was helpful in eliciting feedback from peers who contributed valid points to considerations and potential changes to the cart. Some concerns presented were stability issues regarding the height of the center of gravity of the cart and the wheel placement of the cart. If there were bumps, dirt clods, or other objects that would disrupt the motion of the cart, there was a concern that tipover would ensue. A tipover scenario would eliminate all efficiency improvements and should be avoided at all costs.

Field testing, which occurred on February 16 in Camarillo, CA, was an extremely valuable experience in the development of the cart. In the field, the idea of the cart was first introduced to the harvesters and its feasibility was gauged as an acceptable solution. Several issues with the cart were addressed and noted, and were seriously considered in the final design of the cart. Further details of this test are discussed in Chapter 7.

**Final Design**

The final design incorporated changes taken from feedback received in CDR and field testing to create a cart that is functional, interfaces well with the harvesters, is easy to manufacture and maintain, and most importantly improves efficiency. Below is an image of the final prototype of the cart.

![Final Prototype of Cart](image_url)

*Figure 16. Final Prototype of Cart*
The function of the final design is very similar to the first prototype. It is used in teams of 5, with one picker and 4 packers. There are 6 main features, shown in the labeled CAD rendering. The packing surface on the surface holds all sizes of clamshells, which are the 6 oz., 9 oz., 12 oz., and 18 oz. Angle irons adjacent to the packing surface hold the trays as they are being packed with clamshells. Also on the angle irons is small plate for a portable speaker should the packer wish to use one while using the cart. Below the packing surface is a surface for the unpacked trays to be stored before being folded for packing. It is angled to prevent the trays from falling out as the cart moves throughout the field. At the bottom of the cart is the storage for the packed trays. The trays fit 3 stacks deep, and 5 trays high for a capacity of 15 trays. The stacked trays are stable up to the maximum capacity. However, bungee cords are incorporated as a safety and retaining mechanism for the trays. If the cart were to tip and the trays begin to fall out of the cart, then the bungee cords would restrain them from falling out. The bungee cords are removable without a significant amount of force, so the cart can be unloaded from any side the picker pleases. The adjustable handles were carried over to the final prototype because it was a well-received feature. The handles had some play in them, about half of an inch at the ends, because of the adjustment design, but it is robust and easy to change, making the play an acceptable compromise.

An extra wheel was added to make the cart more stable and mobile. During February’s test, there were issues with the vertical stands at the rear of the cart dragging on the ground. Additionally, a large rut required two people to navigate, defeating the purpose of the cart’s efficiency. Testing, also discussed in Chapter 7, determined that a cart with three or four wheels would overcome these issues. Three wheels was the cheaper configuration without compromising strength, size, or manufacturing difficulty.

The gate and drawer system was eliminated from the cart because the harsh environment inhibited their function quickly. The drawer slides became full of dirt and rocks and quickly became inoperable. The hinge had an excessive amount of play in it, and did not allow the gate to move in a stable, steady manner. Making the sides open, with bungee cord constraints, eliminates the need for a drawer slide system to improve accessi

**Analysis Description & Results**

The primary analysis done throughout this project has been process analysis. The pickers set up at the beginning of the day, pick and pack raspberries, and continue through the field until the end of the day. They perform multiple processes, all which take time and have inefficiencies that can be improved. Analysis first focused on quantifying all aspects of the pickers’ routine including bucket and tray cycle times, full harvest cycle times, and harvesting rates. A full harvest cycle starts when a picker enters the field and ends when they have completed their packing and dropped the completed trays at the trailer for quality inspection. A single picker was followed for their entire harvest cycle, which took 60 minutes and yielded 9 buckets of raspberries, each of which took 4-6 minutes to fill. This specific harvest cycle aligns with general picker data that was collected. Full data can be found in Appendix H. Notable values from the data are shown below in Table 4 and Table 5.
As shown above in Table 4, dedicated packers who are working in the cart configuration will have the highest daily yield of raspberries. This is because their harvest cycle consists of just packing, with a minimal amount of walking to dispose of the cull bucket contents and restock on buckets. The Watsonville process is an estimate based on provided videos and discussion about the differences between Watsonville and Camarillo ranches. The daily harvest rate is lower at the Watsonville fields because of the excess walking that results from only taking a few buckets in at a time and having to exit the field when only those buckets are full. Although the dedicated pickers in the cart configuration have an increased daily yield, the full crew is no longer picking because some are now dedicated packers. Ultimately, the increased picking rate by the dedicated pickers must offset the loss of some crew members to full time packing roles.

Table 4. Individual Daily Packing Rates for Multiple Field Configurations

<table>
<thead>
<tr>
<th>Individual Harvesters</th>
<th>Picking Rate (lbs/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Process (Camarillo)</td>
<td>144</td>
</tr>
<tr>
<td>Current Process (Watsonville)</td>
<td>132</td>
</tr>
<tr>
<td>Dedicated Packer (Cart)</td>
<td>178</td>
</tr>
</tbody>
</table>

The cart is a means to specialize worker labor and maximize efficiency in each task. Instead of all pickers both picking and packing, harvesters focus on one task and eliminate efficiencies in transition and excess walking time. A harvester typically spends 46 minutes picking, 9 minutes packing, and 5 minutes walking. A dedicated picker can combine the packing time with the picking time for a total of 55 minutes picking and 5 minutes packing. This is a conservative estimate because dedicated pickers are no longer going to have to transport their packing tables, filled trays, and packing materials. Nominally a picker can exit the field, dispose of their

Table 5. Efficiency Deviation from Camarillo Baseline

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Estimated Efficiency Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camarillo</td>
<td>0.0%</td>
</tr>
<tr>
<td>Watsonville</td>
<td>-8.5%</td>
</tr>
<tr>
<td>Cart – Teams of 4 (3:1 ratio)</td>
<td>3.0%</td>
</tr>
<tr>
<td>Cart – Teams of 5 (4:1 ratio)</td>
<td>7.5%</td>
</tr>
</tbody>
</table>
cull bucket and get empty buckets, and continue with picking. The packer takes care of all the packing, gathering materials, and dropping completed trays off at the trailer.

The cart design illustrates a trade-off; harvesters that become dedicated packers no longer pick raspberries, and do not contribute to the total harvest rate of the crew. The remaining dedicated pickers must make up for that shortage and beyond to ensure the cart is a successful harvest aid. Data analysis shows that, for a team of 30 harvesters, team sizes of 4, 5, and 6 harvesters will improve efficiency by 0.8%, 7.5%, and 12.0% respectively. Only team sizes of 5 and greater, or 4 pickers and 1 packer, are expected to increase efficiency by over 6%.

Data taken on bucket packing time and tray packing time suggests that a dedicated packer can keep up with a nominal 4.2 dedicated pickers and maintain pace with the group. Rounding up, a packer with a group of 5 pickers would fall behind in the field and would further fall behind when they have to drop off the filled trays and restock on packing supplies. Rounding down to 4 pickers and 1 packer would allow the packer to maintain pace with the group in the field. When the packer falls behind after the tray drop off and material restock in between cycles, they should be able to catch back up slowly in the field.

**Cost Analysis**

Driscoll’s has established a budget for a prototype of $100 per picker. Prototypes which affect more than one picker can have a larger budget. Each cart affects a team of 4-5 pickers and has a prototype cost of $400-$500. The cart structural prototype was produced under budget, and a high-level cost breakdown is shown below in Table 6. Appendix F contains details and links for purchased components and stock. The full estimated cost report can be found in Appendix G.

Table 6. Summary of Estimated Cost Report

<table>
<thead>
<tr>
<th>Type #</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$150.00</td>
</tr>
<tr>
<td>Stock</td>
<td>$167.13</td>
</tr>
<tr>
<td>Purchased</td>
<td>$79.88</td>
</tr>
<tr>
<td>Subtotal</td>
<td>$397.00</td>
</tr>
<tr>
<td>Contingency</td>
<td>$59.55</td>
</tr>
<tr>
<td>Total</td>
<td>$456.55</td>
</tr>
</tbody>
</table>
The cost analysis above contains assumptions that may cause the analysis to differ from the actual cost of constructing a cart. One assumption is the cost of labor, which was estimated at around $150. This value is an estimate and depends on how much welding and machining processes cost. The frame, handles, and drawer support are the primary manufactured pieces. Individually the pieces are not complex, but as a whole the assembly could take a long time to construct, increasing the cost above the current estimate. Stock price is another estimation. The current value given is the price of stock that was used to construct the structural prototype. This estimate is likely too high because extra material was purchased for some experimentation and a manufacturing factor of safety in the event that a mistake was made. In addition, cheaper suppliers could be available, instead of Ace Hardware and Online Metals. Both were good suppliers that had the material we needed, but perhaps cost would be lower with a manufacturer and their usual suppliers. Hardware costs could be lower when bought in bulk, compared to the smaller quantities bought for the structural prototype. Between actual production and the structural prototype, purchased parts are expected to cost a similar amount. Accounting for all associated costs suggests that while material and part costs may go down with larger scale production, the cost of labor could be an underestimate. Overall, cost should not deviate dramatically from the structural prototype to the final version of the cart.

Material, Geometry, & Component Choices

The structural prototype of the packing cart has served to be a valuable experience in regard to material, geometry, and component choices. Steel is the current material used for the structural prototype and it has been easy to weld and machine. It is a heavier material than aluminum, but steel’s cheaper cost made it the material of choice for the structural prototype. For the final prototype, aluminum has been the favored material due to its corrosion resistance and that its lightweight. The structural prototype has illustrated advantages with using steel. The steel frame is relatively easy to maneuver and with a good design and paint, the steel frame’s corrosion resistance can be improved. Environmental factors are critical with the cart application. It is being used outdoors in a farm environment, where wind, moisture, and dirt are prevalent. Some locations are close to the ocean and increased humidity can promote premature rusting. In order to go with steel as a more cost-effective material, corrosion will have to be mitigated.

The geometry of the cart was dictated by function and weight. The cart design will be used for thousands of hours across dozens of packers. It must be functional and ergonomic in order for the packers to be willing to use it and increase the overall harvesting efficiency. The weight dictated a minimalistic frame structure with cross member support, allowing for a strong and lightweight structure. A rectangular structure was the simplest to manufacture and allowed for a large table surface to pack raspberries and large storage space for filled trays.

A majority of the cart components are purchased which is useful in reducing manufacturing time and increasing repeatability. Rubber grips are used at the end of the handles for ease of grip so the cart doesn’t slip. Quick-release pins are used in the handle arms, the drawer, and the drawer stand. These allow the cart components to be locked in place while the cart is in motion, but when needed the components can be unlocked and used quickly. Wheels were purchased for the cart as well. Pneumatic tires and a build in bearing hub eliminated any design or manufacturing need to make the cart mobile.
The above flowchart details the process a harvesting team will perform to complete a harvest cycle. Pickers will focus on filling buckets in the field and packers will handle all packing responsibility. The packers should enter the field after the pickers to minimize waiting while the first sets of buckets are filled. The preparation time for a packer is expected to take longer than picker preparation time, so this offset is expected to happen by default.
Safety, Maintenance, & Repair

The cart is a safe, unpowered solution to increase the efficiency of harvesting raspberries. It operates similar to a generic garden cart or wheelbarrow, so it does not have a steep learning curve to use and operate. The adjustable arms and spoked wheels are possible pinch points, and if proper posture is not maintained ergonomics may present an issue for worker health. The repair of the cart is straightforward due to an abundance of off-the-shelf components, all with no lead time and are easy to replace. If something with the frame fails, simple welding of steel is required. To best maintain the cart, it should be cleaned at the end of the day by removing any dirt or moisture that may have collected throughout the day. The packing and drawer surfaces should be clean to ensure trays and clamshells remain clean throughout the harvest cycle. For full analysis of safety and failure modes, please refer to Appendix I.
Chapter 6. Manufacturing Plan

Material & Component Procurement

All the materials used to create the final prototype can be found and ordered online from various vendors. All metal stock can be ordered from Online Metals, which focuses on low quantity metal orders through a wide variety of choices and a user-friendly website. There are three types of stock used to create the final prototype, each of which are standard in size and could be found elsewhere if desired. The sizes used are one-inch square steel tubing, 22-gauge weldable sheet steel, half-inch steel rod, and eighth inch steel strips. These could be found in a local hardware store as well. The final prototype used ten feet long tubing sections which could be difficult to find locally, but at a large manufacturing plant would be feasible.

The wheels for the final prototype were purchased from Home Depot. The wheels are sturdy and perform well in the field. Since they are pneumatic, vibrations from the cart are dampened out. They are larger in size, around 16 inches in diameter, and include treads and a hub bearing with a shaft diameter of 5/8”.

All other components that complete the assembly of the cart are all purchased from McMaster-Carr. These include the quick-release pins, rubber grips, nylon spacers, and installation screws. The components do not contribute much to the overall cost and are not specialized.

Component Manufacturing Steps & Challenges

Making the final prototype was a valuable experience that provided learning lessons for future product development. The final prototype was used as a test prototype in Watsonville on May 31st, so it is a complete representation of what any future design will entail. Changes are suggested to the design based on feedback and test results, but overall manufacturing steps should remain the same. Below are steps used to create each component:

All Tubing Pieces:
1. Using the frame weldment drawing, cut each piece of tubing to length.
2. If there are holes in the tubing, mark the location of the holes and drill per the drawing. Using a mill or drill press would be best for drilling the holes.
3. Grind the cut edges of the tubing so there are no sharp edges remaining.
4. Bent tubing will be manufactured using a tube bender with a 1” square die.

Axles:
1. Cut half inch rod to specified length.
2. Drill holes for cotter pins into rod
   a. Mark holes with center punch
   b. Drill pilot hole using center hole drill

Rotating Handle Adapters:
1. Cut adapters to shape using an angle grinder, laser cutter, plasma cutter, or a waterjet cutter.
   a. If a plasma cutter or angle grinder is used, fabricate the holes by marking their location per the drawing. Use a center punch, center hole drill bit, then drill bit to achieve precise location.
Frame:

1. Tack weld the rectangular base together. Use magnetic squares or regular squares to ensure the base pieces are perpendicular to each other.
2. Tack weld the rectangular top together. Use magnetic squares or regular squares to ensure the base pieces are perpendicular to each other.
3. Tack weld the cross members to the frame of the cart.
4. Tack weld tray storage sheet metal to the frame of the cart
5. Once the cart is adjusted and square, complete welds per drawings found in Appendix E1.

There are very few challenges in manufacturing each individual component. Simple geometry allows for simple tools and easy cuts and hole drilling. Weldments presented somewhat of a challenge because of heat-induced distortion and ensuring the final weldments are square. Tack welds proved useful when creating the frame because it allowed for easy adjustment and modification as needed. One particular challenge may present itself when the tube is being bent. If there isn’t sufficient lubrication around the tube in the die, it is possible that kinking may occur. Another way to mitigate this problem is to first fill the tube with sand before bending.

Assembly Process and Challenges

The assembly process is straightforward after the components are manufactured. Assembly consists primarily of welding, but the welding process much less time consuming at the assembly level than at the component level. The subassemblies to be integrated into the main cart assembly are:

1. Frame
2. Front Wheel
3. Rear Wheels
4. Handle

The frame serves as the base subassembly, and the rest of the subassemblies are added to it. The front and rear wheel subassemblies are welded to the frame at the location specified in the drawings using two axle housings constructed out of steel tubing. Cotter pins are used to secure the wheels in place. The handle assembly is connected to the frame using quick-disconnect pins. The handles are intended to be easily adjustable and should be very quick to install.

A detailed instruction set on how to manufacture the cart can be found in Appendix E2.

Chapter 7. Design Verification Plan

The Design Verification Plan & Report (DVP&R) is a document that outlines the various tests that have been planned, and completed for the final prototype. The specification, associated description, acceptance criteria, test responsibility, type of test, and time frames are all included in this document. Additionally, there is a section for the results and notes. This allowed the team to effectively test the packing cart with a methodology that keeps everything organized.

The most important tests are those that occur at the overall system level, such as measuring harvesting efficiency, group size, full-load distance, and unload timing. These are critical to the functional success of the
cart in achieving the main goal of the project. Other tests include cart handling and ergonomics; however, these are secondary to the overall system tests. The descriptions and results of each test can be found in the DVP&R in Appendix K.

The structural prototype was tested in Camarillo on February 16, 2018. The structural prototype gauged the overall performance and feasibility. It was a proof of concept that received thorough feedback, both positive and negative, and was exceptionally helpful for completing the final cart design. Some feedback included reducing cart height and width and improving mobility, which was lacking with just the two wheels. Other observations included trays blowing off the cart in the wind, and the necessity of two people to navigate the cart through a rut in the field. Positive feedback included the adjustable handles and bucket and clamshell storage, all of which functioned as intended during the preliminary testing. A strict outline of the harvesting process was not detailed to the harvesters, so performance data was not recorded for this test because the cart was not used in the process it was designed for.

Mobility was a design issue that needed to solved, and unlike other issues illustrated by the February test, this one needed testing to verify. The goal of this redesign was to allow one person to navigate a rut, and not have the feet of the cart drag on the ground. 3-wheel and 4-wheel configurations were implemented into the structural prototype of the cart and tested in rural areas at Cal Poly to emulate the worst field conditions the cart could experience. Overall test findings determined that in general, larger wheels promoted greater maneuverability and there was little distinction between 3 and 4 wheels in terms of mobility. For cost reasons, a 3-wheel design was chosen for the final cart prototype.

The final prototype was tested on May 31, 2018 in Watsonville, CA, with the DVP&R used as a guideline to evaluate the cart. Team members tested the cart using a stopwatch, and a tape measure. Feedback from the pickers, as well as the project sponsor is included in the report notes found in Appendix N.

Overall use of the cart was explained before testing commenced. The cart is not difficult to use, but it does require some explanation to ensure that it is operated in the intended manner to gain the required efficiency. This user manual for the cart is found in Appendix L.

The cart passed most of the listed criterion during testing. Criteria that the cart did not pass according to the DVP&R has been adjusted for future use in drawings and CAD models of the cart (specifically, the height of the handles of the cart).

Data collected during the testing is located in Appendix M. Overall, 23 trays per hour were harvested by the group. For a planned group size of 30, this corresponds to approximately 100 trays harvested per hour. As of this writing, the ranch has return previous harvesting data, so efficiency cannot be calculated at this time. A team of 6 pickers and 1 packer were used during this test. The packer was left behind and unable to keep up with this many pickers. The actual ratio will be either 4:1 or 5:1 depending on the relative speeds of the harvesters.
Chapter 8. Procuring a Quote

Due to the nature of the project, a specific criteria of the cart that had to be met was to obtain a quote from a manufacturer. The specific budget for the project was given to the team from the sponsor as: $100/picker effectively using the product. For this design, a ratio of 4 pickers to 1 packer was effectively chosen, and thus 5 people were effectively using the cart. This allowed for a budget of $500 to manufacture parts, purchase outside material, assemble, and any other additional processes that would be required to present a finished product to the sponsor. Many manufacturers were contacted (15 total), with only 2 responding with quotes. The first quote received was over the specified budget, and was not submitted to the sponsor. The second quote was based on different quantities of carts ordered, and is broken down in the following table.

Table 7. Price per unit of cart to be manufactured and assembled

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Price/Unit (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>862.00</td>
</tr>
<tr>
<td>100</td>
<td>413.50</td>
</tr>
<tr>
<td>500</td>
<td>388.00</td>
</tr>
<tr>
<td>1000</td>
<td>376.00</td>
</tr>
</tbody>
</table>

It is worth noting that the price/unit dramatically decreases between quantities of 1 and 100, as the manufacturer would be able to “mass produce” the product at this point, making this a better investment for the company. Overall, this criteria was able to be met, based on the quote from this manufacturer.

Chapter 9. Project Management

The process that the team goes through is detailed and meticulously planned. Proven design methods are used to ensure a successful and high-quality solution is achieved. A Preliminary Design Review (PDR) was held at the end of fall quarter that resulted in excellent feedback on the two initial design solutions, the cart and the conveyor. This feedback allowed a decision to be made and the design then proceeded efficiently with all efforts
on the cart solution. Various layouts and configurations were laid out for the cart to best increase efficiency of the dedicated packer and, most importantly, increase the likelihood of acceptance. These ideas were discussed, analyzed, and eventually consolidated for presenting to the class at the start of Winter quarter. This is the Interim Design Review (IDR), which was conducted before the Critical Design Review (CDR) as an informal but cohesive review of the project design. The IDR was used as a transition to the CDR. The CDR was held to present the final engineered design and receive feedback before construction of the final prototype. The Final Design Review (FDR) is a review of the project at completion and will be held in conjunction with the senior project expo at the end of Spring quarter. As demonstrated by the extensive list of reviews and project progress milestones, there needs to be a way to effectively manage the schedule. The team is using a project planning tool called a Gantt chart. This tool assists the team in keeping the project moving within time constraints. Please refer to Appendix J: Gantt Chart to see the Gantt chart created for this project.

The design itself was conducted by identifying key parameters of the solution and incorporating those as permanent design considerations. CAD was made in SolidWorks and must be completed and manufacturable in the final model. Throughout the process, functional concept prototypes were built as proof-of-concept. This includes a structural prototype that will act as the main device in initial tests. These prototypes ensure that the model being built will be practical and feasible. Additionally, it is important that every part designed can easily be bought or manufactured for the final prototype. This will be a check that is done consistently throughout the design development. With CDR, the final prototype design is complete. Per the CDR, changes have been incorporated into the design before the manufacturing has begun.

With the completed design, the manufacturing of the product was started. A preliminary manufacturing plan was created to produce the final prototype. This established the manufacturing processes necessary to produce the parts. It was the team’s goal to manufacture an effective, high-quality product at minimal cost. The manufacturing took place at Cal Poly’s machine shops, and any off-the-shelf parts or materials were purchased in accordance with the sponsor’s approval. Once manufacturing was complete and the cart was painted, it was tested for fit and function with the packaging materials on hand. The cart was verified to work with the buckets, clamshells, and trays. The final testing date was scheduled with the sponsor and the cart was tested in Watsonville on 5/31/18 and Expo occurred on 6/1/18.

As part of the project, it was necessary for the team to identify and obtain quotes from manufacturers that can be utilized by Driscoll’s if the solution if going to proceed further in the implementation process (a phase that would occur after the team has completed the goal as requested by Driscoll’s). A quote packet was produced to help describe the cart to potential manufacturers. It showed CAD screenshots, the final prototype BOM, as well as high-level manufacturing and assembly instructions. This helped secure the quote listed above. Table 8 shows the outline of the team schedule with key milestone dates.

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>Date of Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Prototype Built</td>
<td>11/07/17</td>
</tr>
<tr>
<td>Preliminary Design Review (PDR)</td>
<td>11/14/17</td>
</tr>
</tbody>
</table>

Table 8. Project team schedule of key milestones
<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interim Design Review (IDR)</td>
<td>01/16/18</td>
</tr>
<tr>
<td>Structural Prototype</td>
<td>01/23/18</td>
</tr>
<tr>
<td>Critical Design Review (CDR)</td>
<td>02/06/18</td>
</tr>
<tr>
<td>Manufacturing &amp; Test review (M&amp;T)</td>
<td>03/13/18</td>
</tr>
<tr>
<td>Hardware &amp; Safety Demo (H&amp;SD)</td>
<td>04/26/18</td>
</tr>
<tr>
<td>Testing @ Watsonville Ranch</td>
<td>05/31/18</td>
</tr>
<tr>
<td>Final Design Review (FDR)</td>
<td>06/08/18</td>
</tr>
</tbody>
</table>

Due to the nature of this project, several techniques are utilized to assist in the design process. Process improvement and efficiency is a key topic in this project, and therefore the 6 Sigma/Lean methodology is employed to decrease task time, waste, and unwanted movement. Ergonomics is also an important factor to be aware of for this project. It is important that the raspberry pickers are willing to take in the solution without resistance. Design processes that improve ergonomics, such as taking into account anthropometric measurements, have been helpful to increase the likelihood of acceptance.

**Conclusion & Recommendations**

This final design report builds on the scope of work, preliminary design report, and critical design report to conclude this project. The final design was determined to be best suited to achieve a 6% increase in harvesting efficiency - the measured in weight of the raspberries harvested per man-hour. Efficiency and cost analysis, as well as CAD modeling, was used to evaluate the final design and determine its feasibility. An updated project schedule is outlined in the Gantt chart, which focuses on tasks to be completed by the beginning of March. The objective of this document is to contain a complete design that a third party could review and without any help and completely identifies every component to the selected solution. The next immediate steps are to complete the initial prototype and proceed with in-the-field testing.

**Appendices**

Appendix A: QFD House of Quality
Appendix B: Decision Matrices
Appendix C: Preliminary analyses and/or testing details
Appendix D: Concept Layout Drawing(s)
Appendix E: Complete Drawings Package (BOM, Assembly, detailed parts, processing, wiring)
Appendix F: Purchased Parts Details (links to specifications & data sheets)
Appendix G: Budget/Procurement List (vendors, purchasing details, full budget)
Appendix H: Final analyses and/or testing details
Appendix I: Safety Hazard Checklist, FMEA
Appendix J: Gantt Chart
Appendix K: DVP&R
Appendix L: User Manual
Appendix M: Final testing data

References


Appendix A: QFD House of Quality

The following QFD House of Quality was used to compare different customer needs and wants to viable engineering solutions.

<table>
<thead>
<tr>
<th>Customer Requirements (Step #1)</th>
<th>Engineering Requirements (HOWS)</th>
<th>Benchmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase Efficiency by 6%</td>
<td>Cost $100 per picket</td>
<td>5</td>
</tr>
<tr>
<td>Improve Security</td>
<td>Reduce Overhead</td>
<td>3</td>
</tr>
<tr>
<td>Secure Quoted</td>
<td>Reduce Batching</td>
<td>9</td>
</tr>
<tr>
<td>Reduce Batching</td>
<td>Increase Min. Impact</td>
<td>9</td>
</tr>
<tr>
<td>Increase Min. Impact</td>
<td>Reduce Overhead</td>
<td>9</td>
</tr>
<tr>
<td>Reduce Overhead</td>
<td>Not Disturbing</td>
<td>9</td>
</tr>
<tr>
<td>Not Disturbing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer Requirements (Step #2)</th>
<th>Units</th>
<th>Targets</th>
<th>Benchmark #1</th>
<th>Benchmark #2</th>
<th>Importance Score</th>
<th>Importance Rating (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>38</td>
<td>50</td>
<td></td>
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</tr>
</tbody>
</table>

**Poly Pickers**
The decision matrix is used to evaluate the various concepts against a set of criteria. Each criteria is assigned a different weight in order to reflect their relative importance in solving the problem. Each idea is then evaluated against these criteria on a scale from 1-3 (1 meaning the concept failed the criteria, and 3 meaning it exceeded it). Each value is multiplied by the relative weight and then added together to get one total score. The concept with the highest score becomes the chosen concept.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Wagon (with terset turning considerations)</th>
<th>Aqueduct + Dryer</th>
<th>Automatic Collector (PASSIVE, lots of human intervention)</th>
<th>Automatic Collector (ACTIVE, turkey, very little involvement)</th>
<th>Gondola</th>
<th>Monorail</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturability</td>
<td>5.0%</td>
<td>3</td>
<td>1</td>
<td>2.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1</td>
<td>Calculations</td>
</tr>
<tr>
<td>Initial Cost (per worker)</td>
<td>7.5%</td>
<td>2</td>
<td>5</td>
<td>2.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Calculations</td>
</tr>
<tr>
<td>Operating Cost (per worker)</td>
<td>12.5%</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>Calculations</td>
</tr>
<tr>
<td>Ease of Implementation (Rancher)</td>
<td>10.0%</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>0.5</td>
<td>Calculations</td>
</tr>
<tr>
<td>Worker likelihood of acceptance (Ease of Use/Req Training)</td>
<td>17.5%</td>
<td>2</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>Calculations</td>
</tr>
<tr>
<td>Decrease Touches</td>
<td>11.3%</td>
<td>3</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>Calculations</td>
</tr>
<tr>
<td>Reduce Overpacking</td>
<td>11.3%</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>Calculations</td>
</tr>
<tr>
<td>Increase Lbs/ Hour</td>
<td>25.0%</td>
<td>2</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>1</td>
<td>2.5</td>
<td>Calculations</td>
</tr>
</tbody>
</table>

1 = bad and 3 = good

The concept with the highest score becomes the chosen concept.
The following is data collected from Camarillo during the first trial. It contains a harvest cycle, crop harvesting rate, and analysis on the Camarillo raspberry variety.

### Carmaica

**Time in between between pouring a bucket, packing clamshell, then pouring a new bucket**

<table>
<thead>
<tr>
<th>Bucket Count</th>
<th>Start Time (mm:ss)</th>
<th>End Time (mm:ss)</th>
<th>Elapsed Time (mm:ss)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00:14</td>
<td>00:53</td>
<td>00:39</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>01:06</td>
<td>01:50</td>
<td>00:44</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>02:45</td>
<td>03:15</td>
<td>00:30</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>00:00</td>
<td>00:41</td>
<td>00:41</td>
<td></td>
</tr>
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<td>5</td>
<td>00:41</td>
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<td>6</td>
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<td>02:35</td>
<td>01:08</td>
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<td>03:08</td>
<td>03:57</td>
<td>00:49</td>
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<tr>
<td>8</td>
<td>04:00</td>
<td>05:13</td>
<td>01:13</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>01:55</td>
<td>05:19</td>
<td>03:54</td>
<td></td>
</tr>
</tbody>
</table>

**Average** 00:165 seconds

**Standard Deviation** 00:10.3 seconds

**Time in between between taking a flat cardboard tray, filling it, then starting to fold a new tray**

<table>
<thead>
<tr>
<th>Tray Count</th>
<th>Start Time (mm:ss)</th>
<th>End Time (mm:ss)</th>
<th>Elapsed Time (mm:ss)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00:00</td>
<td>01:57</td>
<td>01:57</td>
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</tr>
<tr>
<td>2</td>
<td>01:50</td>
<td>03:20</td>
<td>01:30</td>
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</tr>
<tr>
<td>3</td>
<td>00:19</td>
<td>01:21</td>
<td>01:02</td>
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<tr>
<td>4</td>
<td>02:00</td>
<td>03:48</td>
<td>01:48</td>
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<td>5</td>
<td>03:08</td>
<td>04:54</td>
<td>01:46</td>
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<td>6</td>
<td>00:44</td>
<td>06:05</td>
<td>05:21</td>
<td></td>
</tr>
</tbody>
</table>

**Average** 01:20.3 seconds

**Standard Deviation** 00:13.4 seconds

### Harvester Round Efficiency

<table>
<thead>
<tr>
<th>Time In (AM)</th>
<th>Time Out (AM)</th>
<th>Elapsed Time (mm:ss)</th>
<th>Buckets From Field</th>
<th>Notes</th>
<th>Min/Bucket (mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:1709 AM</td>
<td>10:41:00 AM</td>
<td>03:00 AM</td>
<td>12:22:00 AM</td>
<td>9</td>
<td>02:00</td>
</tr>
<tr>
<td>10:2009 AM</td>
<td>11:45:00 AM</td>
<td>03:39 AM</td>
<td>12:23:00 AM</td>
<td>8</td>
<td>05:23</td>
</tr>
<tr>
<td>10:2609 AM</td>
<td>11:55:00 AM</td>
<td>04:49 AM</td>
<td>12:24:00 AM</td>
<td>8</td>
<td>06:07</td>
</tr>
<tr>
<td>10:4009 AM</td>
<td>11:35:00 AM</td>
<td>06:42 AM</td>
<td>12:25:00 AM</td>
<td>8</td>
<td>06:53</td>
</tr>
</tbody>
</table>

**Average** 04:43 Average 06:41

**Standard Deviation** 00:06:00

**Standard Deviation** 00:06:00

### Field Length

350 ft

### Other

**Full Bucket** 32.5 lbs

**Empty Bucket** 0.51 lbs

**Bucket Empty Weight** 2.54 lbs

**Trays Harvested** 4

**Total Time (hours)** 4:07:55

**Trays per hour** 183.2

**Lbs/Hour** 1467

**Lbs/Day (8 hrs)** 11700

---

* Data from counting the total trays loaded onto the truck.

** Time from keying in the start time to lunch. (approximately 7:30 to 11:30)

The above data is more representative of an overall harvesting rate, because it includes harvester picking time in the field. However, because it includes setup time at the start of the day, this estimate may be lower than actual harvest rates throughout the whole day.
<table>
<thead>
<tr>
<th>Step</th>
<th>Time Stamp</th>
<th>Action</th>
<th>Time Difference (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10:06</td>
<td>Start time. Moved to row by supervisor.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10:08</td>
<td>Start picking</td>
<td>0.02</td>
</tr>
</tbody>
</table>
| 2    | 10:13      | Finished Bucket #01  
-Grabs many berries in hand before placing in bucket  
-Sorts fruit while picking  
-Placed bucket on other side of fence | 0.05 |
| 3    | 10:17      | Finished Bucket #02 | 0.04 |
| 4    | 10:22      | Finished Bucket #03  
-Only picks on one side of row  
-Hangs full buckets on other side  
-Hands high up in the air (has to reach for berries) | 0.05 |
| 5    | 10:26      | Finished Bucket #04  
-Photo No. 2708 (P:17pm OCT. 6) depicts picked vs. non-picked site | 0.04 |
| 6    | 10:31      | Finished Bucket #05 | 0.05 |
| 7    | 10:36      | Finished Bucket #06 | 0.05 |
| 8    | 10:41      | Finished Row | 0.05 |
| 9    | 10:42      | Finished Bucket #07  
-Left bucket #07 on belt  
-Started on bucket #08 with bucket #07 on belt | 0.01 |
| 10   | 10:47      | Finished bucket #08  
-Passed bucket #06 (10:45). Picked up and placed on belt  
-Left bucket #08 on belt | 0.05 |
| 11   | 10:50      | Stored 4 baskets about 1/4 way down the tunnel (from far side of the trailer) | 0.03 |
| 12   | 10:52      | Finished Bucket #09 | 0.02 |
| 13   | 10:55      | Retired 4 buckets |          |
| 14   | 10:55      | Started picking (9 buckets total) | 0.03 |
| 15   | 10:56      | Grabbed flat boxes and folded 4 | 0.01 |
| 16   | 11:04      | Finished picking (divide total time by 9 for seconds/bucket) | 0.08 |
| 17   | 11:06      | New cycle started | 0.02 |
Appendix D: Concept Development

Ideation Phase 1

Phase 1 of the ideation process required composed of each member writing ideas simultaneously on a whiteboard. Ideas were exchanged, merged, changed, and modified to generate a total of 26 different concepts. It is important to note that during this phase of ideation, no ideas were thrown out or judged, no matter how ridiculous they appeared to be. The thought behind this decision is that crazy ideas can motivate other possible solutions. The following list briefly describes all of the concepts that were developed during this phase.

1. Automated Packer
   a. Electric (mechatronics)
   b. Passive (series of channels)

2. Full on harvester (automatic)

3. Reconfigure field with spiral pattern
   a. Add ‘gondolas’ to transport buckets
   b. Dedicated packers on perimeter
   c. Pickers move from middle out

4. Dedicated Packers

5. Mobile ‘Follower’ packing station.
   a. Wagon that picker pulls with them
   b. Add a break in the middle of the row to allow access to other rows
   c. Wagon has lots of storage for boxes and clamshells. Minimizes trips to tractor

6. Better buckets

7. Hand tools?

8. Arm tubes
   a. Funnel raspberries into bucket

9. New optimized movement paths
   a. Research something about bacteria knowing the ‘path of least resistance’. Use this to define pathways

10. Raspberry vacuum
    a. Portable (backpack?)
    b. ‘Raspberry ‘bank’

11. Clamshell shaped magazine
    a. Replaces buckets. The pickers have a series of magazines on them (held on similarly to those in the military). Fill up these instead of buckets. Dump one magazine per clamshell.

12. Make a device similar to ‘big wall climbing’ gear racks
    a. Research Misty Mountain

13. Zipline to transport buckets back to tractor road

14. Backpack that automatically sorts raspberries into clamshells or magazines
    a. Pour bucket into backpack when full

15. Tiered bucket/container
    a. Reduce damage
Appendix D: Concept Development

16. Customized uniform
17. Increase Raspberry ‘pickability’
   a. Grow raspberries in clamshells
   b. Grow raspberries closer together
   c. Grow raspberries in bunches
18. Special glasses that spot ripe raspberries (colorimeter)
19. Two tractors on each side
20. Make pairs of pickers (match by rate)
21. Break in middle of field
22. Raspberry cargo shorts
   a. Special pockets for clamshells
23. Customized uniform/outfit specialized for harvest
24. Tiered bucket/container to reduce damage
25. Moving sidewalks
26. Tram/conveyor system
   a. Transport bucket to fields edge
   b. Couple with packing option

Ideation Phase 2

Phase 2 composed of motivating ‘out of the box’ thinking through questions. Asking questions, such as “How could we solve the problem with water?” or “What if the pickers didn’t have to carry their packing tables?” forces solutions to be developed in a certain manner that may not have occurred through general brainstorming. The following lists out the three ideas that were developed from this phase in detail.

Aqueduct
- Attach a rain gutter coming off the side of the raspberry bushes
  - One rain gutter for each side
  - Slight slope in rain gutter to promote flow of water
  - Pump water into far side and allow it to flow towards the side with the tractor
- Pickers place ripe raspberries in rain gutter and allow them to float to the end
  - Bad raspberries are still placed into a bucket on their belt
- Grate at end gently removes raspberries from water
  - Water recycled back to other side
- Possibly incorporate some automatic packing system?
Figure 1. Sketch of the aqueduct raspberry harvesting concept.
Appendix D: Concept Development

Monorail
- Stemmed from idea that cart might be too heavy/awkward to carry down rows
- Add a monorail track attached to the bushes very similar to the aqueduct
- A special monorail cart slides along with the pickers
  - Cart acts as a mobile packing table that is always right in front of the picker
  - Holds empty clamshells and unfolded boxes, as well as fully packed/completed trays
  - Could incorporate a scale to reduce over packing
  - Ripe berries are placed right into the clamshell
- Could possibly run track in loops around rows to allow for continuous operation
- Track system keeps holds the weight and makes the cart very easy to move with little effort

Increase Tray Height
- Increasing the tray height is an idea to save money in the parts of the operation that support the picking
- By increasing the tray height, you get 50% more product per tray, with less than 50% extra material
- Could save a few cents for each tray, which adds up over time

Ideation Phase 3

Phase 3 involved “ironing out” some of the concepts that were developed in phases 1 & 2. Rather than taking the “anything goes” mentalities prevalent in the previous two phases, physical and monetary constraints were taken into slight consideration. Further, questions of practicality, actual use, and feasibility were also considered. With this new mentality, the following eight ideas were further developed, and will be discussed in length on the following pages.

1. Mobile Packing Table
2. Aquaduct
3. Gondola
4. Automatic Sorter - Passive
5. Automatic Sorter - Active
6. Arm Tubes
7. Modified Tray Height
8. Monorail
Appendix D: Concept Development

Mobile Packing Table

Description:

The mobile packing table acts as a moving station for the pickers to package clamshells. The table would be on terrain-appropriate wheels to traverse the rows of raspberries. The picker would move the table down the row as they are picking raspberries. The raspberries would go straight from the bush into the clamshells, eliminating the need for buckets or active sorting after the row has been picked. Rather than carrying buckets, the picker would just carry empty clamshells. A section of the station would be reserved for completed clamshells. Additionally, a side shoot could be implemented to prevent the need to twist as the picker finishes a clamshell and adds it to the station. The chute would stick out the side and the picker can simply place a full clamshell on the chute without turning, while the chute transfers the package to the main station area. After completing a row, the picker would bring the mobile packing table to the trailer (or to the side) and put the completed clamshells into trays.

Sketch:

Figure 1. Sketch depicting the mobile packing table.
Appendix D: Concept Development

Aqueduct

Description:

The aqueduct concept involves installing a long rain gutter elevated about 3.5 feet off the ground along the length of the raspberry bush. The gutter would be slightly elevated at one end to allow water to freely flow from end to the other. At the high end, water would be pumped into the gutter. At the low end there would be a grate that the water flows through before returning to the high end. The pickers would go down the rows and place the good raspberries in the trough where the flowing water would carry them to the end. They would slide over the grate and collect in some sort of collection/sorting container or machine where they would then be ready for packaging.

Sketch:

Figure 1. Sketch of the aqueduct concept.
Appendix D: Concept Development

Figure 2. Concept model of the aqueduct.
Appendix D: Concept Development

Gondola

Description:

The gondola concept involves implementing a steel cable pulley system driven by an electric motor that will take the buckets of filled raspberries back to the end of the row automatically. The pickers fill their buckets as usual, but when they are full they hang them on the wire to be taken back to the end. At the end of the pulley there would be a raspberry/bucket collection system that could possibly pack the clamshells automatically and store away the buckets. It was proposed that this design would be implemented in the middle row of each tent only, for this has the most vertical clearance and therefore would likely be able to fit such a device.

Sketch:

Figure 1. Sketch of the gondola.
Appendix D: Concept Development

Figure 2. Concept model of the gondola.
Automatic Sorter - Passive

Description:

The automatic sorter passive) is thought of as some device that can be used to sort the raspberries during the packing stage, after the pickers have brought their buckets back from the rows. The device would filter raspberries into clamshells while maintaining uniform dispersion and not overfilling the trays. The “passive” descriptor refers to the lack of mechatronics/powered controls used in this concept. The device would likely be developed in conjunction with a custom packing table since the current packing tables vary across farms.

Sketch:

Figure 4. Sketch depicting the passive automatic sorter.
Automatic Sorter - Active

Description:
Contrary to the passive sorter, the active automatic sorter would use some sort of control/mechatronics system to sort raspberries into clamshells, speeding up the packing process and providing more consistent packing than the passive sorter. This concept would require electricity (either by battery or supplied) to run. It would also have its own custom table for the same reason as the passive sorter. As the raspberries are dropped into the hopper, they would be directed onto some sort of distributor which moves over a designated clamshell until it is full. Once the clamshell is full, the sorter would move to a new clamshell, and so forth until there are no raspberries left.

Sketch:

Figure 5. Sketch depicting the active automatic sorter.
Appendix D: Concept Development

Arm Tubes

Description:
This idea consists of a wearable “exoskeleton” that the picker would have on while they pick. Tubes would be attached to their arms with “catches” near their wrists. As the worker picks raspberries, they would immediately drop the raspberry into the “catch” which would funnel the raspberry into the tubes on their arms. The raspberry would move through the tubes, either being gravity-fed or vacuum assisted, and be stored into a backpack. The picker would never need to bring their arms down (outside of resting to fight fatigue) and could continuously pick raspberries. After picking the row, the picker can empty the backpack of raspberries into the clamshells at the packing table, similar to how buckets were used.

Sketch:

Figure 6. Sketch depicting the arm tubes.
Appendix D: Concept Development

Modified Tray Height

Description:

The modified tray height concept involves creating a new pattern to make each tray taller by row. In other words, the current trays can hold 12 6 oz. clamshells stacked into two rows of six clamshells. If the height of the tray is increased to accommodate one more row, or six more clamshells, then there will be a 50% increase in volume per box. Making the box bigger in this direction is beneficial because the footprint is still unchanged. More importantly, this lowers the overall operating cost for Dirscoll’s because they will get more raspberries per box.

Sketch:

Figure 7. Sketch depicting the modified tray height.
Appendix D: Concept Development

Monorail

Description:

The monorail solution involves adapting a track onto each raspberry row. A specially adapted monorail cart is then placed on the track and allowed to roll freely. The cart functions as a mobile packing table, empty clamshell storage, and tray storage. There could also be a scale incorporated into the cart to allow the picker to weigh the clamshells. An empty clamshell is placed on the scale. The picker fills the clamshell while they are picking. When the proper weight is reached, the clamshell is closed and placed in the tray below, and a new clamshell is placed on the scale. The track would be designed to be out of the way and sturdy enough to support the weight of a fully loaded monorail cart.

Sketch:

Figure 8. Sketch depicting different rail configurations.
Figure 9. Sketch depicting different monorail cart configurations.
The following outlines the structure of the drawing package that is included as a separate set of documents with this report. Note that each letter (i.e. “a”) denotes a sub-assembly drawing, and each roman numeral (i.e. “i”) represents a part drawing. Numbers within the roman numerals denote drawings that break down the parts even further.

1. **CA – 00 (CART ASSEMBLY)**
   a. **CA – FR – 00 (FRAME ASSEMBLY)**
      i. **CA – FR – 01 (FRAME)**
         1. **CA – FR – 01 – 01 (FRAME SLIDING)**
         2. **CA – FR – 01 – 02 (CROSS MEMBER)**
         3. **CA – FR – 01 – 03 (FRONT WHEEL LINK)**
      ii. **CA – FR – 02 (PACKING SURFACE)**
      iii. **CA – FR – 03 (ANGLE IRON)**
      iv. **CA – FR – 04 (UNFOLDED TRAY STORAGE)**
      v. **CA – FR – 05 (PACKED TRAY STORAGE)**
      vi. **CA – FR – 06 (SPEAKER BOX)**
      vii. **CA – FR – 07 (MCMASTER PART NO. 9489T18)**
      viii. **CA – FR – 08 (CLAMSHELL SUPPORT)**
   b. **CA – HD – 00 (HANDLE ASSEMBLY)**
      i. **CA – HD – 01 (HANDLE)**
      ii. **CA – HD – 02 (PIVOT BRACKET)**
      iii. **CA – AC – 04 (MCMASTER PART NO. 94975A235)**
      iv. **CA – AC – 05 (MCMASTER PART NO. 90128A221)**
      v. **CA – AC – 06 (MCMASTER PART NO. 90631A011)**
      vi. **CA – AC – 07 (MCMASTER PART NO. 9692K64)**
   c. **CA – FW – 00 (WHEEL ASSEMBLY)**
      i. **CA – FW – 01 (FRONT WHEEL AXLE)**
      ii. **CA – AC – 01 (HOME DEPOT PART NO. 1000595070)**
      iii. **CA – AC – 02 (MCMASTER PART NO. 98338A180)**
      iv. **CA – AC – 03 (MCMASTER PART NO. 94639A833)**
   d. **CA – RW – 00 (WHEEL ASSEMBLY)**
      i. **CA – RW – 01 (REAR WHEEL AXLE)**
      ii. **CA – AC – 01 (HOME DEPOT PART NO. 1000595070)**
      iii. **CA – AC – 02 (MCMASTER PART NO. 98338A180)**
INSTALL LARGE BUNGEE CORDS (ITEM NO. 5) IN AN "X" PATTERN ON TWO SIDES

INSTALL SMALL BUNGEE CORDS (ITEM NO. 6) IN AN "X" PATTERN ON FRONT ONLY

NOTES:
- INSTALL REAR AXLE ONTO FRAME ASSEMBLY BEFORE INSTALLING REAR WHEELS AND COTTER PINS
- BUNGEE CORDS (ITEM NO. 5 & 6 AND DENOTED ON THE DRAWING WITH CENTERED LINES) INSTALLED DURING FINAL ASSEMBLY AND HOOKED ONTO EYE BOLDS IN AN "X" PATTERN ON 3 SIDES AS SHOWN

<table>
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<tr>
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<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
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<td>FRAME ASSEMBLY</td>
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<tr>
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<td>CA - HD - 00</td>
<td>HANDLE ASSEMBLY</td>
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<td>FRONT WHEEL ASSEMBLY</td>
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</tr>
<tr>
<td>4</td>
<td>CA - RW - 00</td>
<td>REAR WHEEL ASSEMBLY</td>
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</tr>
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<td>5</td>
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<td>CA - AC - 09</td>
<td>MCMASTER PART NO. 3891T15</td>
<td>2</td>
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</table>
NOTES

- MIG WELD ALL ITEMS (EXCEPT EYE BOLDS, ITEM NO. 7) TO FRAME.
- WELD SHEET METAL IN SMALL SECTIONS UNTIL SECURELY FASTENED.
- SHEET METAL PARTS CENTERED IN FRAME.

ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
--- | --- | --- | ---
1 | CA - FR - 01 | FRAME SUBASSEMBLY | 1
2 | CA - FR - 02 | PACKING SURFACE | 1
3 | CA - FR - 03 | A36 1/8" X 1" X 1" ANGLE IRON | 2
4 | CA - FR - 04 | UNFOLDED TRAY STORAGE | 1
5 | CA - FR - 05 | PACKED TRAY STORAGE | 1
6 | CA - FR - 06 | SPEAKER BOX | 1
7 | CA - FR - 07 | MCMASTER PART NO. 9489T18 | 8
8 | CA - FR - 08 | CLAMSHELL SUPPORT | 1

SCALE 1:16
NOTES

Holes for axles (denoted with Ø 0.5/8" and Ø 0.11/16" hole callout) should be drilled out different diameters on either side of the tube to avoid over constraining the axle. This will make assembly much easier.

FRAME SUBASSEMBLY COMPONENTS

PART NO.: CA - FR - 01 - 01
QTY.: 2

PART NO.: CA - FR - 01 - 02
QTY.: 4

PART NO.: CA - FR - 01 - 03
QTY.: 2

1/8" GAP MAX

Ø 0.5/8" one side
Ø 0.11/16" other side

2X LETTER F TWIST DRILL THRU ALL

2X Ø 0.25/64 THRU

8X Ø 0.9X .50

5/8" one side
11/16" other side

1 1/2" GAP MAX

2X Ø 0.5/8" one side
Ø 0.005

2X Ø 0.11/16" other side

TOLERANCES:

FRACTIONAL: 1/8

THREE PLACE DECIMAL: 0.005

DIMENSIONS ARE IN INCHES

SCALE: 1:5

MATERIAL: A36 (1"X1"X0.063" SQUARE TUBE

QUANTITY TRACKING:

TOTAL QUANTITY NEEDED: AS NOTED

PART NO.: AS NOTED
PARENT ASM.: CA - FR - 01

REQ. COMPLETION DATE: 1:5

DRAWN BY: STEVEN WAAL
PHONE #: (925) 683-3056

CHECKED BY:

DRAWING COMPLETION DATE:

UNLESS OTHERWISE SPECIFIED:

TORQUE:

SCALE:

TITLE:

NOTE:

NOTES:

THREE PLACE DECIMAL:

TOLERANCING PER:

FRAME SUBASSEMBLY COMPONENTS

UNLESS OTHERWISE SPECIFIED:

TORQUE:

SCALE:

TITLE:
NOTES
- NOTE HOLE ALIGNMENT OF PART NO. CA - FR - 01 - 02 ON SHEET 3
- MIG WELD ALL JOINTS UNTIL SECURELY FASTENED
- UNLESS OTHERWISE NOTED POSITION TUBES ON CENTER

FRAME TUBE PLACEMENT

PART NO. CA - FR - 01 - 02

SECTION A-A

NOTES
- UNLESS OTHERWISE SPECIFIED:
  - SCALE:
  - TITLE:
  - DIMENSIONS ARE IN INCHES
  - TOLERANCES:
    - FRACTIONAL: 1/8
    - ANGULAR: MACH 5
    - TWO PLACE DECIMAL: 0.05
    - THREE PLACE DECIMAL: 0.005
    - TOLERANCING PER: "MM"

QUANTITY TRACKING:
- TOTAL QUANTITY NEEDED: N/A
- QTY. MADE: DATE: INITIALS: REV

DRAWN BY: STEVEN WAAAL
PHONE #: +01 (925) 683-3098
REQ. COMPLETION DATE:

MATERIAL: N/A

QUALITY ENGINEERING:
N/A

SCALE: 1:8
UNLESS OTHERWISE SPECIFIED:

SCALE: 1:5

DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL: ± 1/8

ANGULAR: MACH 5° BEND

TWO PLACE DECIMAL: ± 0.05

THREE PLACE DECIMAL: ± 0.005

TOLERANCING PER: MM

MATERIAL: A36 1/8" X 1" X 1" ANGLE IRON

QUANTITY TRACKING:

TOTAL QUANTITY NEEDED: 02

QTY. MADE: 02

DRAWN BY: AARON FEINSTEIN

PHONE #: +01 (907) 834-0099

REQ. COMPLETION DATE: 01

CHECKED BY:

REV: AA

PART NO.: CA - FR - 03

PARENT ASM.: CA - FR - 00

SCALE: 1:5

MATERIAL: A36 1/8" X 1" X 1" ANGLE IRON
NOTE:
- BEND 90° AT DASHED EDGES UNLESS OTHERWISE SPECIFIED
- MINIMUM BEND RADIUS .2"
- BREAK ALL EDGES
- ROLL OVER ALL EXPOSED EDGES

BEND TO MATCH FRAME

BEND TO LIE FLAT ON FRAME

DIMENSIONS ARE IN INCHES
TOLERANCES:
- FRACTIONAL: 1/8
- ANGULAR: MACH
- TWO PLACE DECIMAL: 0.05
- THREE PLACE DECIMAL: 0.005
TOLERANCING PER: MM
NOTE:
- BEND 90° AT DASHED EDGES
- MINIMUM BEND RADIUS .2"
- BREAK ALL EDGES
- ROLL OVER ALL EXPOSED EDGES
NOTE:
- BEND 90° AT DASHED EDGES
- MINIMUM BEND RADIUS .2"
- BREAK ALL EDGES
- ROLL OVER ALL EXPOSED EDGES

SCALE: 1:2

DIMENSIONS ARE IN INCHES
TOLERANCES:
- FRACTIONAL: 1/8
- ANGULAR: MACH 5
- TWO PLACE DECIMAL: 0.05
- THREE PLACE DECIMAL: 0.005

MATERIAL:
- 22 GAUGE MILD STEEL

QUANTITY TRACKING:
- TOTAL QUANTITY NEEDED: 01
- QTY. MADE: 01
- DATE: 
- INITIALS: 
- REV: AA

DRAWN BY: AARON FEINSTEIN
PHONE #: (907) 834-0099

CHECKED BY: 
REV. COMPLETION DATE: 

UNLESS OTHERWISE SPECIFIED:
- SCALE: 1:1
- TITLE: SPEAKER BOX

PART NO.: CA - FR - 06
PARENT ASM.: CA - FR - 00

QUALITY CHECKED BY: 
MATERIAL: 22 GAUGE MILD STEEL
NOTE:
• BREAK ALL EDGES
• SURFACE PREP ENDS FOR WELDING

CROSS MEMBER BRACING

PART NO.: PARENT ASM.: CA - FR - 08 CA - FR - 00

MATERIAL: A36 0.5" X 0.5" X 0.065" SQUARE TUBE

SCALE: 1/2

QUANTITY TRACKING:

TOTAL QUANTITY NEEDED: 01

QTY. MADE: DATE: INITIALS: REV

DRAWN BY: AARON FEINSTEIN PHONE #: +01 (907) 834-0099

CHECKED BY: ORG. COMPLETION DATE

DIMENSIONS AND TOLERANCES:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL: 1/8

ANGULAR: MACH 5

BEND 2"

TWO PLACE DECIMAL: 0.05

THREE PLACE DECIMAL: 0.005

TOLERANCING PER: MMC

19 3/4
MIG WELD ITEM NO. 1 AND 2 TOGETHER

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<td>CA - AC - 06</td>
<td>MCMASTER PART NO. 90631A011</td>
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</table>
NOTE:
- BREAK ALL EDGES
- SURFACE PREP ONE END FOR WELDING
NOTES:
- BREAK ALL EDGES
- DEBURR HOLE PERIMETERS

DIMENSIONS ARE IN INCHES
TOLERANCES:
- FRACTIONAL: 1/8
- ANGULAR: MACH .005
- TWO PLACE DECIMAL: .05
- THREE PLACE DECIMAL: .005
- COORDINATING PER: MM

MATERIAL: 1/8" MILD STEEL
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.  
--- | --- | --- | ---  
1  | CA - FW - 01  | FRONT WHEEL AXLE  | 1  
2  | CA - AC - 01  | HOME DEPOT PART NO. 1000595070  | 1  
3  | CA - AC - 02  | MCMASTER PART NO. 98338A180  | 2  
4  | CA - AC - 03  | MCMASTER PART NO. 94639A883  | 1  

SCALE: 1:4

FRONT WHEEL ASSEMBLY

UNLESS OTHERWISE SPECIFIED:
- SCALE: 1/4
- TITLE:
- DIMENSIONS ARE IN INCHES
- TOLERANCES:
  - FRACTIONAL: ±1/8
  - ANGULAR: ±5'
  - TWO PLACE DECMAL: ±0.05
  - THREE PLACE DECIMAL: ±0.005
- TOLERANCING PER: MMC
- MATERIAL: N/A
- PHONE #: +1 (925) 683-3098
- DRAWN BY: STEVEN WAAL
- CHECKED BY:  
- REQ. COMPLETION DATE:  
- QUANTITY TRACKING:
  - TOTAL QUANTITY NEEDED: 01
  - QTY. MADE:  
  - DATE:  
  - INITIALS:  
  - REV: 01

REV: AA

PAGE 2 OF 3
NOTES

- GRIND SLIGHT CHAMFER ON EDGE OF AXLE FOR EASE OF ASSEMBLY
- DEBUR ALL SHARP EDGES

DIMENSIONS ARE IN INCHES
TOLERANCES:
- FRACTIONAL: ±1/8
- ANGULAR: MACH 5
- TWO PLACE DECIMAL: ±0.05
- THREE PLACE DECIMAL: ±0.005

TOLERANCING PER: MMC

MATERIAL: 5/8" MILD STEEL BAR

POLY PICKERS

DRAWN BY: STEVEN WAAL
PHONE #: +01 (925) 683-3098

CHECKED BY:

REV

QUANTITY TRACKING:
PART NO.: CA - FW - 00
PARENT ASM.: CA - FW - 01

TOTAL QUANTITY NEEDED: 01
QTY. MADE: DATE: INITIALS: REV 1:1
**NOTE:**
- INSTALL AXLE ON FRAME BEFORE INSTALLING WHEELS OR COTTER PINS

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<td>1</td>
</tr>
<tr>
<td>2</td>
<td>CA - AC - 01</td>
<td>HOME DEPOT PART NO. 1000595070</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>CA - AC - 02</td>
<td>MCMASTER PART NO. 98338A180</td>
<td>2</td>
</tr>
</tbody>
</table>

**SCALE:** 1:12
NOTES:
- GRIND SLIGHT CHAMFER ON EDGE OF AXLE FOR EASE OF ASSEMBLY
- DEBURR ALL SHARP EDGES
Appendix E2: Manufacturing Plan

Introduction

The following plan outlines the necessary steps to successfully construct both the structural and final prototypes of the packing cart. It is important to note that all manufacturing of the structural prototype took place in the Cal Poly Mechanical Engineering shops: both the Aero Hangar and the Mustang 60' shops were used. As such, the structural prototype was built all in house.

The final prototype included a combination of manufacturing in house as well as professionally contracted work. Any part that was sent out to be manufactured will be noted according to the proper symbol, outlined in Table 1.

This plan is broken up into four parts: Introduction, Structural Prototype, Structural Prototype Modifications and Final Prototype. The Introduction outlines the nomenclature used throughout the plan. The Structural Prototype and Final Prototype sections outline the necessary steps to construct each prototype, respectively. The Structural Prototype Modifications outlines the required modifications that were made to test out different wheel configurations.

Symbols

The following symbols will be used in order to communicate the proper manufacturing process to use with each step.

Table 1. Manufacturing operations symbols and the accompanying required tools.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Operation</th>
<th>Required Tools</th>
</tr>
</thead>
</table>
| ![Drilling](image) | Drilling         | • Drill press  
|         |                  | • Center drill  
|         |                  | • Drill bits  
|         |                  | • Layout fluid  
|         |                  | • Ball peen hammer  
|         |                  | • Scribe  
|         |                  | • Center Punch  
|         |                  | • Calipers  
|         |                  | • Debur tool  
|         |                  | • Coolant  |
| ![MIG Welding](image) | MIG Welding     | • MIG Welder  
|         |                  | • Welding gloves  
|         |                  | • Welding helmet  
|         |                  | • Welding jacket  
|         |                  | • Magnetic angle supports  
|         |                  | • Welding table  |
### Appendix E2: Manufacturing Plan

Table 1. Manufacturing operations symbols and the accompanying required tools.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Operation</th>
<th>Required Tools</th>
</tr>
</thead>
</table>
| ![Cutting Symbol] | Cutting         | • Chop saw  
                      • Ear muffs  
                      • Face shield |
| ![Sanding Symbol] | Sanding         | • Belt sander or bench grinder                       |
| ![Sheet Metal Bending Symbol] | Sheet Metal Bending | • Sheet metal bender  
                                • Angle finder |
| ![Waterjet Cutting Symbol] | Waterjet Cutting | • Flash drive                                        |
| ![Check Fitment Symbol] | Check Fitment   | • N/A                                                |
| ![Tube Bending Symbol] | Tube Bending    | • JD Squared Model 32 Tube Bender  
                                • JD Squared 1” Square Tubing Bending Die  
                                • Square  
                                • Tape measure  
                                • Crescent Wrench |
Appendix E2: Manufacturing Plan

Additional Tools
Along with the tools outlined in Table 1, the following tools are necessary for the successful manufacture of the cart.

Table 2. Additional tools.

<table>
<thead>
<tr>
<th>Additional Tools</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tape measure</td>
<td>• Crescent Wrench</td>
</tr>
<tr>
<td>• Carpenter’s square</td>
<td>• Vice grips</td>
</tr>
<tr>
<td>• Sharpie</td>
<td>• Cordless drill</td>
</tr>
</tbody>
</table>
Appendix E2: Manufacturing Plan

Structural Prototype

The following represents the order of operations that were carried out to construct the structural prototype. It is important to note that this plan serves as an overall guide; the details of each component that was made are recorded in the detailed drawings of the cart. Figure 1 depicts the CAD model of the cart before production.

![Figure 1. SolidWorks CAD model of the structural prototype.](image)

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Measure and cut all stock to length.</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Measure and cut all stock to length.
<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 2    | ![Image](image1.png) | **Notes:**  
  - Sand/grind edges to remove sharp edges/burrs. |
| 3    | ![Image](image2.png) | **Notes:**  
  - Mark out holes with layout fluid and a punch.  
  - Drill all holes. |
## Appendix E2: Manufacturing Plan

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 4    | ![Image](image1.png) | **Notes:**  
• Use carpenter’s square to ensure perpendicularity.  
*IMPORTANT: TACK WELD ONLY. CHECK FITMENT BEFORE FULL WELDING.* |
| 5    | ![Image](image2.png) | **Notes:**  
• Bolt on drawer to check for smooth operation.  
• Add wheels to check for interferences. |
## Appendix E2: Manufacturing Plan

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 6    | ![Image](image6.png) | Notes:  
• Full weld all joints. |
| 7    | ![Image](image7.png) | Notes:  
• Waterjet sheet metal components. |
| 8    | ![Image](image8.png) | Notes:  
• Bend all sheet metal components. |
| 9    | ![Image](image9.png) | Notes:  
• Weld all sheet metal components to the frame. |
| 10   | ![Image](image10.png) | Notes:  
• Final fitment test and assembly. |
Appendix E2: Manufacturing Plan

Figure 2. Completed structural prototype.
Appendix E2: Manufacturing Plan

Structural Prototype Modifications

The following modifications were made to the structural prototype in order to allow different wheel configurations to be tested in the field. It is important to note that there were two phases of modifications: the addition of a second axle to allow for four wheels, and the addition of a second axle to allow for three wheels.

Phase 1: Four Wheel Configuration

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Notes:</td>
<td>• Measure and cut all stock to length.</td>
</tr>
<tr>
<td>2</td>
<td>Notes:</td>
<td>• Sand/grind edges to remove sharp edges/burrs.</td>
</tr>
</tbody>
</table>
## Appendix E2: Manufacturing Plan

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 3    | ![Drill](image1.png) | **Notes:**  
  - Mark out holes with layout fluid and a punch.  
  - Drill all holes. |
| 4    | ![Weld](image2.png) | **Notes:**  
  - Use carpenter’s square to ensure perpendicularity.  

*IMPORTANT: TACK WELD ONLY. CHECK FITMENT BEFORE FULL WELDING.*
## Appendix E2: Manufacturing Plan

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 5    | ![Wrench] | ![Image] Notes:  
- Add second axle to check for fitment.  
- Add wheels to check for interferences. |
| 6    | ![Joint Welding] | Notes:  
- Full weld all joints. |
| 7    | ![Wrench] | Notes:  
- Final fitment check and assembly. |

Figure 3. Phase 1: Four Wheel Configuration complete.
## Appendix E2: Manufacturing Plan

### Phase 2: Three Wheel Configuration

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1    | ![Image](image1.png) | Notes:  
- Measure and cut all stock to length. |
| 2    | ![Image](image2.png) | Notes:  
- Sand/grind edges to remove sharp edges/burrs. |
| 3    | ![Image](image3.png) | Notes:  
- Mark out holes with layout fluid and a punch.  
- Drill all holes. |
| 4    | ![Image](image4.png) | Notes:  
- Use carpenter’s square to ensure perpendicularly.  
*IMPORTANT: TACK WELD ONLY. CHECK FITMENT BEFORE FULL WELDING.* |
| 5    | ![Image](image5.png) | Notes:  
- Add second axle to check for fitment.  
- Add wheels to check for interferences. |
| 6    | ![Image](image6.png) | Notes:  
- Full weld all joints. |
| 7    | ![Image](image7.png) | Notes:  
- Final fitment check and assembly. |
Figure 4. Phase 2: Three Wheel Configuration complete.
Appendix E2: Manufacturing Plan

Final Prototype

The following represents the order of operations that were carried out to construct the final prototype. It is important to note that this plan serves as an overall guide; the details of each component that was made are recorded in the detailed drawings of the cart. Figure 5 depicts the CAD model of the cart before production. In order to achieve the highest build quality possible, certain components were contracted out to be professionally manufactured.

![Figure 5. SolidWorks CAD model of the final prototype.](image)

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Notes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Waterjet sheet metal parts</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Measure and cut all stock to length.</td>
</tr>
</tbody>
</table>
### Appendix E2: Manufacturing Plan

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 3    | ![Machine Icon] | **Notes:**  
- Sand/grind edges to remove sharp edges/burrs. |
| 4    | ![Machine Icon] | **Notes:**  
- Mark out holes with layout fluid and a punch.  
- Drill all holes. |
| 5    | ![Sheet Metal Bending Tool] | **Notes:**  
- Bend all sheet metal parts. |
| 6    | ![Sheet Metal Bending Tool] | **Notes:**  
- Bend all sheet metal parts. |
## Appendix E2: Manufacturing Plan

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
</table>
| 7    | ![Image](https://via.placeholder.com/150) | **Notes:**  
- Use carpenter’s square to ensure perpendicularity.  

*IMPORTANT: TACK WELD ONLY. CHECK FITMENT BEFORE FULL WELDING.* |
| 8    | ![Image](https://via.placeholder.com/150) | **Notes:**  
- Bolt on eye bolts.  
- Test fit sheet metal components.  
- Test fit axle.  
- Add wheels to check for interferences. |
| 9    | ![Image](https://via.placeholder.com/150) | **Notes:**  
- Tack weld sheet metal components to the frame.  
- Full weld all parts. |
| 10   | ![Image](https://via.placeholder.com/150) | **Notes:**  
- Final fitment test and assembly. |
Figure 6. Completed final prototype.
Appendix F: Purchased Parts Details

Table 1. Purchased Part Vendors, Numbers, and Descriptions

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Vendor Part Number</th>
<th>Description</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>McMaster</td>
<td>9489T18</td>
<td>Eyebolt with Nut, Zinc-Plated, 1.5&quot; Shank, .25-20</td>
<td>[1]</td>
</tr>
<tr>
<td>McMaster</td>
<td>3891T15</td>
<td>All Weather EPDM Rubber Tie Down, 19&quot; Long</td>
<td>[2]</td>
</tr>
<tr>
<td>McMaster</td>
<td>3891T18</td>
<td>All Weather EPDM Rubber Tie Down, 25&quot; Long</td>
<td>[3]</td>
</tr>
<tr>
<td>McMaster</td>
<td>98338A180</td>
<td>ø1/8&quot; Zinc Plated Steel Cotter Pin, 1&quot; Long</td>
<td>[4]</td>
</tr>
<tr>
<td>McMaster</td>
<td>9692K64</td>
<td>Rectangular Grip, Grooved</td>
<td>[5]</td>
</tr>
<tr>
<td>McMaster</td>
<td>94975A235</td>
<td>Quick-Release Pin, 18-8 SST, ø3/8&quot;, 1.5&quot; Long</td>
<td>[6]</td>
</tr>
<tr>
<td>McMaster</td>
<td>90128A221</td>
<td>SHCS, Zinc-Plated, 10-24, .625 Long</td>
<td>[7]</td>
</tr>
<tr>
<td>McMaster</td>
<td>94407A103</td>
<td>Nylon-Insert Locknut, 18-8 SST, 10-24</td>
<td>[8]</td>
</tr>
<tr>
<td>Home Depot</td>
<td>1000595070</td>
<td>Pneumatic Tire, 16&quot;, ø5/8 Bore</td>
<td>[9]</td>
</tr>
<tr>
<td>Online Metals</td>
<td>10301</td>
<td>1&quot; x .065&quot; wall x 8' A36 Steel</td>
<td>[10]</td>
</tr>
<tr>
<td>Online Metals</td>
<td>12779</td>
<td>Mild Steel CR Sheet, 22 GA, 2' x 2'</td>
<td>[11]</td>
</tr>
<tr>
<td>Online Metals</td>
<td>9905</td>
<td>Mild Steel A36 HR Angle, 1&quot; x 1&quot; x 0.125&quot;, 4' long</td>
<td>[12]</td>
</tr>
<tr>
<td>Online Metals</td>
<td>10238</td>
<td>5/8&quot; x 8' A36 HR Round Bar</td>
<td>[13]</td>
</tr>
<tr>
<td>Online Metals</td>
<td>9882</td>
<td>.125&quot; A1011 HR Steel Sheet - 12&quot; x 12&quot;</td>
<td>[14]</td>
</tr>
</tbody>
</table>

Table 2. Purchased Part Links

<table>
<thead>
<tr>
<th>Item</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td><a href="https://www.mcmaster.com/#9489t18/=1d6nusi">https://www.mcmaster.com/#9489t18/=1d6nusi</a></td>
</tr>
<tr>
<td>[2]</td>
<td><a href="https://www.mcmaster.com/#3891t15/=1d6nv5r">https://www.mcmaster.com/#3891t15/=1d6nv5r</a></td>
</tr>
<tr>
<td>[3]</td>
<td><a href="https://www.mcmaster.com/#3891t18/=1d6nvfz">https://www.mcmaster.com/#3891t18/=1d6nvfz</a></td>
</tr>
<tr>
<td>[4]</td>
<td><a href="https://www.mcmaster.com/#98338a180/=1d6nooz">https://www.mcmaster.com/#98338a180/=1d6nooz</a></td>
</tr>
<tr>
<td>[5]</td>
<td><a href="https://www.mcmaster.com/#9692k64/=1bjssj69">https://www.mcmaster.com/#9692k64/=1bjssj69</a></td>
</tr>
<tr>
<td>[6]</td>
<td><a href="https://www.mcmaster.com/#94975a235/=1d6novoz">https://www.mcmaster.com/#94975a235/=1d6novoz</a></td>
</tr>
<tr>
<td>[7]</td>
<td><a href="https://www.mcmaster.com/#90128a221/=1d6nyi0">https://www.mcmaster.com/#90128a221/=1d6nyi0</a></td>
</tr>
<tr>
<td>[8]</td>
<td><a href="https://www.mcmaster.com/#94407a103/=1d6nyog">https://www.mcmaster.com/#94407a103/=1d6nyog</a></td>
</tr>
</tbody>
</table>
## Appendix G: Budget and Procurement List

### Indented Bill of Material (BOM)

#### Raspberry Cart

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Level</th>
<th>Description</th>
<th>Manufactured/Purchased</th>
<th>Material</th>
<th>Vendor</th>
<th>Vendor PN</th>
<th>Vendor Qty</th>
<th>Vendor Cost</th>
<th>Assy Qty Used</th>
<th>Material Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-00-01</td>
<td></td>
<td>Frame</td>
<td>Manufactured</td>
<td>1” x .065” wall x 8’ A36 Steel</td>
<td>Online Metals</td>
<td>103615</td>
<td>1</td>
<td>9.22</td>
<td>9.41</td>
<td>9.22</td>
</tr>
<tr>
<td>CA-02-02</td>
<td></td>
<td>Pole Holder</td>
<td>Manufactured</td>
<td>Mild Steel C1010, 22 GA, 2” x 2”</td>
<td>Online Metals</td>
<td>12779</td>
<td>1</td>
<td>7.6</td>
<td>7.6</td>
<td>7.6</td>
</tr>
<tr>
<td>CA-03-03</td>
<td></td>
<td>Tray Holder</td>
<td>Manufactured</td>
<td>Mild Steel A500 FF, 1” x 1” x 0.025”, 4” long</td>
<td>Online Metals</td>
<td>5900</td>
<td>1</td>
<td>5.37</td>
<td>5.37</td>
<td>5.37</td>
</tr>
<tr>
<td>CA-04-04</td>
<td></td>
<td>Unpocked Tray Surface</td>
<td>Manufactured</td>
<td>Mild Steel C1010, 22 GA, 2” x 4”</td>
<td>Online Metals</td>
<td>12779</td>
<td>1</td>
<td>10.54</td>
<td>10.54</td>
<td>10.54</td>
</tr>
<tr>
<td>CA-05-05</td>
<td></td>
<td>Pivoted Tray Surface</td>
<td>Manufactured</td>
<td>Mild Steel C1010, 22 GA, 2” x 1”</td>
<td>Online Metals</td>
<td>12779</td>
<td>1</td>
<td>11.17</td>
<td>11.17</td>
<td>11.17</td>
</tr>
<tr>
<td>CA-06-06</td>
<td></td>
<td>Speaker Box</td>
<td>Manufactured</td>
<td>Mild Steel C1010, 22 GA, from Unpocked Tray Surface</td>
<td>Online Metals</td>
<td>12779</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CA-11-11</td>
<td></td>
<td>Eyebolt</td>
<td>Purchased</td>
<td>Eyebolt with Nut, Zinc-Plated, 1.5” Shank, 25-20</td>
<td>McMaster-Carr</td>
<td>94987118</td>
<td>10</td>
<td>1.84</td>
<td>1.84</td>
<td>1.84</td>
</tr>
<tr>
<td>CA-12-12</td>
<td></td>
<td>Curtain Cord</td>
<td>Purchased</td>
<td>All Weather EPDM Rubber Tie Down, 20” Long</td>
<td>McMaster-Carr</td>
<td>38917129</td>
<td>1</td>
<td>1.59</td>
<td>1.59</td>
<td>1.59</td>
</tr>
<tr>
<td>CA-13-13</td>
<td></td>
<td>Curtain Cord</td>
<td>Purchased</td>
<td>All Weather EPDM Rubber Tie Down, 25” Long</td>
<td>McMaster-Carr</td>
<td>38917138</td>
<td>1</td>
<td>1.57</td>
<td>1.57</td>
<td>1.57</td>
</tr>
<tr>
<td>CA-14-14</td>
<td></td>
<td>Wheel Assembly, Front</td>
<td>Manufactured</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CA-15-15</td>
<td></td>
<td>Wheel Assembly, Rear</td>
<td>Manufactured</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CA-16-16</td>
<td></td>
<td>Axle</td>
<td>Manufactured</td>
<td>7/8” x 8’ A36 Hi Round Bar</td>
<td>Online Metals</td>
<td>10283</td>
<td>1</td>
<td>12.06</td>
<td>12.06</td>
<td>12.06</td>
</tr>
<tr>
<td>CA-17-17</td>
<td></td>
<td>Cotter Pin</td>
<td>Purchased</td>
<td>#1/8” Zinc Plated Steel Cotter Pin, 1” Long</td>
<td>McMaster-Carr</td>
<td>98388434</td>
<td>100</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>CA-18-18</td>
<td></td>
<td>Axle</td>
<td>Manufactured</td>
<td>7/8” x 8’ A36 Hi Round Bar</td>
<td>Online Metals</td>
<td>10283</td>
<td>1</td>
<td>12.06</td>
<td>12.06</td>
<td>12.06</td>
</tr>
<tr>
<td>CA-19-19</td>
<td></td>
<td>Cotter Pin</td>
<td>Purchased</td>
<td>#1/8” Zinc Plated Steel Cotter Pin, 1” Long</td>
<td>McMaster-Carr</td>
<td>98388434</td>
<td>100</td>
<td>4.49</td>
<td>4.49</td>
<td>4.49</td>
</tr>
<tr>
<td>CA-20-20</td>
<td></td>
<td>Handle Assembly</td>
<td>Manufactured</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CA-21-21</td>
<td></td>
<td>Handle Arm</td>
<td>Manufactured</td>
<td>1” x .065” wall x 8’ A36 Steel</td>
<td>Online Metals</td>
<td>103615</td>
<td>1</td>
<td>9.43</td>
<td>9.43</td>
<td>9.43</td>
</tr>
<tr>
<td>CA-22-22</td>
<td></td>
<td>Handle Bracket</td>
<td>Manufactured</td>
<td>#22” A1011 HR Steel Sheet, 12” x 12”</td>
<td>Online Metals</td>
<td>5900</td>
<td>1</td>
<td>9.36</td>
<td>9.36</td>
<td>9.36</td>
</tr>
<tr>
<td>CA-23-23</td>
<td></td>
<td>Rectangular Gris, Grooved</td>
<td>Purchased</td>
<td>Rectangle Gris, 1” x 1”, 1/4” Ribs</td>
<td>McMaster-Carr</td>
<td>96026964</td>
<td>4</td>
<td>10.75</td>
<td>10.75</td>
<td>10.75</td>
</tr>
<tr>
<td>CA-24-24</td>
<td></td>
<td>Quick Release Pin</td>
<td>Purchased</td>
<td>Quick-Release Pin, 18-8 S/S, 0.65”, 1/2” Long</td>
<td>McMaster-Carr</td>
<td>940754235</td>
<td>1</td>
<td>4.91</td>
<td>4.91</td>
<td>4.91</td>
</tr>
<tr>
<td>CA-25-25</td>
<td></td>
<td>18-24 Screw</td>
<td>Purchased</td>
<td>9HCLS, Zinc-Plated, 18-24, 0.25 Long</td>
<td>McMaster-Carr</td>
<td>902388221</td>
<td>50</td>
<td>6.82</td>
<td>6.82</td>
<td>6.82</td>
</tr>
</tbody>
</table>

**Total Cost** $166.89
Appendix H: Preliminary Analysis and Testing

The following is analysis of data collected from Camarillo during the first visit. Overpacking and cart efficiency are examined for valid solutions to improve efficiency.

<table>
<thead>
<tr>
<th>Overpacking Elimination Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constants</strong></td>
</tr>
<tr>
<td>Trays/hour</td>
</tr>
<tr>
<td>lbs/hour</td>
</tr>
<tr>
<td>6 oz Clamshells/Tray</td>
</tr>
<tr>
<td>Extra Berries/Clamshell</td>
</tr>
<tr>
<td>Berries/Clamshell</td>
</tr>
<tr>
<td><strong>Calculations</strong></td>
</tr>
<tr>
<td>Clamshells/hour</td>
</tr>
<tr>
<td>Extra Berries/hour</td>
</tr>
<tr>
<td>Extra Clamshells</td>
</tr>
<tr>
<td>Extra Trays/hour</td>
</tr>
<tr>
<td>Extra Lbs/Hour</td>
</tr>
<tr>
<td>Efficiency Increase</td>
</tr>
</tbody>
</table>
Appendix H: Preliminary Analysis and Testing

![Pie charts and tables showing data on picking and walking times.](image-url)
Appendix H: Preliminary Analysis and Testing

Cart Data Analysis

**Current Configuration: From Harvest Cycle detail**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picking</td>
<td>46 min</td>
</tr>
<tr>
<td>Packing</td>
<td>9 min</td>
</tr>
<tr>
<td>Walking</td>
<td>5 min</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>60 min</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity</th>
<th>Quantity/Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picked Buckets</td>
<td>9 buckets</td>
</tr>
<tr>
<td>Raw weight</td>
<td>26.55 lbs</td>
</tr>
<tr>
<td>Trays Packed</td>
<td>4 trays</td>
</tr>
<tr>
<td>Final weight</td>
<td>18 lbs</td>
</tr>
</tbody>
</table>

**Crew of 30, 8 hr day**

*Nominal

**4320 lbs**

**Potential Watsonville Configuration**

Assumes 4 buckets per trip

<table>
<thead>
<tr>
<th>Round 1 - start new row</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picking</td>
<td>20.4 min</td>
</tr>
<tr>
<td>packing</td>
<td>4 min</td>
</tr>
<tr>
<td>Walking distance</td>
<td>131 ft</td>
</tr>
<tr>
<td>Nominal walking speed</td>
<td>4.3 ft/s</td>
</tr>
<tr>
<td>Field walking speed with buck</td>
<td>2.15 ft/s</td>
</tr>
<tr>
<td>Walk out of field</td>
<td>61 seconds</td>
</tr>
<tr>
<td>Supplies, etc</td>
<td>2.5 min</td>
</tr>
<tr>
<td>Walking total</td>
<td>3.5 min</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>28.0 min</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Round 2 - middle of row round, reach other side and start returning</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picking</td>
<td>20.4 min</td>
</tr>
<tr>
<td>packing</td>
<td>4 min</td>
</tr>
<tr>
<td>Walking *</td>
<td>7.04 min</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>31.5 min</td>
</tr>
</tbody>
</table>

*must go into field and then come out again

<table>
<thead>
<tr>
<th>Round 3 - mirror of Round 1</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picking</td>
<td>20.4 min</td>
</tr>
<tr>
<td>packing</td>
<td>4 min</td>
</tr>
<tr>
<td>Walking total</td>
<td>3.5 min</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>28.0 min</td>
</tr>
</tbody>
</table>

**Round Approximate Grand total**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time</th>
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</thead>
<tbody>
<tr>
<td>Time</td>
<td>87.4 min</td>
</tr>
<tr>
<td>Est. Buckets</td>
<td>12</td>
</tr>
<tr>
<td>Raw Weight</td>
<td>35.4 lbs</td>
</tr>
<tr>
<td>Actual weight</td>
<td>24 lbs</td>
</tr>
<tr>
<td>Lbs/hour</td>
<td>16.48</td>
</tr>
</tbody>
</table>

**Crew of 30, 8 hr day**

**3954 lbs**

**Location 1**

<table>
<thead>
<tr>
<th>Bucket Spacing</th>
<th>Distance [ft]</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>28.4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>26.1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>22.1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>42.8</td>
<td></td>
</tr>
</tbody>
</table>

**Average**

**32.8 ft/bucket**

**Cart Configuration**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time</th>
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</thead>
<tbody>
<tr>
<td>Minutes/Bucket</td>
<td>04:58</td>
</tr>
<tr>
<td>Seconds/Bucket</td>
<td>297.8</td>
</tr>
<tr>
<td>Buckets/Day</td>
<td>96.7</td>
</tr>
<tr>
<td>Lbs/day (raw)</td>
<td>285.3</td>
</tr>
<tr>
<td>Lbs/Day (Actual)*</td>
<td>193.5</td>
</tr>
</tbody>
</table>

**Crew of 30 (Teams of 4)**

**4449 lbs**

**3.0%**

**Crew of 30 (Teams of 5)**

**4643 lbs**

**7.5%**

**Crew of 30 (Teams of 6)**

**4836 lbs**

**12.0%**

*Based on approximate weight of buckets collected compared to tray weight
Appendix I: Safety Hazards & FMEA

DESIGN HAZARD CHECKLIST – PACKING CART

Team: PolyPickers (Trent Peterson, Steven Waal, Aaron Feinstein) Advisor: McFarland Date: 11/15/17

Y  N
• 1. Will the system include hazardous revolving, running, rolling, or mixing actions?
• 2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
• 3. Will any part of the design undergo high accelerations/decelerations?
• 4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
• 5. Could the system produce a projectile?
• 6. Could the system fall (due to gravity), creating injury?
• 7. Will a user be exposed to overhanging weights as part of the design?
• 8. Will the system have any burrs, sharp edges, shear points, or pinch points?
• 9. Will any part of the electrical systems not be grounded?
• 10. Will there be any large batteries (over 30 V)?
• 11. Will there be any exposed electrical connections in the system (over 40 V)?
• 12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
• 13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
• 14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
• 15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
• 16. Could the system generate high levels (>90 dBA) of noise?
• 17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
• 18. Is it possible for the system to be used in an unsafe manner?
• 19. For powered systems, is there an emergency stop button?
• 20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any “Y” responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.
## Appendix I: Safety Hazards & FMEA

<table>
<thead>
<tr>
<th>Description of Hazard</th>
<th>Planned Corrective Action</th>
<th>Planned Date</th>
<th>Actual Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Outdoors in field. Exposure to fog, moisture, and all bay area and southern CA weather conditions</td>
<td>Material of cart will have to resist corrosion from sunlight and moisture. Will be designed to be subject to daily wear. Care of cart (drying, cleaning) at end of day will prolong life, but cart should last over a year in the field without special care.</td>
<td>By CDR (2/6/17)</td>
<td>Final Testing 5/31/18</td>
</tr>
<tr>
<td>18. Cart can be used in an unsafe manner that does not follow ergonomic principles.</td>
<td>Design of the cart, in order to fulfill its intended purpose of aiding raspberry harvesting, will have inherent potential for abuse. Training is recommended to ensure proper body mechanics while using the cart.</td>
<td>By CDR (2/6/17)</td>
<td>Final Testing 5/31/18</td>
</tr>
</tbody>
</table>
Appendix I: Safety Hazards & FMEA

Figure 1. Function Tree
Figure 2. System Failure Analysis
Appendix I: Safety Hazards & FMEA

Wheel
- Wheel breaks while turning
- Wheel can't turn fully

Wheels
- Support wheel load
- Axle breaks during use
- Axle deflects, prevent wheels from turning properly

Axle
- Bearings shift from load on cart
- Bearings fill with dirt or corrode from water

Bearings

Storage
- Secure in Place
- Trays slide out from storage area
- Trays are damaged from moisture due to storage not protecting from environment

Tray Storage (Unpacked)
- Secure in Place
- Packed trays slide out from storage area
- Protect
- Berries are crushed from weight or compression in cart
- Berries are damaged from rain or dust

Tray Storage (Packed)
- Secure in Place
- Empty Chnabell Storage
- Chnabells slide out from storage area

Protect

Poly Pickers
Page 5 of 9
Figure 3. Component Failure Analysis
## designsafe Report

**Application:** Poly Pickers Packing Cart  
**Analyst Name(s):** Steven Waal, Trent Peterson, Aaron Feinstein  
**Description:**  
**Company:** Poly Pickers  
**Product Identifier:**  
**Facility Location:** California Polytechnic State University  
**Assessment Type:** Detailed  
**Limits:** This analysis was performed considering the normal cart operations in a typical raspberry field.  
**Sources:** personnel experiences, ANSI B11 standards  
**Risk Scoring System:** ANSI B11.0 (TR3) Two Factor  

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

<table>
<thead>
<tr>
<th>Item Id</th>
<th>User / Task</th>
<th>Hazard / Failure Mode</th>
<th>Initial Assessment Severity Probability</th>
<th>Risk Level</th>
<th>Risk Reduction Methods /Control System</th>
<th>Final Assessment Severity Probability</th>
<th>Risk Level</th>
<th>Status / Responsible /Comments /Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1-1</td>
<td>operator normal operation</td>
<td>mechanical / Pinch Adjustable handles</td>
<td>Moderate Remote</td>
<td>Negligible</td>
<td>Moderate</td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1-2</td>
<td>operator normal operation</td>
<td>slips / trips / falls : trip Uneven field ground</td>
<td>Minor Remote</td>
<td>Negligible</td>
<td>weed block on field, clear branches, keep members off ground</td>
<td>Minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1-3</td>
<td>operator normal operation</td>
<td>ergonomics / human factors : excessive force / exertion Collision with obtrusive object</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>design table for correct height Moderate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1-4</td>
<td>operator normal operation</td>
<td>ergonomics / human factors : posture Moving cart, packing on table</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1-5</td>
<td>operator normal operation</td>
<td>ergonomics / human factors : repetition Repeated clammshell filling and tray loading</td>
<td>Minor Remote</td>
<td>Negligible</td>
<td>Minor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1-6</td>
<td>operator normal operation</td>
<td>ergonomics / human factors : duration Full day of handling cart</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td></td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-1-7</td>
<td>operator normal operation</td>
<td>ergonomics / human factors : lifting / bending / twisting Gathering buckets, navigating ruts</td>
<td>Minor Remote</td>
<td>Negligible</td>
<td>Minor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix I: Safety Hazards & FMEA

<table>
<thead>
<tr>
<th>Item #</th>
<th>User / Task</th>
<th>Initial Assessment Hazard / Failure Mode</th>
<th>Risk Level</th>
<th>Final Assessment Hazard / Failure Mode</th>
<th>Risk Level</th>
<th>Risk Reduction Methods</th>
<th>Control System</th>
<th>Status / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1-8</td>
<td>operator normal operation</td>
<td>material handling: stacking</td>
<td>Negligible</td>
<td>material handling: instability</td>
<td>Negligible</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-1-9</td>
<td>operator normal operation</td>
<td>material handling: stacking</td>
<td>Negligible</td>
<td>material handling: instability</td>
<td>Negligible</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-2-1</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-2-2</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-3-1</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-3-2</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-3-3</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-3-4</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-4-1</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-4-2</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>1-4-3</td>
<td>operator loading/unload materials</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>strain on operator's wrists</td>
<td>Moderate</td>
<td>Low</td>
<td>Remote</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

4/26/2018

Privileged and Confidential Information

Page 2
<table>
<thead>
<tr>
<th>Item Id</th>
<th>User / Task</th>
<th>Hazard / Failure Mode</th>
<th>Initial Assessment Severity Probability</th>
<th>Risk Level</th>
<th>Risk Reduction Methods / Control System</th>
<th>Final Assessment Severity Probability</th>
<th>Risk Level</th>
<th>Status / Responsible / Comments / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3-2</td>
<td>operator stocking / restocking</td>
<td>ergonomics / human factors posture Loading trays and clamshells</td>
<td>Minor Likely</td>
<td>Low</td>
<td></td>
<td>Minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3-3</td>
<td>operator stocking / restocking</td>
<td>material handling: stacking / storing Clamshells and Trays</td>
<td>Minor Unlikely</td>
<td>Negligible</td>
<td></td>
<td>Minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-4-1</td>
<td>operator clean system</td>
<td>mechanical: Pinch Adjustable handles</td>
<td>Minor Remote</td>
<td>Negligible</td>
<td></td>
<td>Minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-4-2</td>
<td>operator clean system</td>
<td>ergonomics / human factors posture Bending over</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>obtain transfer cart to eliminate lift</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Action Item</td>
</tr>
<tr>
<td>2-1-1</td>
<td>maintenance technician parts replacement</td>
<td>mechanical: Pinch Adjustable handles</td>
<td>Minor Remote</td>
<td>Negligible</td>
<td></td>
<td>Minor</td>
<td></td>
<td></td>
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<tr>
<td>2-2-1</td>
<td>maintenance technician periodic maintenance</td>
<td>mechanical: Pinch Adjustable handles</td>
<td>Minor Remote</td>
<td>Negligible</td>
<td></td>
<td>Minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-2-2</td>
<td>maintenance technician periodic maintenance</td>
<td>ergonomics / human factors lifting / bending / twisting</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>obtain transfer cart to eliminate lift</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>Action Item</td>
</tr>
<tr>
<td>2-3-1</td>
<td>maintenance technician trouble-shooting / problem solving</td>
<td>mechanical: Pinch Adjustable handles</td>
<td>Minor Remote</td>
<td>Negligible</td>
<td></td>
<td>Minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3-2</td>
<td>maintenance technician trouble-shooting / problem solving</td>
<td>ergonomics / human factors lifting / bending / twisting</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>2 person lift, look into hoist system</td>
<td>Moderate Unlikely</td>
<td>Low</td>
<td>in-process</td>
</tr>
</tbody>
</table>
Appendix J: Gantt Chart
Appendix J: Gantt Chart

<table>
<thead>
<tr>
<th>Task Description</th>
<th>0h</th>
<th>100%</th>
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<tbody>
<tr>
<td>Modify Ch 6, Final Manufacturing plan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modify Ch 7, Design Verification (TC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modify Ch 8, project management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add Ch 9. Conclusions and recommendations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add section on mass production approach</td>
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</tr>
</tbody>
</table>

**Appendices**
- QFD: 100%
- Decision Matrices: 100%
- Preliminary analysis: 100%
- Concept Layout Drawings: 100%
- Complete BOM Package: 100%
- Purchased Parts Details: 100%
- Final Analysis and testing details: 100%
- Safety Hazard Checklist, FMEA, Risk assessment: 100%
- User Manual: 100%
- Gantt Chart: 100%
- Any other Appendices from report: 100%
- Manufacturing Plan: 100%

**Final Prototype Construction**
- Order Materials: 100%
  - Home Depot - Wheels: 100%
  - Online Metals - Stock: 100%
  - McMaster - Hardware: 100%
  - Tube Bending - Pals: 100%
  - Order Pablo Contingency Materials: 100%
  - Order Toby Contingency Materials: 100%

**Fabrication - In house**
- Sheet Metal - DXF (and drawings): 100%
- Sheet Metal - Waterjet or Regular: 100%
- Weld Cross members to frame: 100%
- Manufacture Axles: 100%
- Manufacture handle adapter plate: 100%
- Cut handles: 100%
- Weld handles: 100%
- Complete handle assembly: 100%
- Weld sheet metal: 100%
- Install wheel assemblies: 100%

**Quote for Mass Production**
- Create Quote Document: 100%
- Outreach to Suppliers: 100%
- Company: 100%

---

Poly Pickers

Page 2 of 2
## Senior Project DVP&R

**Description of System:** Harvesting Aid - Picking Cart

**DVP&R Engineer:** Aaron Feinstein

### TEST PLAN

<table>
<thead>
<tr>
<th>Item No</th>
<th>Specification</th>
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<th>Acceptance Criteria</th>
<th>Test Responsibility</th>
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<td>Increase by 6%</td>
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Appendix L: User Manual

Important information about this manual

This user manual contains important information regarding the proper use, care, and user-safety of the cart. It is very important to read through this manual entirely before beginning operation of the cart.

Symbols

The following symbols are used in this manual to help point out important information.

- **Warning** - This is a warning against something that may cause injury to the user or damage to the cart.

- **Stop** - This is to warn the user not to do something.

- **Tip** - This informs the user about helpful tips that will ensure smooth operation of the cart.
Appendix L: User Manual

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<tr>
<td>Changing Tire Bearings</td>
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Cart Overview

Overview of Parts and Features

1. Handles
2. Quick-release pins
3. Unfolded tray storage
4. Packing surface
5. Folded tray storage
6. Bucket storage
7. Auxiliary Storage
8. Wheels
9. Bungee Cords

Replacement Parts

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<td>Handle grips</td>
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<td>EPDM Bungee (19”)</td>
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<td>EPDM Bungee (25”)</td>
<td>McMaster-Carr/3891T18</td>
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<tr>
<td>10-24 Screw</td>
<td>McMaster-Carr/90128A221</td>
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<tr>
<td>10-24 Nylock Nut</td>
<td>McMaster-Carr/94407A103</td>
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Load/Operation Limits

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<th>Feature</th>
<th>Maximum Working Load</th>
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<td>Packing Surface</td>
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<tr>
<td>Folded Tray Storage</td>
<td>150 lbs</td>
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<tr>
<td>Bucket Storage</td>
<td>Max. 10 buckets per slot</td>
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Never exceed the working load limits of the cart. Failure to adhere to these limits may result in personal injury and/or failure of the cart.
Figure 1. The different sides of the cart will be referred to as “front,” “back,” “left,” and “right,” as depicted in this picture.

**Adjusting the Handles**

The handles are adjustable to ensure safety and proper posture during handling of the cart. The handles are attached with quick-release pins, shown below in Figure 2.
There are two pins per handle. Before adjusting, ensure the cart is stopped and on level ground.

1. Hold the handle with one hand, and remove the two quick-release pins, one at a time. The locking pins are attached to the handle and do not have to be held during the entirety of the operation.
2. Raise or lower the handle to a comfortable height, and align the handle holes with holes in the cart.
3. Insert a pin into the top hole of the handle, ensuring that it goes completely through both sets of holes, and the retaining ball is engaged.
4. Repeat Step 3 with the remaining pin, inserted into the lower handle hole.
5. Align the other handle with the same height holes on the opposite side of the frame, and steps 1 - 4.

Loading Buckets

After a bucket has been filled and emptied to pack clamshells, it can be stored on the (determine which is right or left) side of the cart. The right side contains 3 slots that can be used to hold 1 stack of buckets each. Each slot can hold a single stack of 12 buckets, with the hooks from the bucket being inserted through the slot from the top of the cart. When storing a bucket, do not reach over the length of the cart. Do not stack more than 12 buckets per holder. shows an example of a fully loaded bucket storage space.
Figure 3. (a) Fully Loaded cart, (b)-(d) Loading the buckets onto the cart

**Attaching/Detaching Bungee Cords**

**Attaching Bungee Cords**

The cart comes equipped with 8 bungee cords to be used to retain the fully packed trays in the fully packed tray storage area. There are 4 short (19”) bungee cords that are to be used in the front and back of the cart, and four long (25”) bungee cords to be used on the left and right sides of the cart.

1. Attach one side of the bungee hook to the lower eyebolt, as seen in Figure 4 (a)
2. Take the unattached end of the bungee, and stretch this up to the upper eyebolt, across from the first eyebolt.
3. Insert the hook through the eyebolt. This will form a diagonal line across the cart.
4. Repeat steps 1-3 with a second cord, starting from the opposite lower corner.
5. The two bungees should form an “X,” across the side of the cart.
6. Steps 1-5 should be repeated for each side of the cart to ensure the security of the fully packed trays.
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Detaching Bungee Cords

Ensure that the cart is at a full stop, and on a flat surface.
1. Start with the cord that is furthest from the cart, closest to the user.
2. Pull the cord in the direction that it is stretched in order to increase the amount of slack in the cord.
3. Detach the bungee hook from the upper eyebolt.
4. Remove the hook from the lower eyebolt.
5. Repeat steps 2-4 with the other bungee cord.

This process can be used to take off one set of bungee cords in order to load and unload the trays, or to remove all of the bungee cords on the cart.

Figure 4. (a)-(d) Attaching the bungee cords to the cart

Figure 5. Detaching the bungee cord from the cart
Loading Unfolded Trays/Empty Clamshells

Loading Unfolded Trays
The unfolded trays are to be put into the cart from the front into the unfolded tray storage area. The trays should lay flat, and will only fit if the short edge of the tray enters the storage area first. No more than 18 unfolded trays should be stored at one time in the cart.

Figure 6. (a) View of unfolded trays from the side of the cart, (b) view of the unfolded trays from the back of the cart

Loading Empty Clamshells
The capacity and orientation of the clamshells on the upper packing surface varies upon the size of the clamshells used.

Figure 7 shows the recommended orientations of several different sized clamshells in order to increase the capacity of the packing surface.
Loading/Unloading Packed Trays

Loading Packed Trays

To load the packed trays, the operator will first need to detach the bungee cords in the back of the cart. Please review the “Attaching/Detaching Bungee Cord” Section of this user manual to safely perform this maneuver. Load the packed trays into the lower tray storage compartment, starting furthest away from the handles, one layer at a time. This will help evenly load the cart. Avoid loading multiple filled trays in one location without distributing evenly. A fully loaded tray space can hold up to 18 trays. This process is described below in Figure 8.
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Figure 8. Demonstrating packing the lower surface, starting with the front and filling up towards the back.

Unloading Packed Trays

Unload the trays to the trailer in a safe manner. Do not lift more than 3 packed trays at once. Do not reach across cart to unload trays. Unload the stacks of trays from the front of the cart.

Auxiliary Tray Usage

The auxiliary tray can be used to hold different objects, such as a speaker, or water bottles.

Attaching the object with a carabiner to the cart will add to the stability, and security of the object while the cart is in motion.
Appendix L: User Manual

Rut Navigation

Large ruts are inherent in some field configurations. Proper navigation can be achieved by adhering to the following guidelines:

1. Approach the rut straight on, do not come at an angle to ensure that the cart does not tip over.
2. Push down on the handles to raise the front wheel and begin navigating the cart through the rut, turning as little as possible.

3. As the front wheel makes contact with the other side of the rut, continue pushing forward to keep the momentum of the cart.

At this point, it will help to both lift and push at the same time to assist the cart out of the rut.

Navigation through ruts can be dangerous. Make sure to follow all guidelines to avoid damage to the fruit and personal injury.

Recommended Field Use

To get the best performance from the cart, adhere to the following guidelines:

1. The cart is designed to have the pickers operate in groups. The optimal picker to packer ratio will depend on the current yield, but should remain at or near 4 pickers per packer to best utilize the cart’s function and capacity.
2. The picking operation should start with the pickers beginning to pick, each taking their own row. Once a bucket is full, the picker should place the bucket onto the middle row trellis (on the outside rows, the picker must reach through the vines to the opposite to place the bucket).
3. The packer should prepare the cart for packing at the same time as the pickers begin preparing for the day, which will allow for the pickers to get a head start in filling their buckets.

4. As the packer moves past a full bucket, they pick it up from the trellis and begin packing the contents into clamshells and trays. After a full tray is completed, it is placed in the storage area at the bottom of the cart. The empty buckets are placed in the slots designed to hold them on the side of the cart.

5. Once the end of a row is reached with the cart, it is then moved to the adjacent tent’s middle row. Ideally, the pickers are always ahead of the cart so full buckets should always be present ahead.

6. This process continues until the cart is fully loaded. The packer then brings the cart back to the main trailer to unload the full trays and replenish any other supplies.

7. Once pickers run out of buckets, they can take empty buckets from the cart.
Appendix L: User Manual

Maintenance/Repair

Preventative Maintenance

Corrosion
The frame of the cart is made from steel tubing and will corrode if continuously exposed to the environment. During manufacturing, a coat of paint has been applied to the cart to protect it from exposure; however, this paint may chip or wear off over time. The user should apply another coat of paint or other protectant (zinc coating, oil base, etc.) to the exposed areas.

Greasing Bearings
The bearings on the wheels come from the factory with a sodium grease already applied to the balls. Over time, this grease will be contaminated by dirt and will also be lost to the environment. To maximize the life of the bearings, new grease can be applied. To apply grease, remove the tire from the frame. Thoroughly clean any existing grease from the bearing - there should be no contaminants left. Apply the new grease using a syringe into the bearing. Add just enough grease to cover each ball in the bearing. The wheel can then be reattached.

Never apply grease that is not specifically specified by the manufacturer.

Changing a Tire
The tires can be easily replaced if they are worn or damaged beyond repair. The tires are mounted using a shoulder bolt and nut. Follow these steps to change a tire on the cart.
1. Prop up the cart to raise the tire off the ground.
2. Use a 9/16 inch wrench to secure the nut, and a 1/4 inch drive allen key to loosen the nut from the shoulder bolt.
3. Separate and remove the shoulder bolt and tire. Replace tire with a new tire, part number specified in the spare parts list.

Never let the cart rest on the axle mount when the wheel is off the cart. Make sure to prop up the cart to securely support it while changing the wheel.

Changing Tire Bearings
The bearings on each wheel can be replaced in the event of a faulty, damaged, or worn out bearing.
1. Remove the wheel from the frame.
2. Lay the wheel across a surface(s) where the bearing is free to drop through, such as over the edge of a table or between two flat surfaces.

3. Take a flathead screwdriver and press the blade against the backside of the bearing (through the axle hole).

4. Using a soft-faced hammer or mallet, gently tap the edges of the bearing to pop it out of the wheel.

| ! | Be careful not to hit too aggressively, as this may damage the bearing surface in the wheel. A damaged bearing surface may not form a solid seal for the replacement bearing. |

5. Take the now bearing and firmly press it into the axle hole. Use the soft-faced hammer or mallet to tap it fully into place.
Appendix M: Final Testing Data

Below is the data collected from the final test in Watsonville, CA on May 31st, 2018. This data was collected for a team of six, where one person was a dedicated packer and the rest were pickers. The field operation instructions were given to a translator to relay to the harvesting team.

<table>
<thead>
<tr>
<th>Time</th>
<th>Trays Collected</th>
<th>Notes</th>
<th>Picking Rate [trays/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:55:00 AM</td>
<td>-</td>
<td>Start Picking</td>
<td>13.71</td>
</tr>
<tr>
<td>9:30:00 AM</td>
<td>8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9:35:00 AM</td>
<td>-</td>
<td>Started Break</td>
<td></td>
</tr>
<tr>
<td>9:50:00 AM</td>
<td>-</td>
<td>Ended Break</td>
<td></td>
</tr>
<tr>
<td>10:10:00 AM</td>
<td>10</td>
<td>-</td>
<td>30.638</td>
</tr>
<tr>
<td>10:15:00 AM</td>
<td>2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10:17:00 AM</td>
<td>-</td>
<td>Restock</td>
<td>24.62</td>
</tr>
<tr>
<td>10:19:00 AM</td>
<td>-</td>
<td>Picking Start</td>
<td></td>
</tr>
<tr>
<td>10:40:00 AM</td>
<td>8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10:43:00 AM</td>
<td>-</td>
<td>Start Picking</td>
<td>32</td>
</tr>
<tr>
<td>11:08:00 AM</td>
<td>12</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>11:18:00 AM</td>
<td>-</td>
<td>Start Picking</td>
<td></td>
</tr>
<tr>
<td>11:32:00 AM</td>
<td>-</td>
<td>Started Break</td>
<td>19.09</td>
</tr>
<tr>
<td>12:03:00 PM</td>
<td>-</td>
<td>Ended Break</td>
<td></td>
</tr>
<tr>
<td>12:12:00 PM</td>
<td>7</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>12:12:00 PM</td>
<td>-</td>
<td>Start Picking</td>
<td>17.87</td>
</tr>
<tr>
<td>12:36:00 PM</td>
<td>8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>12:59:00 PM</td>
<td>6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Total Trays</td>
<td></td>
<td></td>
<td>61</td>
</tr>
<tr>
<td>Picking Rate [trays/hr]</td>
<td></td>
<td></td>
<td>22.99</td>
</tr>
</tbody>
</table>
Summary

The following document outlines the tests that were performed on the cart. It is important to note that the following tests occurred over a two week period and tested both three and four wheel configurations. The structural prototype was modified to allow for a four wheel configuration first and brought into the field for testing. Afterwards, it was modified in the shop to allow for a three wheel configuration and the same tests were carried out a week later. No significant weather or field alterations were noted in between tests, thus guaranteeing good accuracy of results.

After testing each possible combination of the small, medium, and large wheels in the different testing locations, it was determined that the radius of the wheel is the most important constraint governing performance. Another important factor is wheel type, for it was found that there was a large difference in vibration resistance between the pneumatic and plastic wheels. Further, no significant differences were noted between performance of the three wheel and four wheel configurations. As a result, the three wheel configuration was chosen to be superior due to the lower cost of purchasing three wheels instead of four.

As a result of the tests, the 16” diameter bicycle wheel is the recommended wheel for the final design. The large diameter, pneumatic “cushioning” action, and low price point make it the ideal choice for the type of use most likely to be seen by the cart. For a complete description of the tests that were carried out, please refer to the following sections in the document.

Testing Details

Figure 1, shown below, depicts the different locations in the Cal Poly agriculture unit where the tests were carried out.

Figure 1. Locations of various tests performed in the Cal Poly agriculture unit. At each test location, six different wheel configurations were tested out. Figure 2. depicts the different wheels that were used and the different wheel configurations are summarized in Table 1.
Appendix N: Wheel Configuration Testing

<table>
<thead>
<tr>
<th>Large Wheel:</th>
<th>Medium Wheel:</th>
<th>Small Wheel:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marathon 20” x 2.0” flat free cart tire on plastic rim, ¾” bearing</td>
<td>Marathon 16” x 1.75” steel spoked pneumatic wheel, ½” bearing</td>
<td>Harbor Freight 10” x 3.75” pneumatic wheel, ¾” bearing</td>
</tr>
</tbody>
</table>

Figure 2. Summary of the three wheels using during testing of the cart.
Table 1. Wheel configurations tested. Note that the configurations listed apply to both the three and four-wheel configurations of the cart.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Rear Wheels (closest to handles)</th>
<th>Front Wheel(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td><img src="image" alt="Large Wheel" /></td>
<td><img src="image" alt="Small Wheel" /></td>
</tr>
<tr>
<td>B</td>
<td><img src="image" alt="Large Wheel" /></td>
<td><img src="image" alt="Medium Wheel" /></td>
</tr>
<tr>
<td>C</td>
<td><img src="image" alt="Medium Wheel" /></td>
<td><img src="image" alt="Small Wheel" /></td>
</tr>
<tr>
<td>D</td>
<td><img src="image" alt="Medium Wheel" /></td>
<td><img src="image" alt="Large Wheel" /></td>
</tr>
<tr>
<td>E</td>
<td><img src="image" alt="Small Wheel" /></td>
<td><img src="image" alt="Medium Wheel" /></td>
</tr>
<tr>
<td>F</td>
<td><img src="image" alt="Small Wheel" /></td>
<td><img src="image" alt="Large Wheel" /></td>
</tr>
</tbody>
</table>
Appendix N: Wheel Configuration Testing

Ditch Test

The ditch test was designed to test the ability of a fully-loaded cart to navigate through a large drainage ditch. During the initial testing visit, one of the largest issues that was seen was the inability of the cart to navigate through a large drainage ditch. With the initial two-wheel configuration, two pickers were required to navigate the cart over the drainage ditch at the end of the row.

During testing, notes summarizing the user feedback were recorded for each configuration after multiple passes through the ditch were attempted. Figure 3 depicts the three and four wheel configurations of the carts during this test.

![Ditch Test](image)

Figure 3. Pictures of the cart in both three and four wheel configurations during the ditch test.

At the end of the test, each configuration was ranked on a scale of 1-6 (for 6 configurations), where a score of 1 was given to the best performing configuration. The three-wheel configurations and four-wheel configurations scores are summarized in Table 2.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>3 Wheel Configuration Rank</th>
<th>4 Wheel Configuration Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

It is important to note that in both the three and four-wheel configurations, A and B yielded a very similar performance. As a result, they were both given the highest rank.
Appendix N: Wheel Configuration Testing

Bad Terrain Test

The bad terrain test was carried out on a rototilled field. Before any testing began, the cart was tested in the initial two-wheel configuration in order to get a baseline. Figure 4 depicts this test.

![Figure 4. Baseline testing of the cart in a rototilled field.](image)

After getting an idea of performance, the cart was tested with the new wheel configurations. Figure 5 depicts these tests.

![Figure 5. Pictures of the cart in both three and four wheel configurations during the ditch test.](image)

a) Testing four wheels in configuration D  
b) Testing three wheels in configuration B

While this field exhibits conditions far worse than anything that is expected on a raspberry farm, the test still allowed off-road performance to be evaluated on an inflated scale. Similar to the ditch test, notes were taken during each test and then used to rank each wheel configuration. Table 3 summarizes these results.
Appendix N: Wheel Configuration Testing

Table 3. Bad terrain test results

<table>
<thead>
<tr>
<th>Configuration</th>
<th>3 Wheel Configuration Rank</th>
<th>4 Wheel Configuration Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Similar to the previous test, the larger wheels outperformed the smaller wheels. In this case, however, navigation was almost impossible with the small wheels, and the cart became stuck frequently.

Sand/Loose Gravel Test

The sand/loose gravel test was designed to test the cart in a different type of rough terrain that may be encountered in the field. Figure 6 shows the cart during this test.

![Testing four wheels in configuration A](image1)

![Testing three wheels in configuration B](image2)

Figure 6. Pictures of the cart in both three and four wheel configurations during the sand/loose gravel test.
Appendix N: Wheel Configuration Testing

As done in the previous tests, each configuration was rated. Table 4 summarizes the results.

Table 4. Sand/loose gravel test results

<table>
<thead>
<tr>
<th>Configuration</th>
<th>3 Wheel Configuration Rank</th>
<th>4 Wheel Configuration Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Again, the larger wheels performed better than the smaller wheels. During this test, in fact, there were multiple times that the cart got stuck on large rocks when a small wheel was installed on it. When pushed over the same rocks with larger wheels, the cart handled very well.

Vibration Test

The vibration test was carried out by towing the cart behind a car on a dirt road at about 10 mph. The cart was observed to see how well it handled vibrations; the “fast” speed exaggerated any vibrations encountered from the cart and made it easier to observe differences in performance. While this test was not conducted for every configuration of wheels, the results were clear: pneumatic wheels far out-performed the plastic wheels.

Testing Conclusions

After summarizing and combing through the data, it was concluded that the biggest factor that contributed to good performance was wheel diameter. Simply put, the larger the diameter, the better the handling and ability to navigate poor terrain. Further, and mainly as a result of the vibration test, it was concluded that a pneumatic wheel assisted greatly in smoothing out the vibrations that could damage the fruit. As a result, out of the wheels tested, the 16” diameter wheel was recommended for use on the final cart. The low price, large diameter, and pneumatic action made it the best option of all the wheels for the final design. It is important to note, however, that any wheel selected with a similar or bigger diameter and pneumatic treads would be a suitable fit.