Senior Design Project: Phase I
Last Stage Drone Delivery

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"I pledge my honor that I have abided by the Stevens Honor System."

Abstract

The objective of this project is to design and prototype a system capable of completing package delivery to a residential balcony in an urban area using current drone delivery technology. The following report summarizes Phase I of the project, which includes the project statement, concept generation, and the concept decision.

The notion of using autonomous drones to deliver packages is still in its early stages of development. On the forefront of such a notion is online retailer Amazon, who announced in 2013 that they are testing a system that utilizes quadcopter drones to deliver small packages to residents in suburban areas. More recently, small drone delivery startups such as Flytrex have developed in countries with looser unmanned aircraft regulations. However, these drone delivery systems are very limited in their use. They can only deliver to suburban areas where air and ground space is abundant enough for the drone to fly and land safely. Additionally, unmanned aircraft regulations play a significant role in limiting drone use for package delivery, even in countries like Iceland and the United Kingdom where regulations are comparably lenient.[1]

In the USA, regulations are strict, but the reality of drone delivery is within sight. The efficiency and applicability of drone delivery is especially apparent in high density metropolitan areas, where basic delivery by vehicle is hindered by constant traffic. Still, state of the art drone technology is not developed enough to be able to autonomously deliver a small package directly to an apartment owner's balcony where walls, ceilings, and other obstacles compromise the safety of the drone. No technology currently exists that is able to complete the last stage of quadcopter drone delivery to a precise location, like a balcony, in an urban area.

The goal of this project is to develop a system that fulfills in the last stage requirements of urban drone delivery. The project team created four viable concepts that allow for a delivery drone to keep a safe distance from buildings and major obstacles while simultaneously ensuring the package is safely transferred from the drone to the balcony. The following report details each design and examines why the chosen design is going to be developed. Additionally, a plan is laid out detailing how the device will be tested and prototyped in the upcoming project phases.

[1] "Delivery Drone." Wikipedia. September 12, 2018. Accessed September 27, 2018. https://en.wikipedia.org/wiki/Delivery_drone#Postal_deliveries.

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Introduction

Drones have been around much longer than commonly thought. The first drone was invented in 1974 by a team of engineers working under a man named Abraham Karem. They called this drone Amber.[2] Since the discovery of drone technology, government sectors including the Central Intelligence Agency (CIA) have been constantly using and developing drones. For example, the CIA has been using unarmed drones for surveillance in Afghanistan since 2000. They were used in the air war against the Taliban in 2001. They were even used after the terrorist attacks on the World Trade Center towers on September 11, 2001.[3] Over the past decade, considerable research has been put into drone technology to not only improve military use but also expand functionality to personal use.

Drones did not gain popularity in the eyes public until 2014 when they were sold as toys to assist with high elevation camera shots.[2] Companies such as Amazon saw the potential in the newly developed quadcopter drone and concluded they could utilize the technology to deliver packages to people's doorsteps. Amazon calls its new form of drone delivery Prime Air and already has development centers in the United States, United Kingdom, Austria, France, and Israel. Amazon's first completely autonomous delivery occurred on December 7, 2016 in the rural residential area of Cambridgeshire, England as a beta test. The test was completed in thirteen minutes from click to delivery.[4] Although Prime Air is still the testing phase, it will not be long until Amazon drones make their way around the sky delivering packages to people in all types of residential environments.

Project Statement

In order to clearly define the issue the team is faced with solving, a problem statement was created that specifies the project's major assumptions and shows that the team understands the task at hand. The problem statement acts as a guide to ensure the team reaches a viable end goal. The problem statement is as follows:

> "Develop a system capable of completing package delivery to a residential balcony in an urban area via quadcopter drone, which does not come within 5 feet of the balcony to prevent human interference and maintain drone and human safety. The system should be able to handle packages weighing up to 5 pounds with dimensions that are within

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[2] "When Did Drones Become Popular?: History of Drones." Droney Bee. August 02, 2017. Accessed September 24, 2018. http://www.droneybee.com/when-drones-popular/.

[3] Sifton, John. "A Brief History of Drones." The Nation. June 29, 2015. Accessed September 24, 2018. https://www.thenation.com/article/brief-history-drones/.

[4] "Robot Check." Amazon. Accessed September 24, 2018. https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011.

Amazon's definition of a large standard-size package of 18''x 14''x 8''. This task will be completed while considering current FAA Drone Laws and Regulations, with emphasis on the maximum drone flight height regulation of 400 feet and a standard balcony railing height of 36''."

Motivation

The team wanted to undertake this challenge because reaching the true potential of drone delivery technology is something that is bound to happen in the near future. The benefits of utilizing drones to deliver packages in urban environments have yet to be thoroughly explored despite problems with the current ground transportation delivery system. Urban traffic and processing times make modern package delivery slow and difficult for both the delivery company and the package recipient. Furthermore, many large apartment mail systems do not guarantee the safety of one's package and the risk of having a package stolen is nowhere near zero. Creating a system that allows for package extraction directly from drone to balcony will minimize that risk, eliminate delivery time from ground travel, and minimize consumer effort by delivering straight to a balcony. However, major issues with urban drone delivery still have to be worked out through additional beta testing and conformance with current FAA regulations. Nonetheless, this type of technology is going to enter everyone's lives soon enough.

Additionally, the members of the team want to physically design and build a prototype. The team agreed that there is no better way to test the knowledge and skills developed at Stevens Institute of Technology than to be able to complete a novel design project from start to finish. To be able to come up with a concept, perform all the necessary calculations, physically build a prototype, and finally be able to test the product to see if it works according to plan.

Goals/Objectives

The team's main goal is to be able to have a functioning prototype at the end of the project term. The team wants to be able to create a novel design and bring that design to a proof of concept based on the problem statement. At the conclusion of the project term, every team member wants to look at the completed product and feel proud of the work that was completed. This includes creating a system that functions as intended, is safe for consumers, and is aesthetically pleasing. The team wants to create a prototype that drone delivery companies want their customers to have to simplify the process in urban areas.

Individually, each team member has a mutual objective to learn how to work more efficiently as a group as well as to be able to identify and apply his strengths for the benefit of the team. Such skills are vital for a successful engineering career. The team also wants to experience the design process in its entirety with limited guidance, from the creation of an idea all the way to a functioning, physical prototype.

Major Issues

Design & Analysis

While drone package delivery shows the potential to be revolutionary by offering a faster, more convenient delivery option than those currently available, there are many issues associated with it. Despite package delivery by drone already being an option for a very small number of customers in rural areas of the UK and Iceland, expanding drone delivery to urban areas will come with its own set of obstacles.[5]

The first major issue to consider is the drone's proximity to obstructions in order to avoid interference with the delivery. While a drone is delivering a package, there are many physical obstacles that could interfere with the drone. The last stage of the delivery process will require the drone to approach a balcony. However, the drone will often not be able to fly over a balcony since it is a confined space. If the drone were to fly into the area of a balcony, it would have a higher chance of colliding with a person, railing, pet, furniture, or other obstacle. Also, the space may simply be too confined for the drone's obstacle detection systems to function properly. For this reason, the system developed for the last stage of the delivery must allow the drone to complete delivery without coming too close to the balcony.

Another major issue to consider is safety. This also relates to the issue of drone proximity since if the drone were to interact with a person or pet, it could pose a safety hazard. Additionally, since balconies are often overlooking areas of heavy foot traffic, there is potential for a falling hazard if the package is not delivered successfully. If the delivery mechanism is located on the outside of the balcony, it poses a much higher risk to become a falling hazard. For example, if the product is improperly installed or becomes damaged as opposed to if it was located on the inside of the balcony.

Another issue to consider is the appearance of the delivery system. Since it will likely be installed to a balcony, it should ideally be as discreet as possible, or otherwise be aesthetically pleasing. The product should not be undesirable for those who are concerned with the appearance of their balcony.

Prototyping & Experimentation

Since one of the primary goals by the end of Spring 2019 is to have a functioning prototype, there are other potential issues pertaining to the prototyping and experimentation that need to considered.

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[5] Pocket-lint. "How Does Amazon Prime Air Work and Where Is Drone Delivery Available?" Pocket-lint. December 16, 2016. Accessed October 02, 2018. https://www.pocket-lint.com/drones/news/amazon/139746-how-does-amazon-prime-air-work-and-where-is-drone-delivery-available.

One consideration will be the size of the alpha prototype. While the final prototype that is to be be completed by the end of Spring 2019 will likely be machined in order to take advantage of the strong material properties of most metals, an earlier phase prototype will likely be fabricated. A possible fabrication method for the alpha prototype is using Fused Deposition Modeling (FDM). The prototype would be made out of a thermopolymer, likely ABSplus.

One promising FDM machine, a Stratasys Dimension 1200es, is relatively easy access and is located in Carnegie Lab. The build size for this specific machine is 10x10x12 inches with a layer thickness is 0.010 inches.[6] The resolution of 0.010 inches is important to consider when designing tolerances and the build size is important because each part of the prototype must be small enough to fit within the build volume. If some parts do not fit in the build volume, 3D printing at a smaller scale is an option to consider.

Other available additive manufacturing systems with prototyping functionality, such as the liquid-based Objet Connex multi-jet printer, are less viable than an FDM option since FDM is generally better for functioning parts and is much cheaper.

When producing a prototype to showcase at the end of Spring 2019, some testing will need to be done. Utilization of CAD modeling and simulation softwares, such as Creo or SolidWorks, will first be used to develop the technical details and specifications for the prototype. When the prototype is produced, physical testing will be done to make sure that the mechanism functions as intended by fully extending, accepting the package delivery, and fully retracting. The testing and troubleshooting of the gear train is an area that is anticipated to be the toughest aspect to fine-tune to perfection. For this reason, designing the gear train will begin as early as possible.

Literature Review

State of the Art Review

Before brainstorming and generating concepts, the team conducted extensive market research to gain a better understanding of which products are currently in the drone delivery market and what makes them successful. Although the market is still quite new, the team was able to identify that Amazon is a large contributor to the innovation of drone delivery systems. A good part of the assumptions that the team made (see Stakeholder Needs and Specifications) while beginning to tackle this specific problem are based on information put forth by Amazon and their researchers. Amazon's system, Prime Air, essentially uses small autonomous drones to drop off packages on landing pads located on a rural residential property. Smaller drone companies have also started to emerge over the last two years in countries with lenient airspace regulations. In Iceland, a company called Flytrex supplies all the tools needed to start one's own

[6] "Stratasys Dimension 1200es." *Http://Usglobalimages.stratasys.com*, Stratasys, 2015, usglobalimages.stratasys.com/Main/Files/Machine_Spec_Sheets/PSS_FDM_Dim1200es.pdf.

drone delivery system. Flytrex provides products such as cloud based drones (see Figure 1), a control center app, and solutions to complete end-to-end operations. The company operates in the city of Reykjavik, which is considered an urban environment in Iceland. However, Reykjavik has significantly more open space than this project's target environment, a large city like New York City. Additionally, the Flytrex system still requires significant human interaction at the last stage of the delivery when the recipient has to manually approach the drone and extract the package.[7]

Figure 1: Flytrex cloud-based drone

In Switzerland, a company called Matternet provides a similar service to Flytrex. The only major difference between the two companies is that Matternet utilities a "dropbox" that holds the package securely when it is delivered, as seen in Figure 2.[8]

Figure 2: Matternet dropbox

Despite Amazon, Flytrex, and Metternet being on the forefront of drone delivery, the last stage of the urban delivery process is still missing and can make the whole delivery system even more efficient.

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[7] "How Drone Delivery Works." Flytrex. Accessed September 28, 2018. http://www.flytrex.com/how-it-works/.
[8] "On-demand Delivery Platform." Matternet. Accessed September 28, 2018. https://mttr.net/product.

Regulatory compliance is a large restraint on the advances in drone delivery technology, especially in the USA. The Federal Aviation Administration (FAA) has numerous laws in place that have slowed the progression of this technology. For example, testing equipment in a proper environment, like a city, typically results in large compliance issues. Some drone operating requirements are as follows: the drone must be kept within unaided sight of the operator or visual observer, the maximum drone flight height is 400 feet, and a drone can not be flown over anyone not participating in its operation.[9] Although regulations are not currently in the teams favor, the engineering issues at hand can be tackled without problem.

Drone Technology

The current state of the art in the realm of drone package delivery is a mixed use of quadcopter drones and plane-type drones. Due to differences in maneuverability, the quadcopter drone is more suited to operate in urban environments as it is able to hover, change altitude rapidly, and make sharp turns. Plane-type drones are very efficient in long-distance flight. However, they lack the ability to make sharp turns and therefore move as quickly as their quadcopter counterparts. Plane-type drones are therefore best suited for medium to low-density suburban or rural areas. For the sake of this project, we will focus solely on the specifications and applications of the quadcopter drone, specifically the current Amazon Prime Air drone, due to our urban target market.

Commercial Applications

Currently, the commercial applications of drone package delivery are in early-development. With regulations on airspace lagging behind the state of this technology, compliance issues associated with launching the drone delivery initiative are stifling the progression of the market. With that being said, Amazon has been able to begin making deliveries in select areas of the world utilizing some of the aforementioned technology. At present, the commercial application of drone delivery to this project's target market - urban apartment building residents - is nonexistent. It is the mission of this project to tackle the engineering problems associated with urban drone package delivery. However, it will take major regulation alterations in order for this technology to reach the general public. Proving the safety and functionality of new technology will help kickstart the regulation alteration process and thus research and design is necessary in order to generate progress on the legal front.

Stakeholder Needs and Specifications

The stakeholders in this business are any entities with a potential interest, concern, or direct impact on the project. Identifying and categorizing stakeholders allows for an

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[9] "Fact Sheet – Small Unmanned Aircraft Regulations (Part 107)." FAA Seal. September 19, 2014. Accessed September 28, 2018. https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=22615.

understanding of third party influence on the project. Some assumptions are made in order to establish a strong base for the project since the technology required (a fully functioning and compliant drone delivery system) has yet to make its way into the consumer market. The assumptions are as follows:

AS-1: A third party, Amazon, will have full responsibility for control of the drone for the entirety of its flight.
AS-2: Unmanned aircraft regulations dealing with drone flight will be handled by the third party.
AS-3: Amazon will be the third party mentioned above and will be able and willing to cooperate with the team as well as integrate its current state of the art drone delivery system with the developed product.

The above assumptions allow the team to restrict the scope of the project to something feasible while also taking into account possible stakeholders should the product be suitable for the consumer market. With the assumptions made, the stakeholders are categorized into primary and secondary stakeholders. Primary stakeholders have a direct impact on the project. Secondary stakeholders do not engage with the project but still may be influential.[10] Table 1 lists the categorized stakeholders and their impact on the project.

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[10] Morphy. "Secondary Stakeholders." Stakeholdermap.com. February 05, 2017. Accessed September 28, 2018. https://www.stakeholdermap.com/secondary-stakeholders.html.

Table 1: Stakeholders

Primary Stakeholders	
Project Advisor and Staff	Direct influence on path of project through report and presentation feedback. Provides guidance when needed.
Project Team	Individual members working on the project. Have the most influence on the project's success.
Stevens Institute of Technology	Governing body, provides budget and ownership of product.
Online Retailers/Amazon	Direct coordination to ensure delivery of package. Must cooperate with retailers for product to be successful.
Customers	Directly use the product.
Secondary Stakeholders	
Drone Manufacturers	Drone technology will influence the efficiency of delivery by drone. Design will have to comply with state of the art technology.
Disposal Companies	Influence end of life cycle. No influence on product success,
FAA	Regulatory body. Influences drone flight.
Material Distributors	Provide building materials.
Building Owners	Additional regulatory body.

In addition to identifying the stakeholders, the team identified the customer needs. The customer needs are pivotal for any design proposal, especially a novel project without much information available. Customer needs drive concept development based on assigned priorities. Table 2 below lists the major needs the team is focusing on throughout the design process.

Table 2: Customer Needs

#	Need	Priority*
1	Fits on balcony	2
2	Aesthetically pleasing	4
3	Keeps package safe	1
4	Minimal human interaction	3
5	Reliable	2
6	Does not endanger drone	2
7	Communicates with user	5
8	Durable	2
9	Extracts package from drone quickly	3

*Based on a 1-5 scale where 1 is the most important and 5 is the least important

Once the needs are listed and rated by importance, they are quantified into specifications. A well defined set of specs lists measurable, precise values each concept must try to meet. Table 3 below lists the specifications the team developed to guide the design choices.

Table 3: Specifications

#	Need	Spec	Value
1	Fits on balcony	Size	Fits within 2’x2’ area on balcony
2	Aesthetically pleasing	Customer Feedback	Subjective, 75% approval
3	Keeps package safe	Temperature/Weather	-20℉ to 120℉ operating temperature, waterproof
4	Minimal human interaction	Bluetooth capability	4 dBm, 30 foot range
5	Reliable	Percent failure of electrical components	0.2%
6	Does not endanger drone	Length of extension arm	5 feet
7	Communicates with user	Time to notify user of package delivery	<5 minutes
8	Durable	Percent failure of mechanical components	0.2%
9	Extracts package from drone quickly	Operating time	< 1 minute

The cost of the product is not included in the customer needs or specifications. This project is in the early research stage where cost is outweighed by the goal of a proof of concept. However, the team has a $700 budget to manufacture a prototype that meets as many needs and specifications as possible.

Concept Generation/Selection

<u>Concepts Generated</u>

With initial research completed, the team generated four unique concepts which all provide feasible solutions to the problem at hand. Each concept was discussed and refined by the team as a whole to ensure that all design concerns, needs, and specs were addressed. The four concepts are referred to as the Four-Bar Linkage, Slider Mechanism, Gear Train, and Zip Line System, and are discussed individually in greater detail below.

Four-Bar Linkage

The Four-Bar Linkage concept uses a four-bar mechanism to extend a platform for the drone to release the package on. The mechanism is powered by a DC motor on the crank link which in turn provides lateral motion for the package delivery platform. The mechanism moves the platform from its resting position inside the balcony to its extended position 5 feet outside the balcony ledge where the drone could safely release its cargo. The mechanism is mounted to the front and side balcony railings for maximum stability using C clamps and communicates with the drone via bluetooth to allow the mechanism to only be activated when the drone is ready to deliver the package. The landing platform is fairly uniform throughout all of the concepts and consists of a cage with an open top and padded bottom, as well as side walls to prevent the package from falling when the device is retracting to its original position. A mechanical sensor located in the landing platform will let the device know the package is successfully on the padding. The sequence of operations for the Four-Bar Linkage device is as follows:

1. The device is in its retracted position inside balcony.
2. The drone approaches balcony with the package.
3. Bluetooth communication tells the device that the drone is within 30 feet.
4. The device extends while the drone approaches the balcony.
5. The drone hovers over the extended arm and drops the package into the padded cage.
6. A mechanical sensor tells the device to retract once the package is confirmed to be delivered.
7. The device retracts and sends a notification to the consumer that his/her package is delivered.

An example lateral motion four-bar mechanism is shown in Figure 3 as a possible design for this concept.

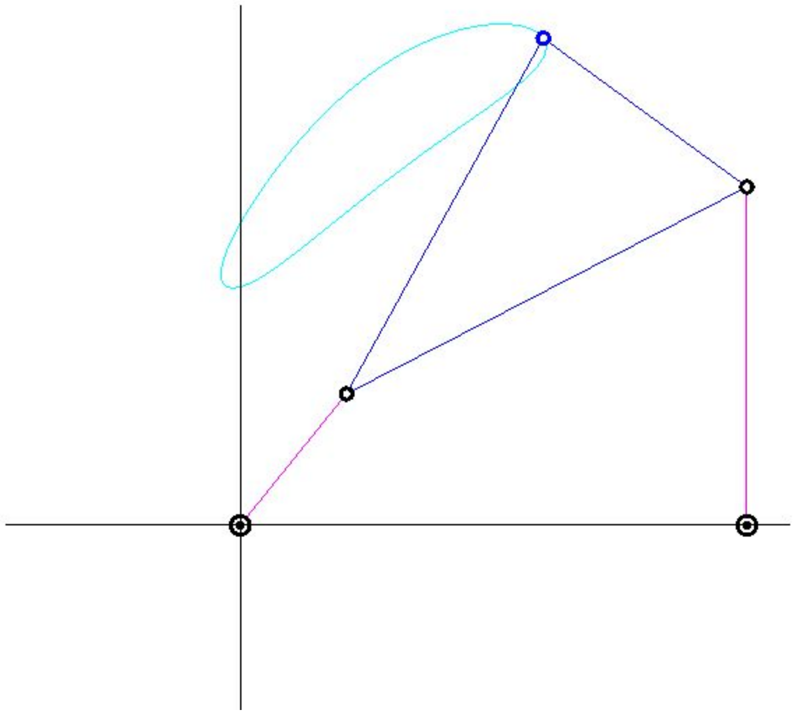

Figure 3: Four Bar Linkage

Slider Mechanism

The Slider Mechanism uses a four-bar slider which allows for lateral motion similar to the Four-Bar Linkage concept. The Slider Mechanism, however, would be able to operate on balconies that only have a front ledge unlike the Four-Bar Linkage which can only operate if the balcony has at least one side ledge. Another benefit of the Slider Mechanism is that it provides straight line motion so there is no risk of the package falling out of the platform cage when retracting. Even though this mechanism only needs the front of the balcony to operate, it is attached to the outside of the balcony rail. This causes safety issues as discussed in the Project Statement section of the report. The Slider Mechanism is also powered by a DC motor, communicates to the delivery drone using bluetooth connection, and follows the same sequence of operations as the Four Bar Mechanism. Figure 4 provides a visual representation of the Slider Mechanism concept.

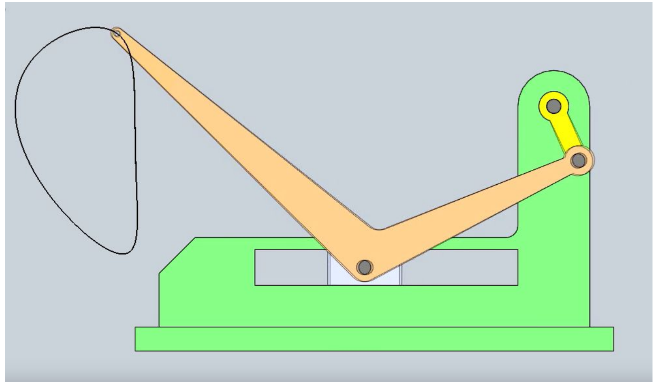

Figure 4: Slider Mechanism

Gear Train

The Gear Train concept uses a multiple gear train design to create the horizontal motion required to extend a wide, flat arm and the package platform a safe distance away from the balcony. This design is unique in that only horizontal motion is produced. Figure 5 below shows a simple mechanism the team could develop for this design. Another consideration is to use a similar gear mechanism to create a motorized telescopic extension arm. Having the arm be telescopic will significantly reduce the space required to hold the retracted arm while still keeping the same extension distance. The Gear Train mechanism is also placed and supported completely inside the balcony and will utilize balcony railings solely for extra support. The gear train, motor, extending arm, and package landing platform are all housed within a protective box when retracted. Such a design allows for the package to be safely stored inside the same box on the balcony, protecting the package and the internal components of the mechanism from nature. The sequence of operations is the same as the two other mechanisms above.

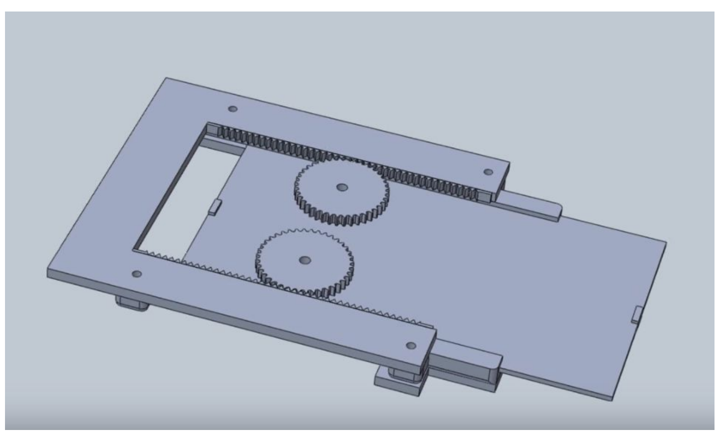

Figure 5: Gear Train Platform Motion

Zip Line System

The Zip Line System concept uses a cable connection from the drone to the balcony to allow the drone to safely deliver the package. The system works by mounting a delivery box on the outside railing of the balcony using C clamps. The delivery box communicates via bluetooth to detect the incoming drone's proximity and extends a telescoping arm laterally that carries the connection cable. The delivery drone would hover directly adjacent to guide wire arm and be equipped with an attachment ready to accept the cable and secure the connection. Once connected the drone will rise to a higher elevation and the telescoping arm will retract back to the delivery box. The drone will release the package, allowing it to safely descend along the cable into the delivery box. To allow the package to descend down the cable, the package container will use a custom collar style lid. The Zip Line design eliminates the load of the package being placed on a cantilever beam but in turn places the load on the drone as it descends down the cable. The load on the drone will change as the package moves and may cause problems with drone stability. The lid design and system design are shown in Figure 6 below.

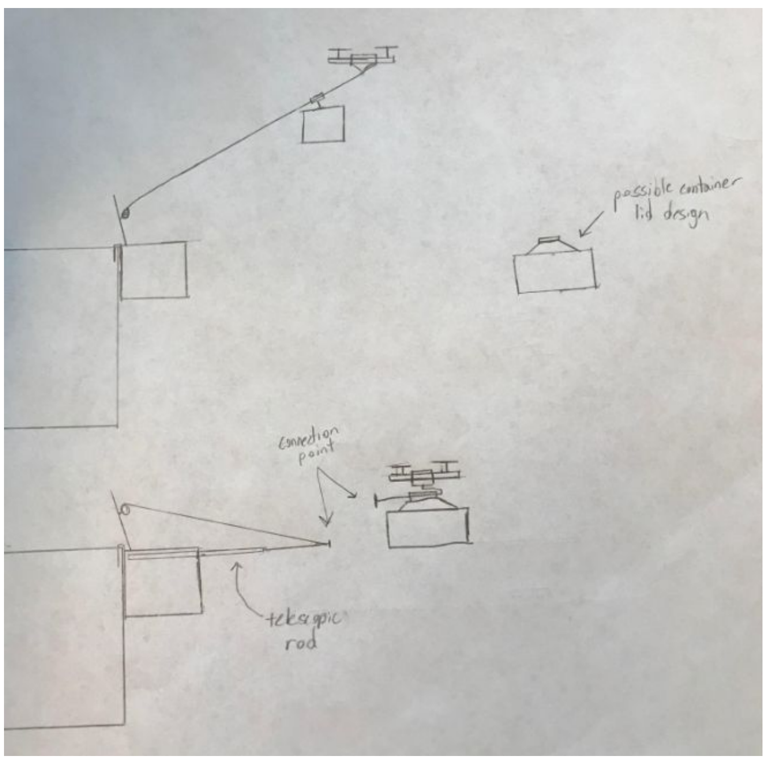

Figure 6: Zip Line System

Design Comparison

In order to make a meaningful comparison between each of the aforementioned designs, the team focused on how the concepts performed in each of the specified customer needs. As seen in Table 4, the four concepts were compared based on how well they satisfied each customer need: ability to fit on a balcony, aesthetic appeal, package security, autonomy, reliability, safe for drones, interactivity with the user, durability, and functionality. This comparison can be seen below.

Table 4: Concept Selection Matrix

Criteria	Weight	Four-bar Linkage	Slider Mechanism	Gear Train	Zip-Line System
Fits on balcony	2	2	3	3	2
Aesthetics	4	2	2	3	2
Package Security	1	1	1	2	1
Autonomy	3	2	2	3	3
Reliability	2	2	2	2	1
Safety	2	2	2	2	1
Communicates w/ User	5	1	1	2	1
Durability	2	2	2	2	2
Speed of dropoff	3	2	3	2	2
TOTAL		**44**	**47**	**57**	**41**
Rank		**3**	**2**	**1**	**4**

Concept Selection

Upon review of the concept selection matrix, the design which proves most feasible is seen to be the gear train system. The gear train concept was heavily favored as it offers an increase in package security and stability once the package has been released from the drone, it does not crowd the railing of the balcony and therefore is more aesthetically pleasing than its counterparts, and lastly, it incorporates additional protection services when the package is delivered and on the balcony. The team will focus more heavily on the mechanical problems involved in developing the gear train mechanism and worry less about the technology required drone-side.

Technical Analysis

Areas for Phase II

After choosing the gear train system by using the Concept Selection Matrix, multiple areas were analyzed to determine which will need technical analysis and development during Phase II. The first area that will need a significant amount of technical analysis is the actual gear train system. Designing and developing the optimal gear assembly will be a lengthy, involved task. For this reason, the design of the gear assembly will likely be the first technical task the team takes on in Phase II.

Another area for technical analysis will be determining the footprint and size of the unit. It will need to be able to contain the entire mechanism, but also should be as compact and with the smallest footprint as possible to take up the smallest amount of space on a balcony.

The design of the cantilever while fully extended is also an area that will need to be evaluated. This is the position of the mechanism where failure is most likely to occur due to bending. Simulations and testing will need to be conducted to determine the load, full extension length, and thickness and profile of the cantilever. While some target specifications have already been identified, some will need to be refined and re-evaluated, such as the max load able to be carried, the size of the package, and how far from the balcony the drone safely drop a package.

Sensors are also another area that will need to be analyzed. While the exact types of sensors that will be used are not yet known, there will likely need to be a sensor to detect when the package has been delivered. There are multiple types of sensors that could achieve this, one of the simplest being a mechanical sensor to detect the weight of a package on the landing platform to determine that the package has been delivered.

Similar Systems

The technology being researched and developed in this project is unique and new. Existing drone delivery systems, like Prime Air, are still in testing and will most likely need several more years to find their way into the consumer market in the US. As a result, extremely little information is available on the research being put into a last stage drone delivery system. Knowledge of similar systems do not exist or have yet to be released to the public. The closest last stage drone delivery design the team could find is a Google patent for a delivery receptacle on wheels.[11] Such a device can still only operate in a suburban environment where the receptacle has room to maneuver. However, the idea of creating a system that extracts and secures a package from a drone exists and is something being researched behind closed doors.

Since there is such a sparse amount of information available, the technical analysis and other analytical practices need to be completely developed from scratch, just as the gear train design was developed from scratch. Establishing a robust technical analysis as well as creating and refining the gear train design will consume most of the team's efforts in Phase II.

[11] Sandoval, Greg. "Google Patents Secure Rolling Box to Receive Packages from Drones." GeekWire. January 28, 2016. Accessed October 01, 2018. https://www.geekwire.com/2016/google-pondering-drone-delivery-even-about-boxes-it-flies-to-front-doors/

Project Plan

Gantt Chart

A Gantt chart (Appendix A) was drafted covering the first three phases of the project. The chart provides major and minor milestones as well as team member assignments. Many smaller tasks are done simultaneously by individual team members. Other items (reports, presentations, and concept generation) require the entire teams effort and are not assigned to any individual team member but still include a member's name. This team member is the assigned item leader. In order to maintain efficiency for items that require the whole team, a leader is chosen to ensure all team members complete their assigned tasks. Another benefit to assigning a leader for items such as reports and presentations is that the flow and voice of the document is maintained.

Major deadlines for each phase are provided but the tasks required to meet the deadlines still need to be completely defined for Phases II and III. Therefore, the timelines for Phases II and III in the provided Gantt chart are estimations and will be constantly updated to reflect the actual progress of the project.

Deliverables

Each phase of the project comes with a list of predefined, non project specific deliverables. The team developed a seperate list of project specific deliverables that align with the Gantt chart. Table 5 provides an organized list of both the project specific and non project specific deliverables. Project specific deliverables are indicated by an asterisk (*).

Table 5: Project Deliverables

Phase	**Project Deliverables**
Phase I	*Four viable concept designs
Phase I	Project Plan
Phase I	Written Proposal
Phase I	Phase 1 Presentation
Phase II	*Preliminary CAD model of chosen concept
Phase II	Website Shell
Phase II	Phase II Presentation
Phase III	Updated Website
Phase III	Engineering Design Report
Phase III	Phase III Presentation
Phase III	Project Charter
Phase IV-VI	*Working prototype

Budget

The team is given a $700 budget to complete the project and create a prototype. Since the team has been more concerned with concept generation in Phase I, the type of material, power supply needed, and other small components are not as developed. However, they will be more thoroughly thought out in the next phase when the team is creating CAD models and completes additional research. Table 6 gives a rough estimate of how the team plans on spending the $700 of funding. The budget plan in Table 6 gives an overestimate cost on the components to ensure that the team has enough money for any decisions or problems.

Table 6: Budget Breakdown

Component	Estimated Cost	Remaining Budget
Gears	< $60	$640
DC Motor	< $60	$580
Raw Metal/Plastic	< $300	$280
Sensors (weight/ pressure)	< $80	$200
Alpha prototype (Mostly fabricated via FDM)	< $40	$160

Based on Table 6, the team is left with $160 that can be used for additional funding. An example of this could be purchasing a more accurate sensor or purchasing more raw metal/plastic. A $160 cushion gives the team some comfort in knowing that there is money left aside for anything that can occur over the duration of the project.

Discussion/Conclusion

Having a package delivered to a doorstep by a drone is an exciting concept. Select suburban environments where airspace regulations are lenient are already enjoying such a luxury technology. Even the largest online retailer in the world, Amazon, sees the potential in using drones to cut down delivery costs and time. However, current delivery by drone systems are focusing solely on select suburban environments. The efficacy of drone delivery becomes apparent in areas with heavy foot traffic and vehicle traffic, where delivery time per mile is at its peak and the recipient of a package must put in a significant effort just to get the package in his or her hands. This project aims to develop a system that will make drone delivery to an urban area possible. The team developed four concepts that allow for safe drone delivery to an urban balcony. Each design allows a package carrying drone to relieve a package a safe distance away from a balcony via an extended arm and platform or a cable. The design the team chose to develop utilizes a gear train to extend a telescopic arm a safe distance away from the balcony, where the drone can easily release the package without having to approach the balcony and risk its safety. The mechanism sits inside the balcony and will work autonomously with the drone to extract and secure the package for the recipient to retrieve. The consumer package retrieval process is what makes this project commercial viable; all the recipient has to do it walk outside to the balcony.

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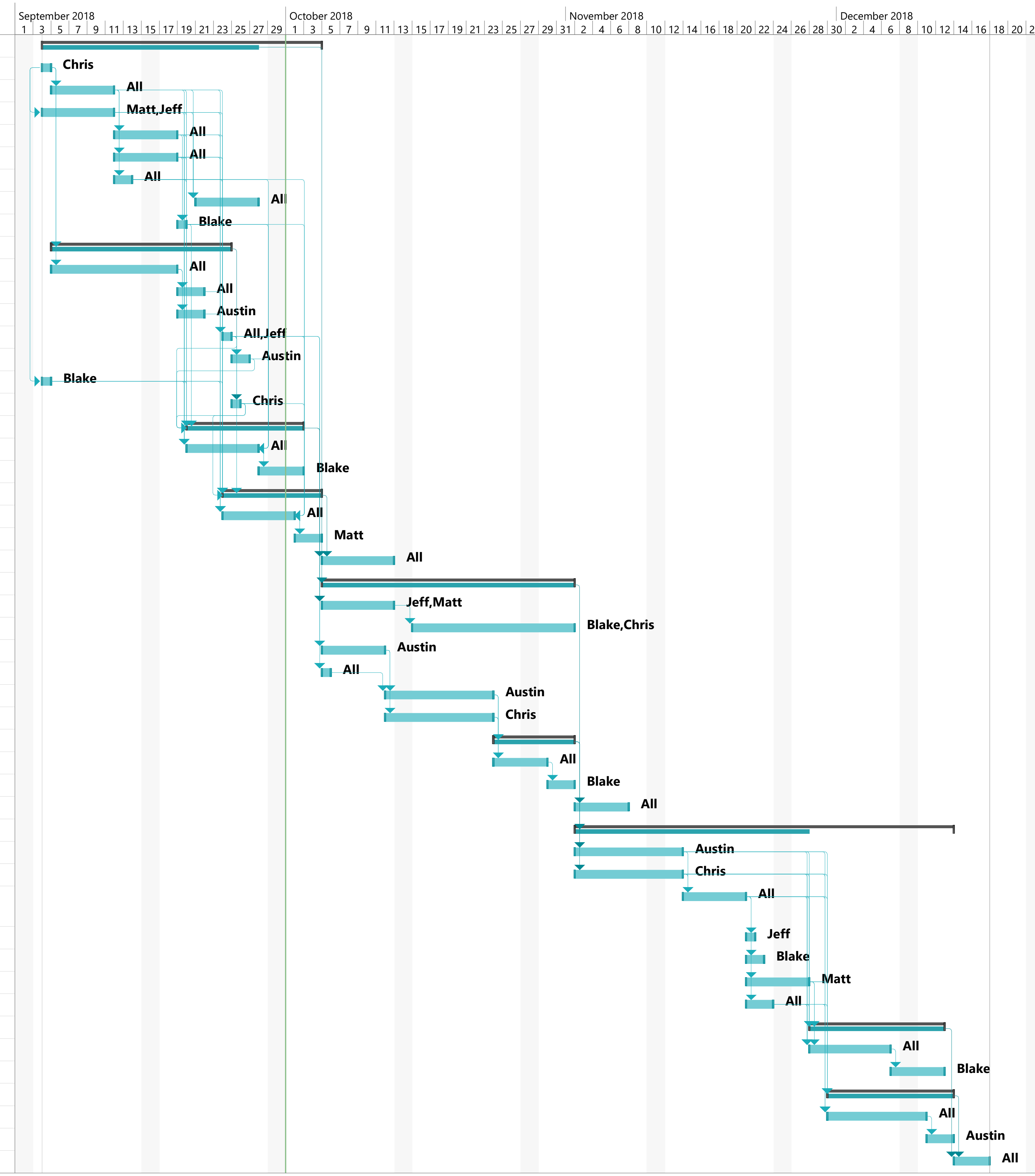
Appendix

Appendix A: Gantt Chart

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		**Phase 1 - Proposal and Conceptual Design**	**23 days**	**Tue 9/4/18**	**Thu 10/4/18**		**All**
2		Develop Problem Statement	1 day	Tue 9/4/18	Tue 9/4/18		Chris
3		Refine and Finalize Problem Statement	5 days	Wed 9/5/18	Tue 9/11/18	2	All
4		Literature Review	6 days	Tue 9/4/18	Tue 9/11/18	2SS	Matt,Jeff
5		Establish Stakeholders	5 days	Wed 9/12/18	Tue 9/18/18	3	All
6		Establish Customer Voice	5 days	Wed 9/12/18	Tue 9/18/18	3	All
7		Mission Statement	2 days	Wed 9/12/18	Thu 9/13/18	3	All
8		Draft Project Charter	5 days	Fri 9/21/18	Thu 9/27/18	3,5,4,6	All
9		Needs and Specifications	1 day	Wed 9/19/18	Wed 9/19/18	6,5	Blake
10		**Concept Generation**	**14 days**	**Wed 9/5/18**	**Mon 9/24/18**	**2**	**All**
11		Concept Brainstorming	10 days	Wed 9/5/18	Tue 9/18/18	2	All
12		Concept Refinement	3 days	Wed 9/19/18	Fri 9/21/18	11	All
13		Preliminary Concept Modeling	3 days	Wed 9/19/18	Fri 9/21/18	11	Austin
14		Concept Selection	1 day	Mon 9/24/18	Mon 9/24/18	12,13	All,Jeff
15		Preliminary Technical Analysis	2 days	Tue 9/25/18	Wed 9/26/18	14	Austin
16		Gantt Chart	1 day	Tue 9/4/18	Tue 9/4/18	2SS	Blake
17		Budget	1 day	Tue 9/25/18	Tue 9/25/18	10	Chris
18		**Phase 1 Report**	**9 days**	**Thu 9/20/18**	**Tue 10/2/18**	**17,14,6,5,16,4,3,9,7,15**	**All,Blake**
19		Draft Report 1	6 days	Thu 9/20/18	Thu 9/27/18	5,3,16,6,4,17FF,14FF,7FF,9FF,15FF	All
20		Edit and Finalize Report 1	3 days	Fri 9/28/18	Tue 10/2/18	19	Blake
21		**Phase 1 Presentation**	**9 days**	**Mon 9/24/18**	**Thu 10/4/18**	**17,14,6,5,16,4,3,9,7**	**All,Matt**
22		Draft Presentation 1	6 days	Mon 9/24/18	Mon 10/1/18	5,3,16,6,4,17FF,14FF,7FF,9FF	All
23		Edit and Finalize Presentation 1	3 days	Tue 10/2/18	Thu 10/4/18	22	Matt
24		**Phase 1 Peer Review**	6 days	Fri 10/5/18	Fri 10/12/18	18,21	All
25		**Phase 2 - Technical Analysis**	**20 days**	**Fri 10/5/18**	**Thu 11/1/18**	**1**	**All**
26		Develop Website Shell Design	6 days	Fri 10/5/18	Fri 10/12/18	18	Jeff,Matt
27		Create Website Shell	14 days	Mon 10/15/18	Thu 11/1/18	26	Blake,Chris
28		Create CAD Model of Concept	5 days	Fri 10/5/18	Thu 10/11/18	14	Austin
29		Determine Simulation Tests	1 day	Fri 10/5/18	Fri 10/5/18	14	All
30		Preliminary Simulations	8 days	Fri 10/12/18	Tue 10/23/18	28,29	Austin
31		Technical Analysis Calculations	8 days	Fri 10/12/18	Tue 10/23/18	28	Chris
32		**Phase 2 Presentation**	**7 days**	**Wed 10/24/18**	**Thu 11/1/18**	**30,31**	**All,Blake**
33		Draft Presentation 2	4 days	Wed 10/24/18	Mon 10/29/18	30,31	All
34		Edit and Finalize Presentation 2	3 days	Tue 10/30/18	Thu 11/1/18	33	Blake
35		**Phase 2 Peer Review**	4 days	Fri 11/2/18	Wed 11/7/18	32	All
36		**Phase 3 - Engineering Design**	**30 days**	**Fri 11/2/18**	**Thu 12/13/18**	**25**	**All**
37		Complete Simulation Testing	8 days	Fri 11/2/18	Tue 11/13/18	32	Austin
38		Complete Technical Analysis	8 days	Fri 11/2/18	Tue 11/13/18	32	Chris
39		Complete Necessary Design Alterations Based on Technical and Simulated Analyses	5 days	Wed 11/14/18	Tue 11/20/18	37,38	All
40		Order Parts	1 day	Wed 11/21/18	Wed 11/21/18	39	Jeff
41		Update Website	2 days	Wed 11/21/18	Thu 11/22/18	39	Blake
42		Determine Physical Testing MOP	5 days	Wed 11/21/18	Tue 11/27/18	39	Matt
43		Finalize Project Charter	3 days	Wed 11/21/18	Fri 11/23/18	39	All
44		**Phase 3 Report**	**11 days**	**Wed 11/28/18**	**Wed 12/12/18**	**39,37,38,42,43**	**All,Blake**
45		Draft Report 3	7 days	Wed 11/28/18	Thu 12/6/18	39,37,38,42,43	All
46		Edit and Finalize Report 3	4 days	Fri 12/7/18	Wed 12/12/18	45	Blake
47		**Phase 3 Presentation**	**10 days**	**Fri 11/30/18**	**Thu 12/13/18**	**39,37,38,42,43**	**All,Austin**
48		Draft Presentation 3	7 days	Fri 11/30/18	Mon 12/10/18	39,37,38,42,43	All
49		Edit and Finalize Presentation 3	3 days	Tue 12/11/18	Thu 12/13/18	48	Austin
50		**Phase 3 Peer Review**	2 days	Fri 12/14/18	Mon 12/17/18	47,44	All



Project: Last Stage Gantt Chart
Date: Mon 10/1/18

Task	Summary	Inactive Milestone	Duration-only	Start-only	External Milestone	Manual Progress	
Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline		
Milestone	Inactive Task	Manual Task	Manual Summary	External Tasks	Progress		