

**Understanding the Value Proposition Unmanned Aerial Systems Provide  
During the Phases of the Crop Cycle**

by

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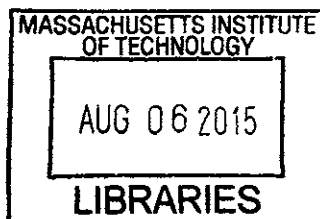
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**Tobias J. Walters**

Submitted to the System Design and Management Program on  
May 15, 2015 in Partial Fulfillment of the Requirements for the  
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## **ABSTRACT**

Increasing crop productivity is a challenge as old as human history. Advancements in technology have allowed farmers to produce ever-increasing amounts of food on a given amount of land. With the world's population expected to reach roughly nine billion by 2050 (United Nations 2013), the demand for food will require increasingly improved methods of agricultural production. One of these potential methods is the use of unmanned aerial vehicles (UAVs) to monitor crop health and identify potential issues.

This thesis will explore how current stakeholders plan to utilize this technology and the perceived value they believe it will deliver across the various phases of the crop cycle. This thesis begins by reviewing modern precision agriculture management practices and discussing how remote sensing plays a role in improving the efficiency of these types of farming methods. It also identifies a number of challenges facing the industry to include the impact of current regulations on the market. This thesis develops a stakeholder value network that clarifies the tangible and intangible value exchanges between the focal organization and its stakeholders. As well as constructing an OPM (Object Process Methodology) model to describe the system and demonstrate the stakeholder interactions and system process and sub-process decomposition. It also provides visual display of how the value is delivered across these processes. The final aspect of the research for this thesis is to identify the lead users for these systems and determine how they measure the value of the data provided by UAVs for remote sensing and crop management decisions in support of farming operations.

The value proposition for the various crop phases and the ideal uses cases discussed by lead users in this thesis may be used to guide future research in agriculture technology development, and drive further innovation in the emerging field of commercial unmanned aerial system use.

Thesis Supervisor: Joan Rubin  
Title: SDM Industry Co-director

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## DEDICATION

Every joy in my life comes from my family. I dedicate this thesis to my wife Sara, and three amazing children. Sara, you are the very foundation for the success I have experienced throughout my career in the Navy and my school experience here at MIT. Thank you for your support and friendship. I love you. To James, Elias, and Cora, you bring happiness and joy to my life every day. I am grateful for the opportunity to be your father. Thank you for putting up with the long days, the cramped apartment and crazy mornings. I love you and yes, daddy is done, we now have Legos to build, stories to read and adventures to catch up on.

Lastly, I would like to dedicate this thesis to my father and mother. You taught me the value of hard work and perseverance. You also sparked a love of the land and sky to which I am forever grateful. I am who I am because of your love, the opportunities that you provided me, and your constant support throughout my life. Thank you for everything you have ever done for me; I love you.

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# **1. PROBLEM AND MOTIVATION**

The world's population is expected to reach roughly nine billion by 2050 (United Nations 2013), and the demand for food and fiber will require improved methods of agricultural production. One of these potential methods is the use of unmanned aerial vehicles (UAVs) to monitor crop health and identify potential issues. This thesis will explore how current stakeholders plan to utilize this technology and the perceived value they believe it will deliver across the various phases of the crop cycle.

## **1.1. INTRODUCTION AND RESEARCH QUESTION**

Increasing crop productivity is a challenge as old as human history. Over the centuries agriculture has become a sophisticated and technologically advanced industry. Advancements in technology have allowed farmers to produce ever-increasing amounts of food on a given amount of land, as well as have allowed a single farmer to manage larger amounts of land. This increased ability of farmers to produce more food has been a key factor in enabling world population to grow, and this growth has in turn placed greater demands on agriculture to continue improving production. As the population increases, the number of arable acres is decreasing, adding to the demand for more food from less land.

Several factors impact crop productivity including fertility, insect damage, disease, weed infestation and water availability. In fact, United States farmers face an estimated loss of \$20-\$33 billion (Qualset 2005) a year as a result of these factors. For example, in 2012 insects infested 12.6 million hectares of cotton causing losses of over \$247 million (Williams 2012). Soybean rust takes \$1 billion out of the US soybean market each year, and potato blight cost farmers \$400 million annually (Qualset 2005). Another important factor in crop productivity is nutrient management. Proper balance of nutrients is key for maximum field performance. More

efficient application of nutrients lowers input costs, minimizes overflow to the environment and increases the value of farming operations.

In order to diagnose issues and determine solutions, farmers have relied on walking the field to scout their crop's progress. However, this method of scouting is slow and labor intensive (Tenkorang 2008). Because of the limited area covered the associated solutions to the observed issues are often blanket applications across whole fields. This type of application of fertilizer, pesticides, irrigation and drainage does not consider the variability across a given field. Today, with an increase in concern in managing surface and groundwater quality and overall environmental impact, agriculture is looking for more efficient ways to manage fertilizers, pesticides and water in fields.

One method to better understand the condition of a field is through the use of crop monitoring. Crop monitoring is a measurement of the crop's performance during each phase of the crop cycle. It is a process of gaining better information about the field's condition in order to pro-actively make crop management decisions that can positively influence the final crop yield. The use of UAVs for remote sensing in agriculture has slowly evolved over the past few years. As the acceptance of this technology increases, the market potential and the value they bring has been estimated to be \$2.1 billion by 2025 (AUVSI 2013). Current Federal Aviation Administration (FAA) airspace regulations are the main inhibitor of the commercial development of these systems. As regulations are being decided and implemented, it is important to fully understand how to best utilize the systems and be prepared to take advantage of this new marketplace. Figure 1 below is an example of several different UAVs currently being developed to address this market.



*Figure 1: Examples of UAVs Used for Remote Sensing in Agriculture*

While some research has been done on how these systems will provide data that can be used for improved efficiency in farm operations, the reception of this technology is still uncertain. Understanding how these systems will be utilized and the value placed on the data provided will allow for better integration and acceptance. This thesis will attempt to understand the value stakeholders believe these systems will bring and the utility they will provide for the various phases of the crop cycle. The crop cycle will be decomposed into four distinct phases: planning, emergence, crop care, and harvest. The planning phase includes the decisions for crop rotation, placing a field into fallow, and crop cover planting decisions. The emergence phase focuses on the early crop development, and includes crop sprouting progress and thickness, and decisions on re-seeding. The crop care phase comprises decisions on irrigation, chemical and fertilizer application, and weed management. The harvest phase centers on crop condition during the weeks leading up to and the decisions on when to start harvest.

To better understand the value proposition of these systems, several factors need to be explored. First an understanding of modern agricultural practices needs to be developed, as well as a determination on how remote sensing plays a role in improving the efficiency of these types of farming practices. Finally the lead users for these systems need to be identified in order to

understand how they are currently using Agriculture (Ag) UAVs in support of their farming operations.

## **1.2. RESEARCH METHODOLOGY**

In order to better understand the goal of this thesis it is important to understand what a “stakeholder” is and how “value” will be determined. A stakeholder is “any group or individual who directly or indirectly affects or is affected by the level of achievement of an enterprise’s value creation process” (Nightingale 2011). This research will focus on farmers, UAV manufacturers, and crop consultants as the primary stakeholders for these systems. A diversity of stakeholders is included to prevent bias associated with any one field. Value is defined as a fair return or the equivalent in goods, services, or money for something exchanged. In other words value is based on what you receive relative to what it cost. It is represented by the relationship:  $Value = Functions / Resources$  (INCOSE 2011).

In an attempt to better understand the various stakeholder’s needs and goals a multi tier survey (Appendix A) was sent out to those members of the agriculture community who have exposure to these types of systems. The survey aimed to determine how lead users measure the value of the data provided by UAVs for remote sensing and crop management decisions across each of the four phases of the crop cycle. It is important to recognize that the survey participants were limited to individuals who have had some exposure or experience with this technology, and may not represent agriculture as a whole.

The survey is composed of three sections. The first section will determine a participant’s level of UAV knowledge, in an attempt to see if the knowledge level about these systems impacts the perceived value. Along with determining the participant’s prior knowledge about Agricultural (Ag) UAV systems the survey also queried about the size of the farming operation.

This was done to determine if operation size impacted the perceived value of the data, and how useful different sized farming operations would find these systems.

The second section focuses on the value proposition across the four phases of the crop cycle. The participants were first asked what information is important for crop management decisions for that phase and then several images and data from current systems were displayed for that respective phase of the crop cycle. The participants were then asked to provide a rank (1: no value, to 7: very important), to determine how important the data would be influencing management decisions during that phase.

The third section focuses on stakeholder use, to determine how they would utilize the systems if cost were not a factor. This section looks at the data provided and how it would be best analyzed for the stakeholders use. It provides the participant an opportunity to describe their ideal system and use case scenario.

The final aspect of the research for this thesis is to construct an OPM (Object Process Methodology) model-based approach to describe the system and demonstrate the stakeholder interactions and system process and sub-process decomposition. It will also provide visual display of how the value is delivered across these processes.

## **2. INDUSTRY REVIEW PRECISION AGRICULTURE**

In 2012 America's farms contributed \$166.9 billion or 1% to Gross Domestic Product (GDP), and direct on farm employment provide over 2.6 million jobs (USDA 2014). The Ag industry also directly impacts other areas of the economy as it provides the raw materials for many different products. This section will cover a brief history of technological advancement in agriculture and the impact on historical crop yields. It will also discuss the current trends in

precision agriculture, as well as how remote sensing integrates into these methods of crop production.

## **2.1. HISTORY OF PRECISION AGRICULTURE**

Over the centuries agriculture has become an ever-increasing sophisticated and technologically advanced industry. Improvements in technology have allowed farmers to produce ever-increasing amounts of food on a given amount of land, as well as allowing a single farmer to manage larger amounts of land. These enhancements in agriculture have occurred over a long period of time. The earliest examples of humans gathering wild nuts, fruits and grains for consumption were limited by the amount of work required to gather a sustainable amount of food. The appropriate measure of yield would not be kilograms per hectare, but the amount of grain harvested per hour or per calorie of effort (Evans 1980). Plants that were quickly and easily harvested were those crops that were first domesticated.

The domestication of wild plants allowed for several other advancements in production such as different crop selection, and the development of specialized tools that allowed for more efficient harvesting. The evolution of these improvements changed the basic measurement of agricultural production. While time and effort were still considerations, the new metric for field production was the ratio of seeds planted to those harvested. This is the measure of yield mentioned in the Bible and by Roman writers such as Columella, who refers to a fourfold return of wheat, a figure common in poor, dry areas... however yields could be much higher with up to 45-fold being recorded (Evans 1980). For most of human history agriculture consisted of subsistence farming, growing little more than what was required for survival.

Yields have increased slowly over time, during the Middle Ages wheat yield in Europe ranged between one half and three quarters metric ton per hectare (Evans 1980). This is

comparable to the .74 metric tons per hectare the United States was averaging in 1866, but significantly less than the 3.2 metric tons per hectare being produced today (USDA 2014). The increase in yields can be traced back to the late 1800's with the development of mechanization. The modernization of agriculture led to another shift in the means of production measurement from harvest ratio to yield per acre. While the use of new equipment allowed an individual farmer to cultivate more acreage, it did not increase the yield per acre production. Figure 2 below shows the historical yields of various crops in the United States in bushels per acre from 1865-2010. It shows how yield was relatively consistent until the 1940s, when production began to increase dramatically. Several parallel developments during that time are responsible for the increase in crop production. The use of fertilizers, pesticides and herbicides began to grow dramatically after the First World War, as well as the emergence of hybrid seeds and selective breeding during the 1940's (Evans 1980). Maintaining this trend is difficult, and with the estimated increase in population, it has been projected that crop yield must double by the year 2050 to prevent a worldwide food crisis (United Nations 2013).

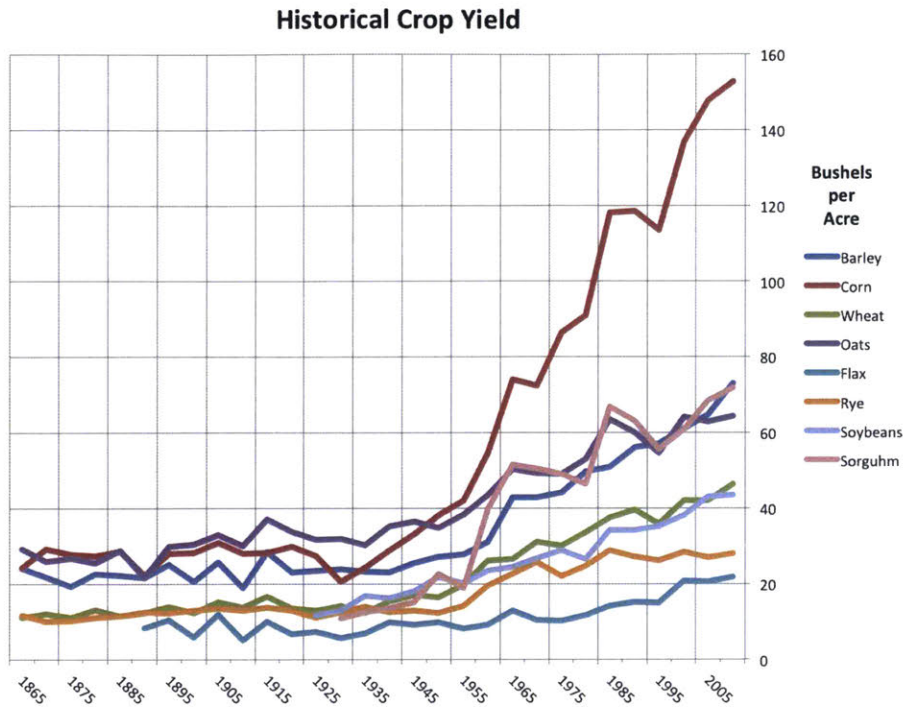


Figure 2: Historical Crop Yields 1865-2005 USDA

In an attempt to continue increasing production, farmers turned to new methods of managing their land. Precision farming is an approach to crop management that follows similar concepts to lean manufacturing. In the case of agriculture, controlling production inputs and eliminating waste demonstrate this. Production inputs such as seed, fertilizer and chemicals should be applied only when and where needed to achieve the most economic production (Searcy 2011). It is a management strategy that employs detailed, geographic specific data to precisely manage inputs for improved production.

Precision farming is a relatively young farming management practice originating in the late 1980's and the early 1990's. The development of several different technologies such as grid based soil sampling, yield maps, and variable rate application (VRA) fostered the development of precision farming. The availability of the NAVSTAR Global Positioning System (GPS) for civilian use allowed for these different technologies to be utilized together to provide fine-scale



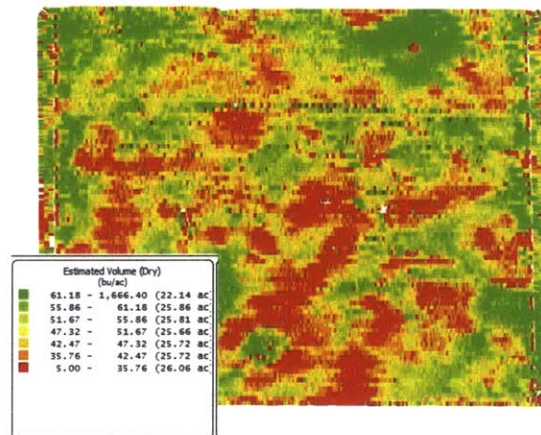
monitoring and mapping of variations with fields (Taylor and Whelan 2010). As the technologies improved, the adoption of these techniques by producers in the US has increased as well. Recent data from the Agricultural Resource Management Survey found that roughly 40-45 percent of corn and soybean acres in 2005-06 have utilized some form of yield maps in their operations, and that roughly 24 and 17 percent have adopted variable rate technologies as well (Ebel and Schimmelpfennig 2011). The report also determined operations that utilize precision farming techniques have had higher yields and lower expenses than those who do not. These techniques currently only employ data gathered at harvest and before planting. The use of UAVs during the growing cycle could allow farmers to adjust their management decisions in near real time to take action that will impact the current yield vice waiting a full cycle to implement changes.

## **2.2. CURRENT TRENDS FOR PRECISION AGRICULTURE**

Precision farming is categorized by the following technologies: GPS, Geographical Information Systems (GIS), Guidance Systems, Yield Monitors, and Variable Rate Technology (VRT). (Neville 2014). Several applications of current precision farming trends, such as yield monitoring; field mapping, section control, and remote sensing are discussed below. Often times it is the combination of these technologies that provide the most value for the end user.

Yield monitoring allows farmers to collect yield data for specific geospatial areas of their fields. This data can be used to generate yield maps that will exhibit areas of weak performance. This allows for site-specific management of that field to address potential problems. Yield monitors are installed on harvesting equipment and with the use of differential GPS the system can measure the amount of crop being harvested at a specific time and location. These systems also provide the user the ability manually to track areas of interest for pest and weed infestations

discovered during harvest. The data provided by yield monitoring can be stored and analyzed for variations and year-to-year trends that can be used to determine management decisions for improving crop productivity. However, several years worth of data is required to normalize the inputs in order to develop a product that is useable for making crop management decisions. The data also allows farmers to limit the application of fertilizers and chemicals to only the areas requiring it, improving low yield areas, reducing costs, minimizing environmental impact and improving overall profitability.

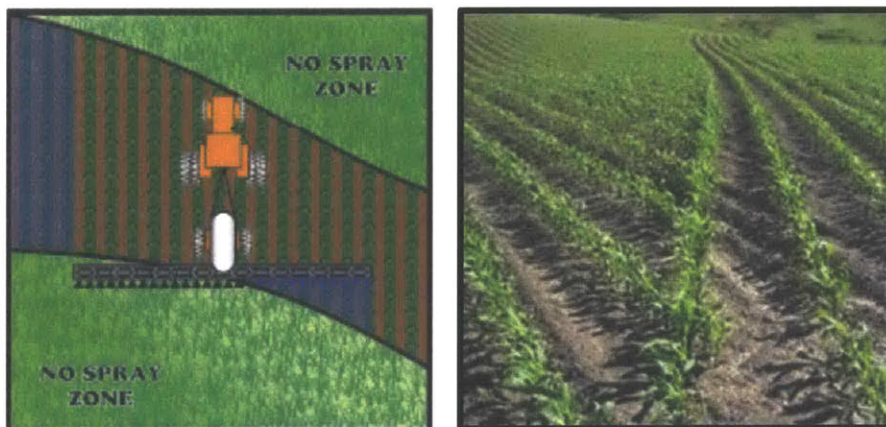


*Figure 3: Yield Map*

Automatic guidance allows farm equipment such as tractors, harvesters, or sprayers to travel from one point in a field to another without operator inputs. Through the use of GPS and automatic steering the equipment can follow a predefined path. The major advantages of automatic guidance systems include: precise positioning preventing overlaps or skipped areas in a field. It also allows for longer operating times due to the lack of fatigue found with human operators. Automatically guided systems are not limited by the conditions they can operate in and can perform safely at night or in limited visibility. The use of automatic guidance allows the farmer to accomplish more work safely with fewer errors.

Variable Rate Technology (VRT), changes the rate of application of various products (fertilizer, pesticides and seeds etc.) in an attempt to adjust for the variations in soil characteristics across a given field. Use of this approach can reduce the environmental impact and minimize waste. In order to implement VRT several different components are required: GPS, mapping, software and controllers to change the rate of application. Utilizing yield-mapping technology, the system can automatically adjust the rate of application for each zone. Manual control is also available allowing the operator to choose the rate of application for the field.

Automatic section control (ASC) is similar to VRT as it controls the application of products to the field. However, instead of varying the concentration of application, it is used to ensure that it is only applied to pre-defined areas. ASC uses GPS guidance that turns spray boom sections or individual nozzles off in areas that have been previous covered or designated as no application areas. This helps with the elimination of waste and minimizing environmental impact by reducing application overlap. This technology can also be used to prevent overlap when planting as seen in Figure 4 below.



*Figure 4: Automatic Section Control for Spraying and Planting*

The current technologies often rely on data gathered during or after harvest and require several years to develop useful products for crop management (Schultz 2015). The use of UAVs during the growing cycle could allow farmers to adjust their management decisions in near real time to take action that will impact the current yield vice waiting a full cycle to implement changes. With the advancement of unmanned technology these systems are become more affordable and have the potential to provide an important set of data to the farmer that is currently unavailable. There are some methods to gather information over the course of the growing, but they are limited in their use, and cost as discussed in the next section.

### **2.3. REMOTE SENSING AND CROP MONITORING OVERVIEW**

One method to better understand the condition of a field is through the use of remote sensing. Remote sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Keifer 2000). Remote sensing is not new to agriculture; it has been used for many years with varying degrees of success. The first use of imagery to identify disease in crops dates back to 1927 when airborne imagery was used to differentiate between healthy cotton plants and those killed by root rot (Tenkorang 2008). In the 1930's the Department of Agriculture began using aerial photography to measure general crop inventories and soil survey mapping as part of the work of the U.S. Soil Conservation Service. The development of infrared photography to detect camouflage during World War II influenced remote sensing techniques that allowed for a greater understanding of crop status. Camouflage, which appears to be vegetation in the visible spectrum, is easily discerned from real vegetation when imaged in the infrared. Research continued through the 1950s and 60s, and with the launch of Land Area Remote Sensing Satellite (LandSat) in 1972 remote sensing over large areas

became possible. The Large Area Crop Inventory Experiment (LACIE) was conducted using the Landsat configuration to estimate wheat production over a large geographical area in the Midwest (Nellis 2010). The project was expanded upon in the late 1980s as the Agriculture and Resource Inventory Surveys through Aerospace Remote Sensing (AgRISTARS) program to monitor other types of crops and to develop agricultural applications from the data.

Just as the method of collecting images evolved over time from aircraft to satellites so too did the sensors, from infrared photography to multi/hyper spectral and thermal imagery, remote sensing has evolved to provide additional information about crop status. The primary method used by remote sensing to measure crop health is through the use of the Normalized Difference Vegetative Index (NDVI). NDVI is defined by the formula  $(\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$ , where (NIR) near infrared is reflectance in the near-infrared spectrum (0.75 – 1.10  $\mu\text{m}$ ) and RED is reflectance in the red band of the visible spectrum (0.58 – 0.68  $\mu\text{m}$ ). Chlorophyll uses electromagnetic energy in the RED band for photosynthesis, and plant structure is reflective of energy in the NIR band. So, for vegetated surfaces, NDVI increases if plant biomass increases or if photosynthetic activity increases (Kastens 2005). The image below provides an example of NDVI calculation.

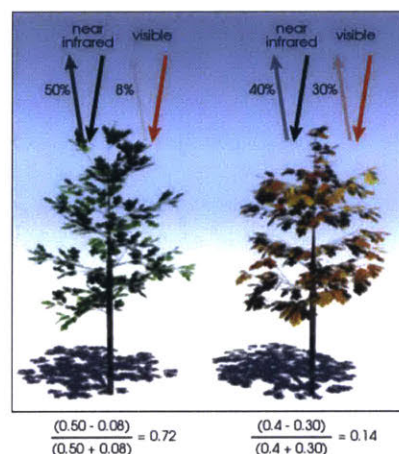


Figure 5: NDVI Example (NASA 2000)

Because the reflectivity measurement values vary with the angle of the sun a ratio of the infrared visible difference to the infrared visible sum is used to normalize the data taken with varying sun angles. While NDVI is widely used as the metric for determining the health status of vegetation, there are several other types of sensors used in remote sensing.

Multi-spectral data via satellite is available for crop evaluation. Multi-spectral imagery collections images across multiple spectral bands to include visible, near-infrared, short wave infrared, and long wave infrared. LandSat 8, launched February 2013, collects imagery across 11 spectral bands and provides the data for download at no charge from the United States Geological Survey (USGS). The resolution of the imagery is much lower than the sensors carried by aircraft, and obscuration is a vital shortcoming of satellite imagery. Satellites imagers must contend with weather blocking the field of view, while aircraft imagers can fly below it. Ground Sampling Distance (GSD), or spatial resolution, is the area that a single image pixel covers on the ground. The GSD of LandSat 8 data in the visible and near infrared is 30 meters, and the revisit time, or time between images is 16 days (NASA 2014). Satellite sensors have less ability to resolve changes in light intensity than the sensors used on aircraft. Intensity resolution is expressed in the number of bits that the sensor uses to digitally quantize the light striking the sensor array. The LandSat 8 data has a bit depth of 8 bits, or 28 (256) intensity bins (NASA 2014). A standard digital camera, by contrast, has a bit depth of 14 bits or 16384 bits in its raw image format.

Hyperspectral sensors offer higher spectral resolution, and typically provide hundreds of simultaneously sampled spectral channels, compared to the relative few tens of channels for multi-spectral sensors. This high spectral resolution enables the capture of an entire spectrum at each specified location. The benefit is that the data can later be mined for spectral signatures

without knowing in advance what to look for. Hyperspectral sensors are complex and typically require custom software to capture data and produce images. Due to the large number of spectral channels, these sensors produce sizeable amounts of data, requiring approximately 100 times more storage than sensors with a few spectral bands. There are a few satellite hyperspectral sensors, NASA's Earth Observing 1 (EO-1) satellite is one equipped with the Hyperion hyperspectral sensor to provide provides visible and near-infrared with a GSD of 30 meter resolution over an areas of 10nm. Once again resolution, obscuration and revisit time are all issues that impact the value provided by these sensors.

Another type of sensor used for remote sensing is thermal imaging. Thermal imaging operates in the long-wave infrared (LWIR: 8- 15  $\mu\text{m}$  wavelength), and is sensitive to small differences in temperature between objects in the field of view (Kelvin 2003). Thermal imaging may supplement NDVI data when identifying crop stress related to irrigation, pests, or disease. In addition to crop stress applications these cameras have agricultural applications such as location of livestock, and monitoring the degradation of applied biodegradable agricultural crop protection films. The resolution of thermal imaging is considerably lower than consumer digital cameras. Small thermal imaging cameras are commercially available, but are more expensive often costing about 10 times the price of a digital single lens reflex (SLR) camera.

The sensor capabilities that were formerly only available from satellites or carried by manned aircraft are now available in a small enough form that makes them ideal for use in large scale, low cost, remote sensing. The use of these new sensors and UAVs will be a key element in the next evolution of remote sensing. The following section will provide a brief history on the development of UAVs and the potential industry development with their commercial application.

### **3. UAV INDUSTRY REVIEW BACKGROUND AND CONTEXT**

This section will cover a brief history of unmanned aerial systems development and usage. It will examine the current trends of commercialization in the industry to include adoption rates and the diffusion of innovation. It will also explore the current state of regulations and its impact on the development of the industry.

#### **3.1. OVERVIEW OF HISTORY OF UAV USAGE AND DEVELOPMENT**

The use of unmanned aerial systems may seem like a relatively new concept, but they have in fact been used throughout history. The earliest recorded use of unmanned flying vehicles was in ancient China for signaling and communications using small balloons and kites during military operations. The early day UAV was born out of the advancement in aviation technology and its use on the battlefield. In 1916 the first flight of a pilotless aircraft took place, the Hewlett Sperry automatic airplane was designed to crash into warships with an explosive charge (Pearson n.d.).

Technology continued to improve and after the American U-2 spy plane was shot down in 1960, there was a surge in demand for systems capable of penetrating deep into enemy airspace and returning with precise military intelligence. The United States Air Force developed a reconnaissance remotely piloted vehicle that was used during the Vietnam War with limited success (Wagner 1982). During the 1973 Yom Kippur War Israel developed the first UAVs with real-time surveillance and electronic warfare capabilities. The use of these UAVs with their real-time video capabilities resulted in the destruction of 28 surface-to-air missile sites along the Lebanon border (McDaid 1997). The success of these UAVs led to a major shift in thinking and the modern UAV was born. The technology continued to improve over the years and during the recent wars in Iraq and Afghanistan their capabilities have been brought into the spotlight.



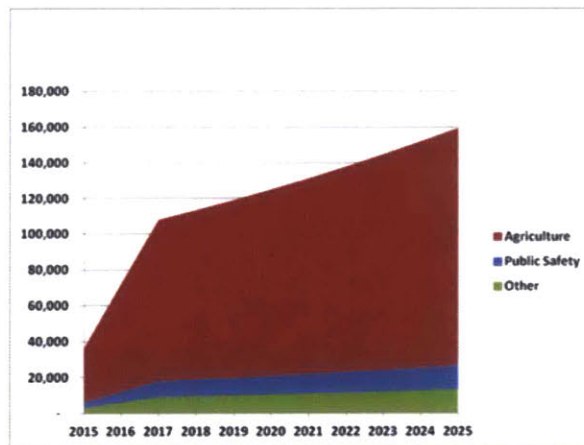
The development of UAVs for commercial application is relatively new in the United States, however some countries have been focused on the development of commercial systems for many years. In 1983, Yamaha Motor Company received a request to develop an unmanned helicopter for crop dusting purposes from the Ministry of Agriculture, Forestry and Fishery of Japan. By 1991 Yamaha began marketing its RMAX unmanned helicopter for agricultural spraying and currently this system is being used to cover 2.5 million acres, or 40% of Japan's rice paddies (Tuttle 2013).

The interest in unmanned systems and the value they will bring to agriculture has increased over the past few years, with several companies developing systems to address the needs of modern precision agriculture. The next section discusses the current trends in UAVs and the regulatory nature of the industry.

### **3.2. CURRENT TRENDS FOR UAVS**

The commercial use of UAVs has slowly evolved over the past few years. As technology for the platforms and imagery systems advanced it became possible for smaller sized payloads to be used to gather data. There are several industries currently developing UAV technology or looking to utilize these systems in their operations. They include: police and security monitoring; UAV systems could be used to complement or replace security cameras and patrols. Disaster recovery and aid efforts: UAVs could be used to locate survivors and direct first responders to assist individuals after natural disasters. Delivery and logistics: rapid delivery of packages of which Amazon is pioneering. Filmmaking and journalism: The use of UAVs for less expensive aerial shots, and providing imagery for news reporting. This list of possible applications is not all encompassing and new uses are being developed everyday. There are many different areas that will benefit from the use of UAS.

The March 2013 Association for Unmanned Systems International (AUVSI) study on the economic impact of UAS integration concludes that the largest markets for UAS is public safety and agriculture. These two markets will make up approximately 90% of the known potential markets for UAS. They estimate the adoption and integration of UAS into the national airspace will contribute approximately \$82 billion to the nation's economy, and roughly 100,000 new jobs will be created between 2015 and 2025. UAS integration is expected to contribute \$75.6 billion economic impact by agriculture, \$3.2 billion by public safety and \$3.2 by other activities (AUVSI 2013).



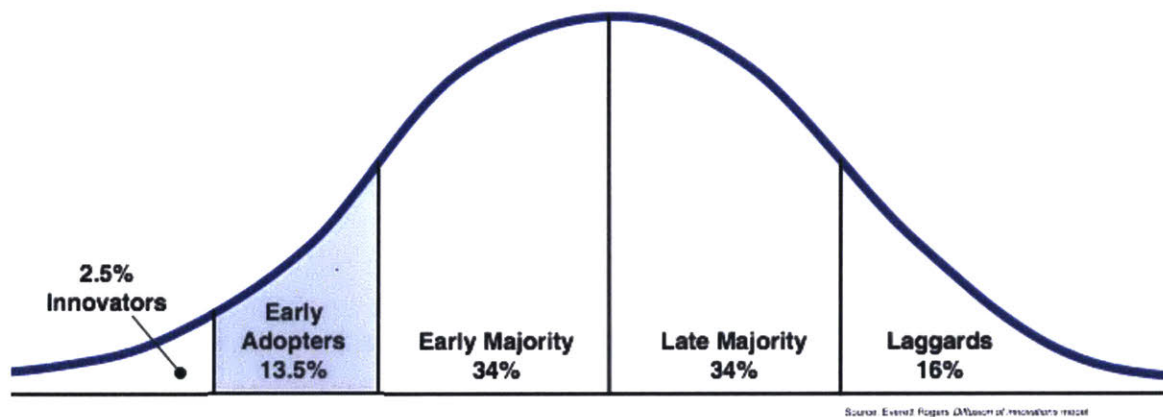
*Figure 6: AUVSI Market Predictions for Commercial UAV Adoption 2015-2025*

Most companies that are currently serving this market are small businesses and hobbyist developers. They are small start-ups that have been working with stakeholders and developers to learn firsthand what farmers want from these types of systems. Despite limited regulations these companies have been developing an established network of lead users and loyal followers. This network gives them an advantage in positioning once regulations are in place and the rules for operations are known.

While the current forecast for the UAS industry is promising, the adoption of this technology has been slow. This is not surprising as the acceptance of technological changes

generally start slow and increase as more people become involved with the technology. The adoption process involves five stages. The first stage is getting to know about the technology (knowledge); second, persuasion of the value of the technology; third, decision to adopt; four, implementation; and five, confirmation (rejection or reaffirmation) of the technology (Rogers 1995). The current industry is in the knowledge phase as information about these systems is disseminated through the Ag community.

The diffusion of innovation curve illustrates how new innovations are generally adopted by users as a function of time. The lead users and early adopters are on the far left side of curve. Individuals who start the process are the innovators and early adopters, who recognize an unfulfilled need and work to develop a solution (von Hippel 2011). The current Ag UAV industry is in the phase of early adoption where lead users and producers are working together to refine the systems, so that they provide the expected value. During this phase the early models are refined and a filtering process by peers and information sharing via social media occurs, resulting in improvement upon the successful models while discarding the failures.



*Figure 7: Diffusion of Innovation Curve*

The purpose of this thesis is to understand the lead users and stakeholders and explore the value they believe UAVs will provide for their farming operations. As the knowledge of these systems grows, and the value they provide is known, the greater the acceptance and adoption of

this technology will be. One of the driving factors for the slow adoption rate is the current state of regulation governing the use of unmanned systems in the national air space.

### 3.3. CURRENT REGULATIONS OBSTACLES

The market and acceptance for commercial unmanned aircraft has been slow to emerge, primarily due to the current state of federal regulations. The Federal Aviation Administration (FAA) is responsible for the safe operations of all aircraft within the U.S. airspace, and develops standards, rules regulations to enforce safety and air traffic control. The FAA Modernization and Reform Act of 2012, lays out the path for the safe integration of unmanned aerial systems into the National Airspace (NA). The figure below displays the timeline that this must occur in; by the end of 2015 the FAA must have rules in place ensure the safe operation of UAVs.

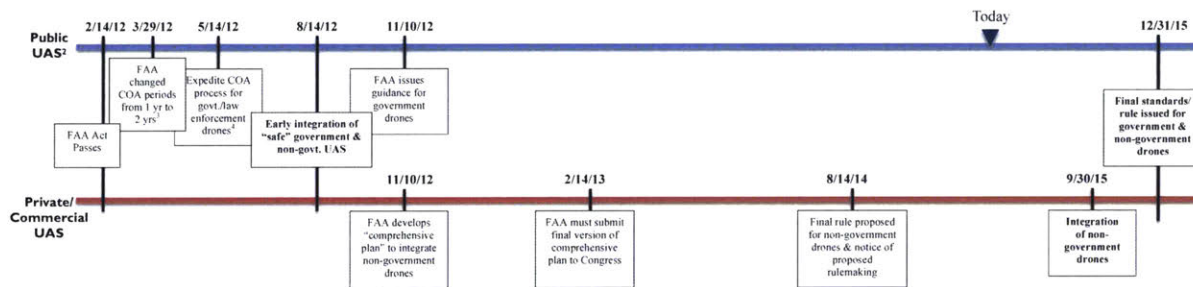


Figure 8: FAA Timeline for Integrating UAS into National Airspace

The current regulations are focused on federal, state and local government entities, and prohibit the use of UAS for commercial gain. Presently public entities must obtain a Certification of Authorization before flying in the National Airspace. This process can be very time consuming and is often done several months in advance of flight operations (FAA 2015). In order for the commercial application of UAVs to become a reality the agency must find a way to expedite or waive this process. Commercial UAS operations are currently governed by the same rules as model aircraft (FAA 2015). A sample of current rules:

- The aircraft is flown strictly for hobby or recreational use.
- The aircraft is operated in accordance with a community-based set of safety guidelines and within the programming of a nationwide community-based organization.
- The aircraft is limited to not more than 55 pounds unless otherwise certified through a design, construction, inspection, flight test, and operational safety program administered by a community-based organization.
- The aircraft is operated in a manner that does not interfere with and gives way to any manned aircraft.
- When flown within 5 miles of an airport, the operator of the aircraft provides the airport operator and the airport air traffic control tower ... with prior notice of the operation....

Section 336 of the FAA Modernization and Reform Act of 2012, “special rules for model aircraft” specifically addresses the use of UAS for commercial gain. “Any operation not conducted strictly for hobby or recreation purpose could not be operated under the special rule for model aircraft. Clearly, commercial operation would not be hobby or recreation flights.” This clarification rules out the ability of using these systems for monetary gain. The existing regulations are a severe obstacle to market and acceptance for commercial unmanned aircraft.

Recently, February 2015, the FAA proposed new rules for the operation of commercial UAS within the NAS. The proposed rules set the guidelines for operator qualifications and rules for operations. It also provides an exemption process for COA requirements for qualified organizations. A sample of the proposed rules for operations:

- Unmanned aircraft must weigh less than 55 lbs. (25 kg).
- Visual line-of-sight (VLOS) only, the unmanned aircraft must remain within VLOS of the operator or visual observer.
- Daylight-only operations (official sunrise to official sunset, local time).
- Must yield right-of-way to other aircraft, manned or unmanned.
- Maximum airspeed of 100 mph (87 knots).
- Maximum altitude of 500 feet (AGL) above ground level.
- Minimum weather visibility of 3 miles from control station.

Operators would be required to pass an initial aeronautical knowledge test, be vetted by the Transportation Security Administration and obtain an unmanned aircraft operator certificate with a small UAS rating (similar to pilot airman certificate), pass a recurrent aeronautical knowledge

exam every 24 months and be at least 17 years old (FAA NPRM 2015). The proposed rules also offer an exemption from the COA process for qualified businesses while the FAA approves permanent rules for the operation of commercial UAS in the National Airspace. While the current regulations are an obstacle for the civil UAS market the proposed rules are a step forward to providing stability for the market.

### **3.4. RESEARCH QUESTIONS REVISITED**

To refresh the reader, the original research question provided in Section One is revisited.

*How do producers, crop consultants and manufactures believe these systems will bring value at the various phases of the crop cycle?*

This thesis will attempt to understand the value proposition stakeholders believe these systems will bring and the utility they will provide for the various phases of the crop cycle. The crop cycle is broken into four distinct phases: planning, emergence, crop care, and harvest. Background on the precision agriculture and how UAVs fit into the thinking and techniques associated with the industry have been provided. In addition, examination of the role of innovation in agriculture and the impact on historical crop yields has been described. This thesis has also reviewed remote sensing and UAV history to provide background on these systems and why they have currently have potential for increased use. The remaining portion of this thesis will examine the relationships between stakeholders, and the value flow provided by Ag UAV systems. It will also explore the perceived value lead users feel these systems will provide.

## **4. STAKEHOLDER IDENTIFICATION AND VALUE FLOW**

This section will identify the stakeholders and what their needs and goals are for this system. It will also map out the value network of the system and discuss the relationships between the members involved. Finally this section will model the system using Object Process

Methodology (OPM) to demonstrate the connections between the various components, their form and function, and how those interfaces produce value for the stakeholder.

#### **4.1. DEFINING THE STAKE HOLDERS**

INCOSE defines stakeholders as a party having a right, share or claim in a system or in its possession of characteristics that meet that party's needs and expectations (INCOSE 2011). The stakeholders focused on for this thesis are: Farming Operation, Agronomist/Crop Consultant, UAV Manufacturer, Data Analysis Software Developer, Farm Material Supplier, Crop Insurance Companies, Regulatory Agencies, and the General Population. A stakeholder value network has been developed to understand the impact of both direct and indirect relationship between the members.

A stakeholder value network is a multi-relational network consisting of a focal organization, the focal organization's stakeholders, and the tangible and intangible value exchanges between the focal organization and its stakeholders, as well as between the stakeholders themselves (Eppinger 2011). In the image below there are 22 value flows between nine stakeholders with the relationships being centered on the farming organization. The different stakeholders are categorized into three different types: the focal organization, the market stakeholder and the non-market stakeholder. There are several varieties of value flow between the types of stakeholders. These include: policy, rules and regulations that impact the operation of these systems, money -- revenue exchanged between stakeholders and return on investment, technology -- the innovation and system being supplied, knowledge -- the information derived through the use of the technology, and finally the goods and services that flow between stakeholders. From the figure below it is possible to see the impact that the UAV system has on the other stakeholders, and the value flow from the data it provides.

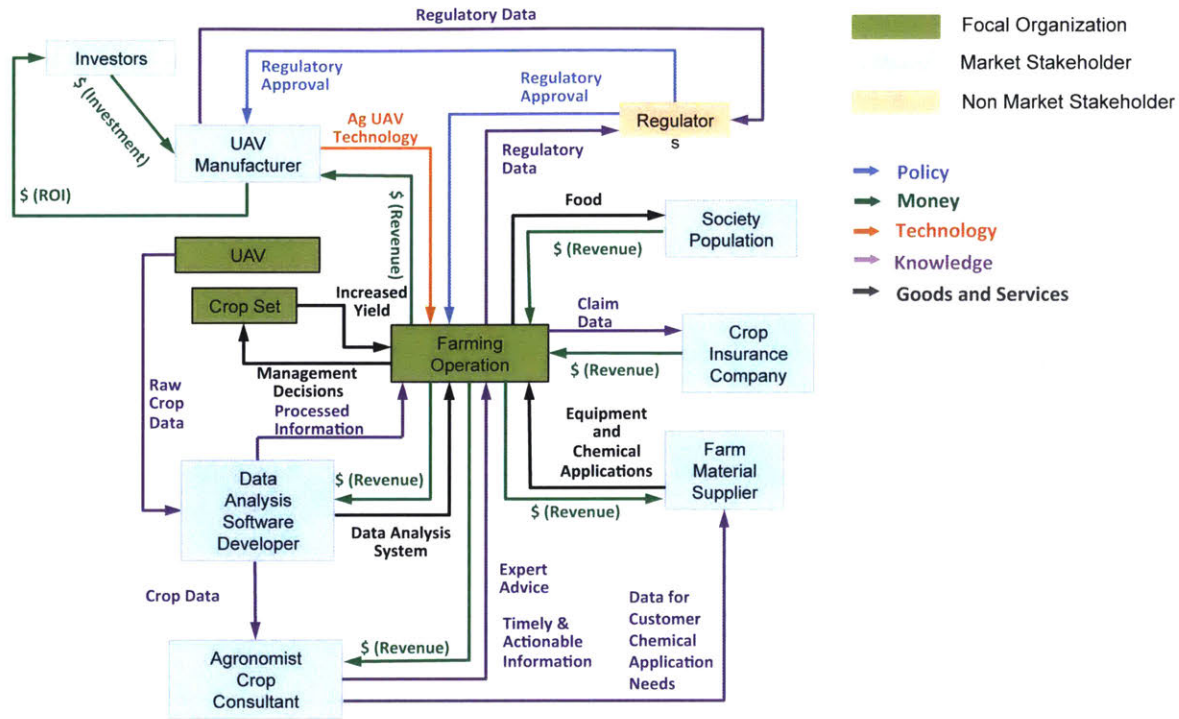


Figure 9: Stakeholder Value Network Diagram

The stakeholder value network provides a large-scale overview of the systems impact on the value flow between stakeholders. From the image above it is possible to see how this system creates value for more than just the farming operation. The next section decomposes the actual Ag UAV system and traces the value flow between the various components and how it delivers that value to the end user.

#### 4.2. OPM MODEL

A valuable system emerges with the combination of UAV technology, optical sensors, and digital imagery analysis software. A conceptual OPM model of a UAV remote sensing system has been developed to demonstrate the form and function value pathway of this type of system. This section will graphically display the relationships between the various forms and their functions and how those interactions produce value for the stakeholder.



#### **4.2.1. Introduction to OPM**

In order to understand and design complex systems, it is essential to have a language for developing models that can effectively and efficiently communicate what these systems do, why they do it, how they do it, and the form used to accomplish it. “Object Process Methodology is a comprehensive approach to systems engineering, it integrates function, structure, and behavior in a single unifying model. It is a bi-modal expression of the model via intuitive yet formal graphics, and equivalent natural language (Dori 2002).” Using a variety of symbols for objects, processes, states and types of connections, it is possible to visually display the interaction between components of a system. The system is first modeled at a very high conceptual level; then through “in-zooming” individual processes of the system are broken down into smaller and smaller interactions between components. The following diagrams use OPM to describe how a UAV remote sensing system delivers value across the components of the system.

#### **4.2.2. The Concept and System Boundary**

Concept is the high level mapping of function-to-form (Crawley and Cameron 2013). It requires an operand, a process and an instrument to deliver a solution. In order to fully understand the concept the boundary of the system problem space must be understood. The figure below presents the concept and the system boundary and displays how each element interacts and provides value to the stakeholder.

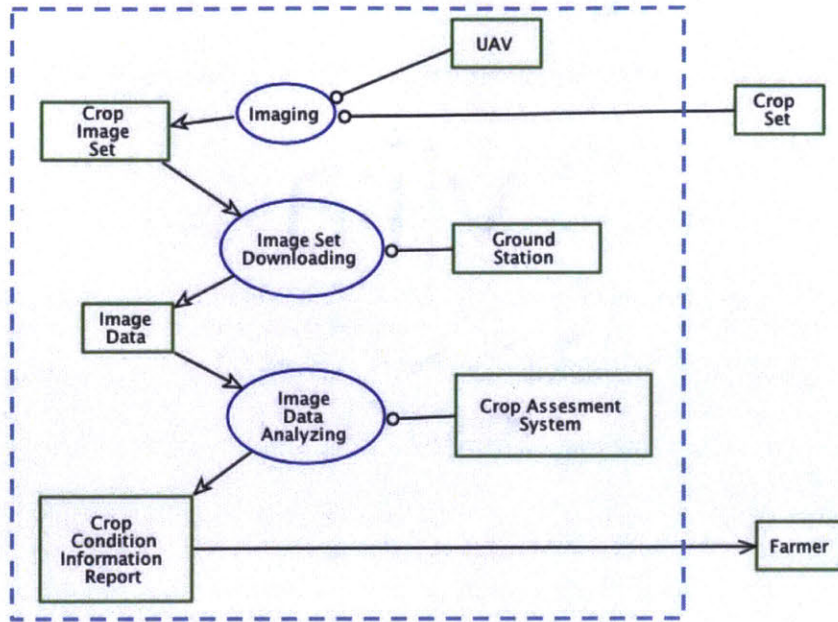


Figure 10: System Boundary Diagram

The image clearly shows how the instrument, (UAV), and the process, (imaging) impact the operand (crop image set). The crop image set goes through the process of image downloading using the ground control station, and is then analyzed using the crop assessment system (instrument) resulting in a report on the crop condition. This is the generic value path for this system; the next section breaks down the concept into various layers and provides more detail on the interaction between components.

#### 4.2.3. High Level System Diagram

The first step of an OPM model is to determine the main process or function of the system and use it as a center point for the rest of the model. Crop condition monitoring will be the process used for the Ag UAV system. The OPM model consists of several levels of Object Process Diagrams (OPDs) and their subsequent Object Process Language (OPL). The top level is labeled the System Diagram (SD), and displays the highest-level view of the crop monitoring system.

As shown in the figure below, the purpose of the system is to allow the farm manager to become informed about the condition of a crop set in a geographical area. The crop condition appraising system consists of three high level components: a UAV system that is composed of an air vehicle used to gather information about the crop set, a ground control station that is used to operate the system, the crop image analysis system that is used to analyze and process the imagery, and a cloud server which is used to store and access crop information and data reports. The process of crop condition monitoring will inform the farm manager about the condition of the crop set.

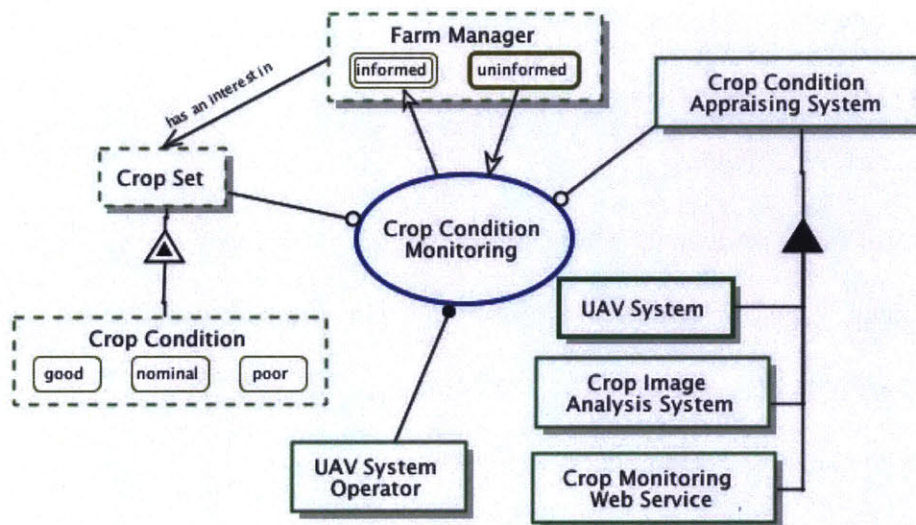


Figure 11: System Diagram for Ag UAV System

Crop Set is environmental and physical.

Crop Set exhibits Crop Condition.

Crop Condition is environmental.

Crop Condition can be good, nominal, or poor.

Farm Manager is environmental and physical.

Farm Manager can be informed or uninformed.

informed is final.

uninformed is initial.

Farm Manager has an interest in Crop Set.

Crop Condition Appraising System is physical.

Crop Condition Appraising System consists of UAV System, Crop Image Analysis System, and Crop Monitoring Web Service.

UAV System is physical.

Crop Image Analysis System is physical.

Crop Monitoring Web Service is physical.

UAV System Operator is physical.

UAV System Operator handles Crop Condition Monitoring.

Crop Condition Monitoring requires Crop Condition Appraising System and Crop Set.

Crop Condition Monitoring changes Farm Manager from uninformed to informed.

#### **4.2.4. Detailed System Diagram**

The following sections will be used to model and describe the lower-level system characteristics of the crop condition monitoring system. As shown in the figure below, the process of crop condition monitoring decomposes into the following sub process:

1. System Initializing and Launching
2. Crop Image Gathering
3. UAV Recovery and Data Downloading
4. Crop Condition Information Computing
5. Crop Condition Communicating

These sub process occur sequentially and the output of one process leads to the next. For example crop image gathering results in a crop image set, which is used by the crop condition information computing sub-process. The following sections will “in-zoom” on each of these sub-process to provide an in-depth understanding of the system.

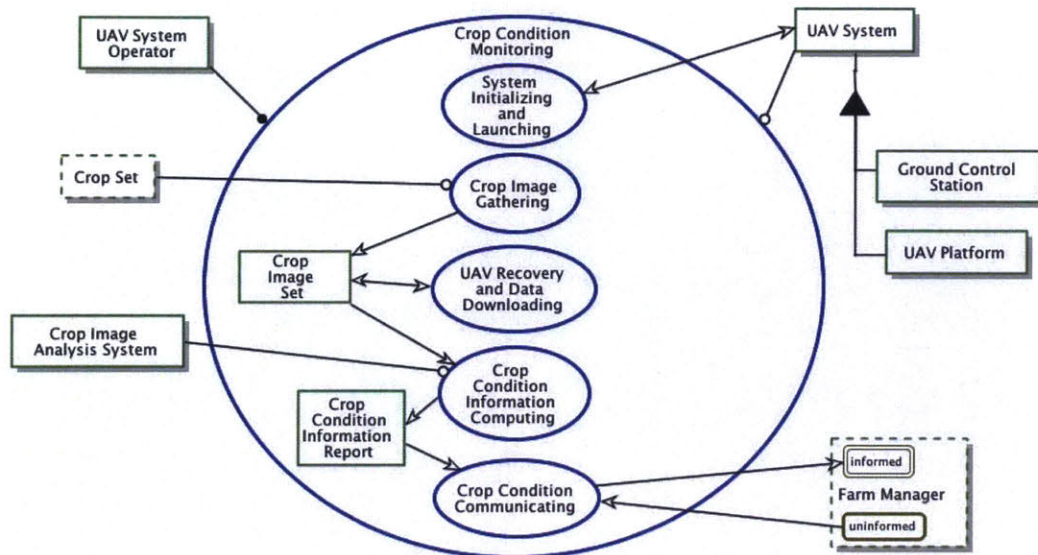


Figure 12: Crop Condition Monitoring

Crop Set is environmental and physical.

Farm Manager is environmental and physical.

Farm Manager can be informed or uninformed.

informed is final.

uninformed is initial.

UAV System is physical.

UAV System consists of Ground Control Station and UAV Platform.

Ground Control Station is physical.

UAV Platform is physical.

Crop Image Analysis System is physical.

UAV System Operator is physical.

UAV System Operator handles Crop Condition Monitoring.

Crop Condition Monitoring requires UAV System.

Crop Condition Monitoring zooms into System Initializing and Launching, Crop Image Gathering, UAV Recovery and Data Downloading, Crop Condition Information Computing, and Crop Condition Communicating, as well as Crop Condition Information Report and Crop Image Set.

System Initializing and Launching affects UAV System.

Crop Image Gathering requires Crop Set.

Crop Image Gathering yields Crop Image Set.

UAV Recovery and Data Downloading affects Crop Image Set.

Crop Condition Information Computing requires Crop Image Analysis System.

Crop Condition Information Computing consumes Crop Image Set.

Crop Condition Information Computing yields Crop Condition Information Report.

Crop Condition Communicating changes Farm Manager from uninformed to informed.

Crop Condition Communicating consumes Crop Condition Information Report.

#### 4.2.5. System Initializing and Launching In-Zoom

Figure 14 depicts the system initializing and launching process for the crop condition monitoring system. Both the ground control station and UAV must be initialized and the

camera/sensor and Global Positioning System (GPS) must be calibrated before the system operations.

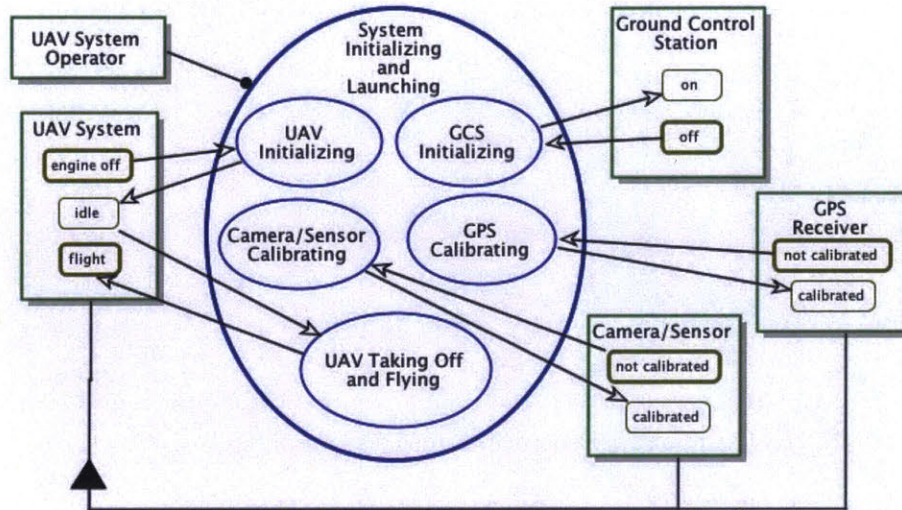


Figure 13: System Initializing and Launching

UAV System is physical.

UAV System can be engine off, idle, or flight.

engine off is initial.

flight is initial.

UAV System consists of Camera/Sensor and GPS Receiver.

Camera/Sensor is physical.

Camera/Sensor can be not calibrated or calibrated.

not calibrated is initial.

GPS Receiver is physical.

GPS Receiver can be calibrated or not calibrated.

not calibrated is initial.

Ground Control Station is physical.

Ground Control Station can be on or off.

off is initial.

UAV System Operator is physical.

UAV System Operator handles System Initializing and Launching.

System Initializing and Launching zooms into GCS Initializing, UAV Initializing, GPS Calibrating, Camera/Sensor Calibrating, and UAV Taking Off and Flying.

GCS Initializing changes Ground Control Station from off to on.

UAV Initializing changes UAV System from engine off to idle.

GPS Calibrating changes GPS Receiver from not calibrated to calibrated.

Camera/Sensor Calibrating changes Camera/Sensor from not calibrated to calibrated.

UAV Taking Off and Flying changes UAV System from idle to flight.

#### 4.2.6. Crop Image Gathering In-Zoom

Figure 15 illustrates the “in-zooming” of the crop image gathering process. The ground control station is used to control the UAV and camera/sensor and capture images. This action results in the generation of a crop image set that will then be downloaded and analyzed.

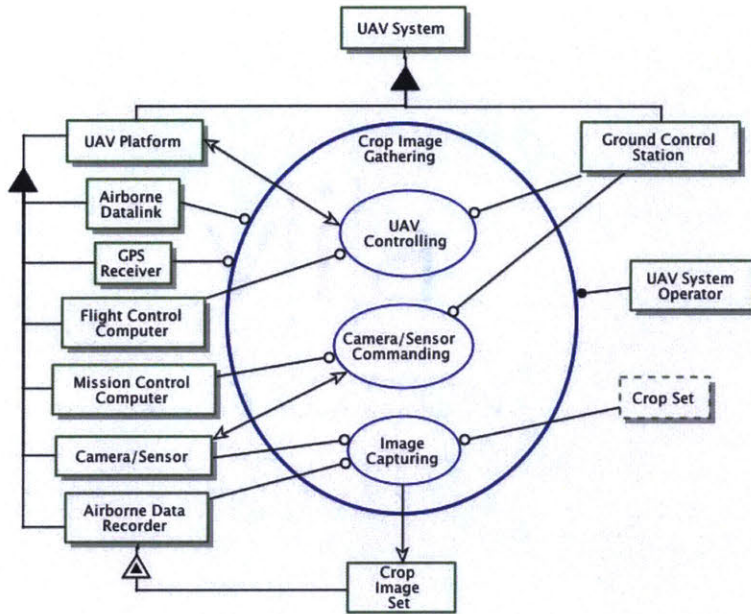


Figure 14: Crop Image Gathering

Crop Set is environmental and physical.

UAV System is physical.

UAV System consists of Ground Control Station and UAV Platform.

Ground Control Station is physical.

UAV Platform is physical.

UAV Platform consists of Camera/Sensor, GPS Receiver, Airborne Datalink, Flight Control Computer, Mission Control Computer, and Airborne Data Recorder.

Camera/Sensor is physical.

GPS Receiver is physical.

Airborne Datalink is physical.

Flight Control Computer is physical.

Mission Control Computer is physical.

Airborne Data Recorder is physical.

Airborne Data Recorder exhibits Crop Image Set.

UAV System Operator is physical.

UAV System Operator handles Crop Image Gathering.

Crop Image Gathering requires Airborne Datalink and GPS Receiver.

Crop Image Gathering zooms into UAV Controlling, Camera/Sensor Commanding, and Image Capturing.

UAV Controlling requires Ground Control Station and Flight Control Computer.

UAV Controlling affects UAV Platform.

Camera/Sensor Commanding requires Ground Control Station and Mission Control Computer.

Camera/Sensor Commanding affects Camera/Sensor.

Image Capturing requires Camera/Sensor, Crop Set, and Airborne Data Recorder.

Image Capturing yields Crop Image Set.

#### 4.2.7. UAV Recovery and Data Downloading

Figure 16 depicts the recovery of the UAV and the downloading of the crop image set. The UAV state changes from inflight to land and the crop image set state changes from collected to downloaded. The UAV operator is the agent responsible for these actions.

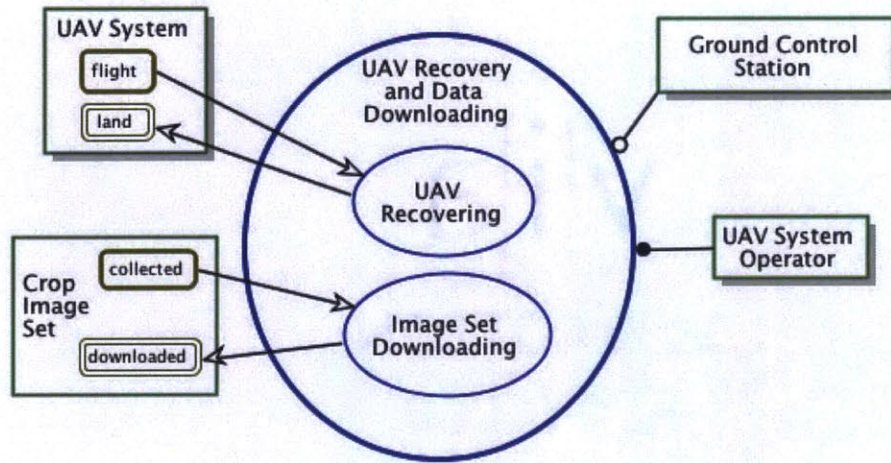


Figure 15: UAV Recovery and Data Downloading

UAV System is physical.

UAV System can be flight or land.

flight is initial.

land is final.

Crop Image Set can be collected or downloaded.

collected is initial.

downloaded is final.

Ground Control Station is physical.

UAV System Operator is physical.

UAV System Operator handles UAV Recovery and Data Downloading.

UAV Recovery and Data Downloading requires Ground Control Station.

UAV Recovery and Data Downloading zooms into UAV Recovering and Image Set Downloading.

UAV Recovering changes UAV System from flight to land.

Image Set Downloading changes Crop Image Set from collected to downloaded.

#### 4.2.8. Crop Condition Information Computing In-Zoom

Figure 17 represents the “in-zooming” of the crop condition information computing process. In this process, the images of the crop image set are assigned control points and GPS coordinates. The geo-referenced image set undergoes digital processing were it goes through



several process of image enhancing, classifying, transforming, and rendering to display the false color association with NDVI to depict areas of plant stress. The processed image set is then gathered and formatted to generate the crop condition information report.

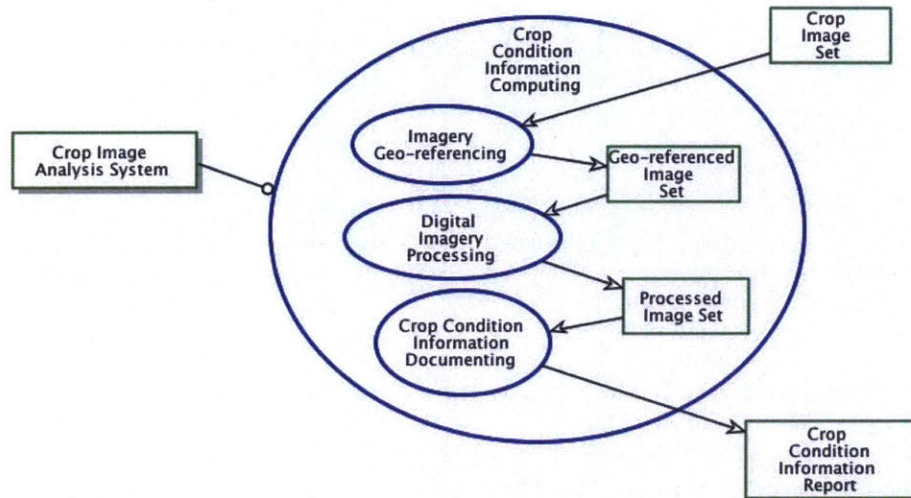


Figure 16: Crop Condition Information Computing

Crop Image Analysis System is physical.

Crop Condition Information Computing requires Crop Image Analysis System.

Crop Condition Information Computing zooms into Imagery Geo-referencing, Digital Imagery Processing, and Crop Condition Information Documenting, as well as Processed Image Set and Geo-referenced Image Set.

Imagery Geo-referencing consumes Crop Image Set.

Imagery Geo-referencing yields Geo-referenced Image Set.

Digital Imagery Processing consumes Geo-referenced Image Set.

Digital Imagery Processing yields Processed Image Set.

Crop Condition Information Documenting consumes Processed Image Set.

Crop Condition Information Documenting yields Crop Condition Information Report.

#### 4.2.9. Crop Condition Communicating

The figure below depicts the process of crop condition communicating. The crop condition information report is uploaded via the cloud, for report displaying on the report web page. The web page allows the farm manager access to the report and gives them the ability to navigate and filter the report as they see fit. The final outcome of the system is changing the farm manager’s knowledge of their crop condition from uninformed to informed.

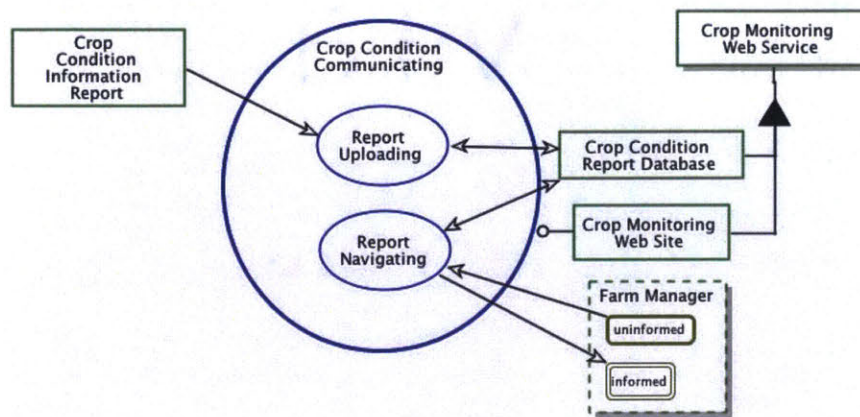


Figure 17: Crop Condition Communicating

Farm Manager is environmental and physical.

Farm Manager can be informed or uninformed.

informed is final.

uninformed is initial.

Crop Monitoring Web Service is physical.

Crop Monitoring Web Service consists of Crop Condition Report Database and Crop Monitoring Web Site.

Crop Condition Communicating requires Crop Monitoring Web Site.

Crop Condition Communicating zooms into Report Uploading and Report Navigating.

Report Uploading affects Crop Condition Report Database.

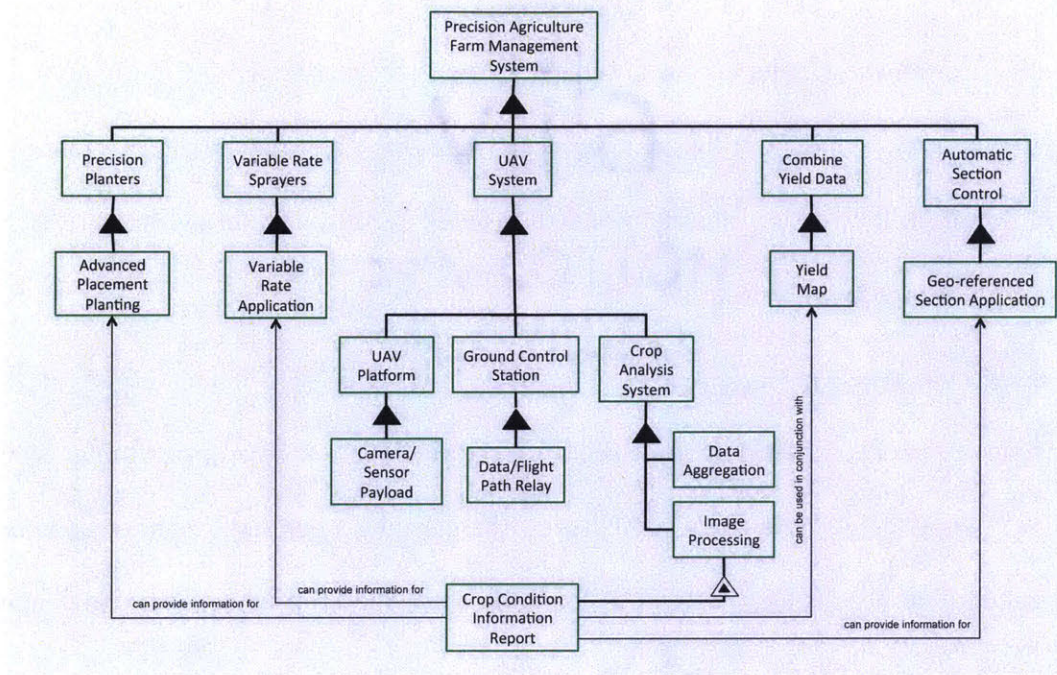
Report Uploading consumes Crop Condition Information Report.

Report Navigating affects Crop Condition Report Database.

Report Navigating changes Farm Manager from uninformed to informed.

#### 4.2.10. Crop Condition Monitoring and Modern Farming Decomposition

The system decomposition illustrates the high-level design elements that are necessary for the value transition between components within the system and how it delivers value in the form of information about the crop condition to the farmer. The diagram below illustrates how this type of system and integrates into the modern farming technology and practices described in section one. The crop management system that uses precision Ag techniques and technology can be decomposed into several different layers. The information provided by the Ag UAV system can be utilized by many different technologies to improve the efficiency of crop management for the farming operation.



*Figure 18: System Integration into Modern Farming Technology*

Precision Agriculture Farm Management System consists of Precision Planters, Variable Rate Sprayers, Combine Yield Data, UAV System, and Automatic Section Control.

Precision Planters consists of Advanced Placement Planting.

Variable Rate Sprayers consists of Variable Rate Application.

Combine Yield Data consists of Yield Mapping.

UAV System consists of UAV Platform, Ground Control Station, and Crop Analysis System.

UAV Platform consists of Camera/Sensor Payload.

Ground Control Station consists of Data/Flight Path Relay.

Crop Analysis System consists of Data Aggregation and Image Processing.

Image Processing exhibits Crop Condition Information Report.

Crop Condition Information Report can provide information for Advanced Placement Planting.

Crop Condition Information Report can provide information for Geo-referenced Section Application.

Crop Condition Information Report can provide information for Variable Rate Application.

Crop Condition Information Report can be used in conjunction with Yield Mapping.

Automatic Section Control consists of Geo-referenced Section Application.

This section explored the value flow provided by an Ag UAV between the various stakeholders, and how it integrates into the modern farming operations. It also modeled the value flow between form and function of the system itself and how it provides information about the crop condition to the end user. The next section will explore the value proposition stakeholders believe these systems will bring and the utility they will provide for the various phases of the crop cycle.

## **5. SURVEY FINDINGS AND ANALYSIS**

In this section the results of the multi tier survey (Appendix A) will be analyzed in an attempt to better understand how the stakeholder's perceive the value of these systems. This section will report on the survey findings and will provide specific insight on the various phases of the crop cycle according to lead users.

### **5.1. SURVEY AND PARTICIPANTS**

The survey was composed of three sections; the first section determined the participant's level of UAV knowledge, as well as the size of the farming operation. The second section focused on the value proposition across the four phases of the crop cycle. The third and final section focused on current systems use by lead users.

The survey was distributed through several different networks: several county agricultural extension agencies throughout states in the Midwest, multiple agricultural UAV forums on social media, and the Kansas Ag Research and Technology Association's annual conference. The survey had fifty-seven responses, across multiple crop specialties and various farm sizes.

The survey was designed to determine how each stakeholder measures the value of the data provided by UAVs for remote sensing and crop management decisions across each of the four phases of the crop cycle.

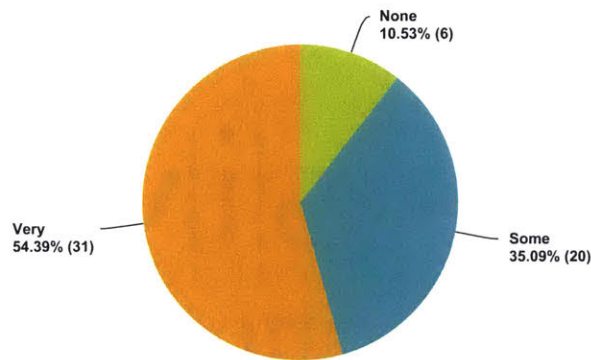
### **5.2. SECTION I: UAV KNOWLEDGE AND FARM SIZE**

The first section determined the participant's familiarity with UAV systems, as well as the size of their farming operation. This information is important in understanding their level of knowledge about these systems, as well as determining if there is a correlation between farm size

and technology awareness. It also provides a better understanding of how involved the lead users are in learning and adopting the technology.

**5.2.1. Question #1: What is your familiarity with Ag UAV technology?**

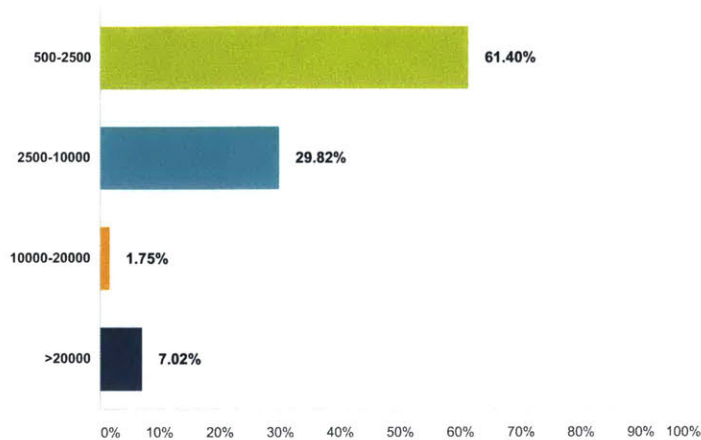
This question is important in determining the knowledge level of the participants, and their exposure to this type of technology. Fifty-seven participants completed the survey, of those, 55% (31) are very familiar with UAV technology, while 35% (20) had some familiarity and only 10% (6) had no familiarity.



*Figure 19: Knowledge Level of Ag UAV Technology*

**5.2.2. Question #2: What is the size of your farming operation (number of acres)?**

This question is essential in determining if the size of farming operations has an impact on the acceptance of UAV technology and the perceived value across the crop phases. From Figure 21 below, 61% (35) of respondents are associated with farm operations between 500-2500 acres, 30% (17) had farms that were between 2500-10000 acres and the largest farming operations 10,000-20,000 acres and greater than 20,000 were 1% (1) and 7% (4) respectively.



*Figure 20: Responses per Farming Operation Size*

### **5.2.3. Summary of Section I**

The purpose of this section of the survey was gauge the Ag UAV knowledge level of the participants as well as to determine if farm-operating size had an impact on the familiarity of the technology. By breaking down the knowledge level according to farm size it is possible to see that the knowledge level does increase with the number of acres. Figure 22 below depicts the level of UAV familiarity according to the number of acres. A majority of respondents with no familiarity belonged to smaller farm operations. Even though they were the largest sample size they still made up the majority of respondents with no familiarity of UAV systems. As the farm operation size increased so did the level of familiarity. While the sample size is smaller, the familiarity level for mid to large size farms increases as the acreage increases.

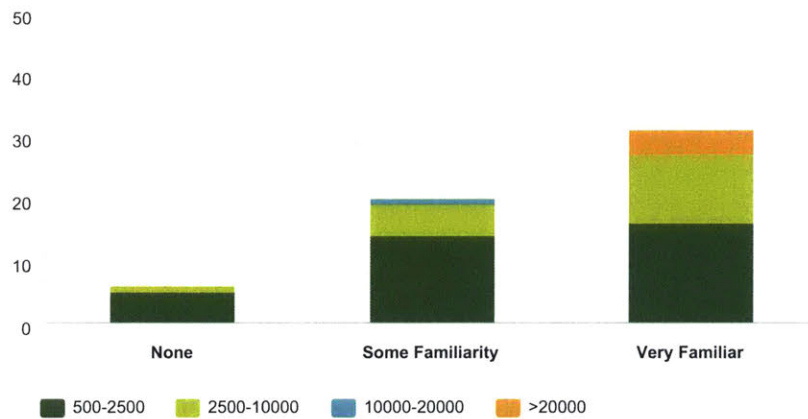


Figure 21: Knowledge Level and Farm Operation Size

### 5.3. SECTION II: CROP PHASE VALUE

The second section focused on the value proposition across the four phases of the crop cycle. The participants were first asked what information is important for crop management decisions for that phase and then several images and data from current UAV systems were displayed for that respective phase of the crop cycle. The participants were then asked to provide a rank (1-7 low to high), to determine how important the data would be influencing management decisions during that phase.

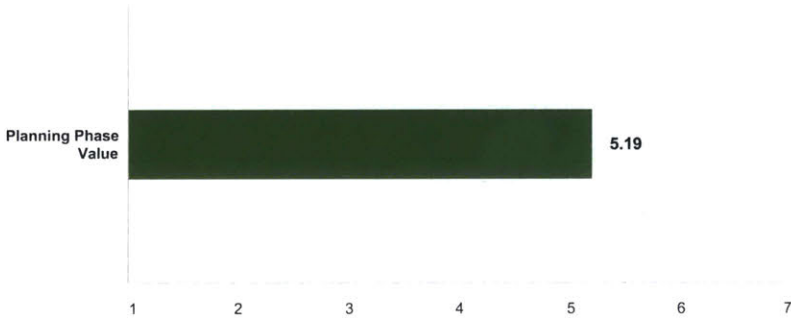
#### 5.3.1. Question #3: What kind of information would you require from a UAV for the crop-planning phase?

This question is critical in determining what stakeholders consider essential information for the planning phase. This phase includes decisions about crop rotation, placing fields into fallow, and cover crop planting choices. The most common responses were centered on variable rate applications (49%) for field preparation for the next crop cycle; specifically for pre-emergence chemical application and weed control. The second most common response was farm research (37%) with focus on field conditions such as: drainage, erosion and terrace conditions.

The third highest response (24%) was for the need to determine cover crops and field residue related to previous crop and/or weed cover concentration.

**5.3.2. Question #4: After reviewing imagery samples of data provided by UAVs; participants were asked how valuable might that information be in making management decision during the planning phase?**

In Question #3, participants provided a list of information they felt would be useful for the planning phase. In Question #4, they were provided a sample of field images and asked to rate the value of that information and why. On a scale of 1 to 7, with 1 having no value and 7 being very valuable, the average ranking value was 5.19 as seen in the image below.



	1	2	3	4	5	6	7	Total	Weighted Average
Planning Phase Value	1.75% 1.00	1.75% 1.00	12.28% 7.00	14.04% 8.00	19.30% 11.00	31.58% 18.00	19.30% 11.00	57	5.19

Basic Statistics				
Minimum	Maximum	Median	Mean	Standard Deviation
1.00	7.00	6.00	5.19	1.46

*Figure 22: Value Proposition for Planning Phase*

The responses to why they ranked the images and data they way they did provide more insight to the information provided in Question #3. Field conditions and weed cover were the top responses with variable rate being slightly lower on the list. A collective response was the data provided them site specific information on where to focus their resources. According to the participants, having the ability to pinpoint trouble spots in the field would save them time and money, by “effectively using resources to include herbicide, tractor time and clearing time”.



Another common thread from the responses was “the ability to have a realistic understanding of what’s going on with the entire field, this is something that is difficult otherwise since don't have an aerial view”. By having a complete overview of the field, the lead users believe that they can develop better management plans before committing resources to the field, which in turn gives them an advantage at improving crop performance and reducing waste.

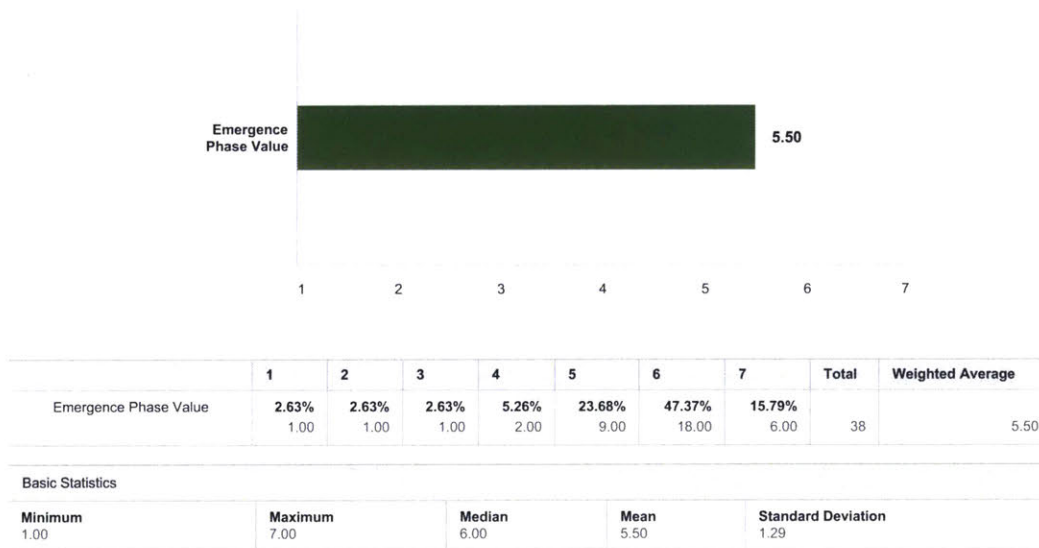
### **5.3.3. Question #5: What kind of information would be required from a UAV system for the emergence phase?**

This question is important in determining what stakeholders consider essential information for the management decisions following the initial emergence of their crop. These early management decisions have the largest impact on crop health and yield. The emergence phase requires an understanding of stand count and emergence, uniformity of emergence, early crop development, weed coverage, crop health, and decisions for reseeding.

The participant’s responses were concerned primarily with reseeding (54%), stand count (34%), and uniformity of emergence (31%). While stand count was limited to 34% of the responses a majority of the comments stress the importance of stand count before making re-seeding decisions. “To be able to accurately evaluate stand count at emergence or shortly thereafter would be beneficial for re-planting”. Other factors that were significant for this phase include stage growth development, water stress and rainfall impacts on young plants, as well as capturing imagery that displays weed development and insect infestations and the early signs of plant stress associated with them. The following comment best summarizes the information the stakeholders believe will be useful for early crop development. “How well the crop is emerging, if there are weak areas that need more irrigation and fertilizer. It would be nice to catch those areas early”.

**5.3.4. Question #6: After reviewing imagery samples of data provided by UAVs of a field shortly after planting; participants were asked how valuable might that data be in making field management decisions during the emergence phase?**

In Question #5, participants provided information they felt would be useful for making management decisions during the emergence phase. In Question #6, they were provided a sample of field images and asked to rate the value of that information and why, the average ranking value was 5.50 as seen in the figure below.



*Figure 23: Value Proposition for Emergence Phase*

The participants felt that the information provided for this phase “could be very valuable information as early development of a crop is the easiest time to fix potential problems”. A shared focus of the contributors was on planter performance, particularly the ability to see where sections of seeding were skipped. The imagery is valuable because it provides an overview and a starting point where they can focus their attentions on the areas that need improvements. “It gives the ability to diagnose issues & change fertility and or pest control for regions of the field, or at least prepare for herbicide application.”

There were several shortcomings to the imagery that potentially reduce the value of the

data. The resolution of the current imagery does not allow for stand counts (plants per acre) which is important in developing an understanding of field fertility conditions and plant growth progress. Once again the desire for ground truth is an important factor in limiting the perceived value of information for this phase. A unique observation for this phase that is important to consider is the variable germination rates of some crops. Some plants germinate later than others and will eventually catch, but multiple flights will be required to verify that the crop emergence is progressing correctly.

#### **5.3.5. Question #7: What kind of information would you require from a UAV for the crop care phase?**

This question is necessary to understand what type of information lead users would need to make better management decisions during the “heart” of the growing season. During this phase, the crop undergoes a majority of its development, and requires multiple inputs such as fertilizer, irrigation and pest management to ensure optimal growing conditions.

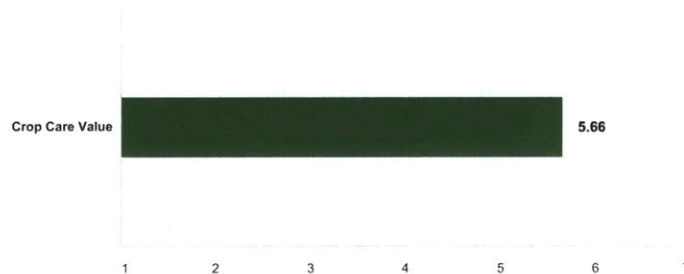
The top response for Question #7 with over 65% of those surveyed, was the ability to recognize areas of fertilizer deficiency and determine locations for optimal fertilizer application. Another mutual topic discussed in the responses was the ability to realize the impact of irrigation and water stress on the crop. A majority of the comments, (58%) referred to irrigation and water management, with pest control (50%) and weed management (38%) being the next most common subjects.

There were several unique comments with this question. One participant from California was mainly concerned with temperature plots for their field to determine where the irrigation was hitting and having the ability to identify any major leaks. This is extremely important for producers in areas suffering from drought conditions. Another distinctive response centered on having the ability to understand the extent of damage caused by wind and hail storms.

The following quote summarizes the responses for this question: “Identifying stresses early enough for mitigation is important, it would be nice to be able to pinpoint exact areas that require extra attention before they become a total loss.”

**5.3.6. Question #8: After reviewing imagery samples of data provided by UAVs; participants were asked how valuable might that data be in making crop care (chemical/fertilizer application, irrigation, pest management) management decisions?**

In Question #7, participants provided a list of information they felt would be useful for making management decisions during the growing season. In Question #8, they were provided sample of field images and asked to rate the value of that information and why. On a scale of 1 to 7, with 1 having no value and 7 being very valuable, the average ranking value was 5.66 as seen in the figure below.



	1	2	3	4	5	6	7	Total	Weighted Average
Crop Care Value	0.00% 0.00	5.26% 2.00	5.26% 2.00	13.16% 5.00	10.53% 4.00	26.32% 10.00	39.47% 15.00	38	5.66
Basic Statistics									
Minimum	Maximum		Median		Mean		Standard Deviation		
2.00	7.00		6.00		5.66		1.49		

*Figure 24: Value Proposition for Crop Care Phase*

The participants gave this phase the highest rated perceived value of the crop cycle. The information provided for this phase “can quantify the amount of a field effected by disease/insects/fertility which can help make the decision making process much more accurate and efficient. It will be useful for targeting inputs to where they are most required and better

understanding the performance of different management zones.” They also felt this information would be valuable to adjust irrigation schedules as well as recognize nozzles that are not performing properly. The overall consensus after viewing the imagery was “if the right amount of chemical/fertilizer can be determined based on quick UAV images they could boost yield and save money on chemical, and reduce the impact on the local environment by applying exactly what is needed rather than a base rate.

There were several noteworthy remarks associated with this question. The first is a long-term approach to the data collected during this phase and how it can be used in conjunction with yield maps to develop variable rate application maps for next season. The premise is to use yield maps from harvest to provide feedback on adjustments made using the UAV data during the growing season to narrow down and optimize applications and input changes for future crops. The second was a suggestion to improve the sensors and data currently provided. “The use of a thermal sensor to show hot spots that correlates to crop disease and possible issues that could be corrected with localized fungicide application.”

In summary there are a lot of input changes that can be made with this type of data. While there is room for improvement, the respondents feel that this data can impact yield; with prompt input changes that deal with the problem and minimize losses early on.

#### **5.3.7. Question #9: What kind of information would you require from a UAV for the harvest phase?**

This question is required to determine what type of information would be needed to make assessments during the harvest phase. Some of the decisions made during this phase include determining field readiness for harvest and moisture content of the crop.

The most common response to this question was field readiness (60% of responses), understanding the variation of crop readiness through out the field in order to determine how

soon they can begin harvesting. Another shared theme was use of the information for budgeting and planning, being able to prepare for harvest proactively instead of reactively. There were several distinctive responses to the question that concentrated on the ability to make predictive measurements of the potential yield and use that information to better market the crop. “Pre harvest expected yield maps, I envision about month before harvest you could fly a field and then follow areas up with hand yield check in good, average, and poor areas to get an approximate yield report so you could market more grain.” One of the common desirables stated for this phase was using the information from over the course of the growing cycle to make estimates on yield. “Moisture and yield correlations to NDVI index would be awesome, would allow for field readiness along with giving insights to the estimated product which might assist in grain marketing.”

**5.3.8. Question #10: After reviewing imagery samples of data provided by UAVs of a field nearing harvest; participants were asked how valuable might that information be in making management decisions for harvest.**

In Question #9, participants provided a list of information they felt would be useful for the harvest phase. In Question #10, they were provided a sample of field images and asked to rate the value of that information and why. On a scale of 1 to 7, with 1 having no value and 7 being very valuable, the average ranking value was 4.88 as seen in the image below.

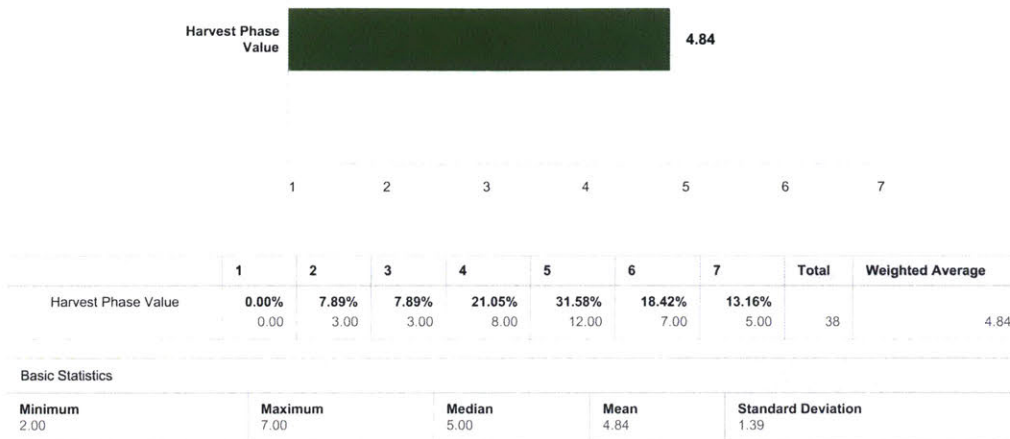


Figure 25: Value Proposition for Harvest Phase

The perceived value for harvest has the lowest score of the various phases. There were common themes among the responses, with the primary focus being on determining field readiness for harvest. Several participants see value in using the system to determine which of their multiple fields are ready and those that may need more time to ripen. They would use this information to decide where to start, and plan the field order for harvest. “Would give you a head start on knowing if a field would be ready quickly or would be lagging behind, and you could compare to other fields and determine which is most ready.” They also expressed the desire to gather information on the state of whole field readiness versus the part of the crop that is ready closest to the edge.

One of the more unique observations about the value provided for the harvest phase was associated with farming blueberries. “If you use the system to make a choice between hand harvest and machine harvest with Blueberries this could be huge. I can get roughly two times the money for hand harvest berries but it cost more. If I know where my best blueberries are, I will

hand harvest those and machine harvest the rest.” This response suggests that there may be different perceived value for different types of crops.

### **5.3.9. Summary of Section II**

The purpose of Section II of the survey was to determine how the proposed value of Ag UAV systems changes across the various phases of the crop cycle. By dividing up the crop cycle, it is possible to see which phase will have the largest impact from the system. The phases with the highest proposed value include the crop care phase, with a score of 5.66 and the emergence phase with a score of 5.50. The planning phase and harvest phase had the lowest scores of 5.19 and 4.84 respectively.

The primary value delivered for the planning phase was the ability to determine field conditions that would impact the next crop. Specifically, focusing on conditions such as drainage, erosion and terrace damage as well as determining the amount of field residue related to the previous crop and/or weed cover concentration. The most value was found in using the imagery for making decisions about preparing the field for the next crop cycle. A common thread throughout the responses for this phase was the need for ground truth. The information was useful, but still required an onsite investigation. The UAV imagery provided actionable intelligence on where to look, but there is still the need to inspect those sites in person. There is still a degree of guesswork associated with imagery, and currently getting the “proper interpretation” of the data can be a challenge.

The leading proposed value for the emergence phase is the desire to have the capability to accurately evaluate stand count at emergence or shortly thereafter for decisions about re-planting. The imagery is valuable because it provides an overview and a starting point to focus



attention on the areas that need improvements. “It gives the ability to diagnose issues & change fertility and or pest control for regions of the field, or at least prepare for herbicide application.”

Other factors that were significant for this phase also include stage growth development, water stress and rainfall impacts on young plants, as well as capturing imagery that displays weed development and insect infestations and the early signs of plant stress associated with them. There were shortcomings in the value provided by the imagery, current resolution does not allow for stand counts (plants per acre) which is important in developing an understanding of field fertility conditions and plant growth progress. Once again the desire for ground truth is an important factor in limiting the perceived value of information for this phase.

The primary value associated with the crop care phase is the ability to recognize areas of fertilizer deficiency and determining locations for optimal fertilizer application, as well as the ability to realize the impact of irrigation and water stress on the crop. A secondary value is the ability to quickly identify pest and weed infestations and make timely, accurate and efficient management decisions based on that information. One participant from California was mainly concerned with temperature plots for their field to determine where the irrigation was hitting and having the ability to identify any major leaks. This is extremely important for producers in areas suffering from drought conditions. Another distinctive response centered on having the ability to understand the extent of damage caused by wind and hail storms. While the current sensors provide actionable data there were several suggestions to improve the value by the addition of thermal sensors to show hot spots that correlates to various crop diseases and fungus infestations.

The harvest phase had the lowest score, primarily due to the fact that it is relatively easy to determine when a field is ready for harvest, and very little can be done to change the conditions of the field or impact the yield at this point in the crop cycle. There value associated

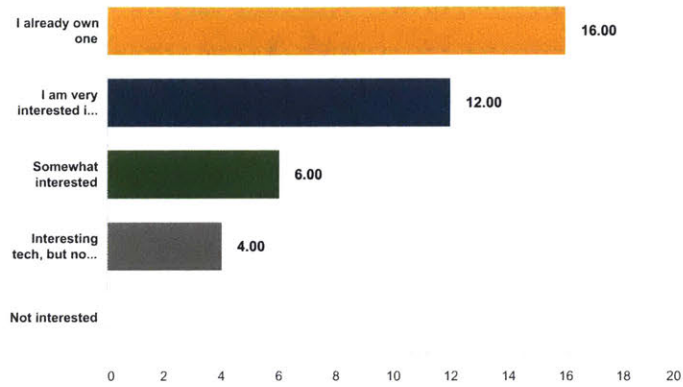
with this phase was centered on the ability to understand the variation of crop readiness throughout the field in order to determine how soon harvest can begin. This was extremely valuable when considering multiple fields and deciding which are ready and which may need more time to ripen. There were shortcomings in the value provided by the imagery one of the common desirables stated for this phase was using the information to determine moisture content of the crop and to use that information to make estimates on yield. This information would be very valuable to provide insight on how to best market their crop.

#### **5.4. SECTION III: CURRENT UTILIZATION**

The third and final section focused on current systems use by lead users to determine how they would utilize the systems if cost were not a factor. It also aimed to determine if exposure to the data provided by these systems would stimulate interest in their use and provide the participant an opportunity to describe their ideal system and use case scenario.

##### **5.4.1. Question #11: After reviewing the images from the survey, participants were asked how likely they were to investigate the potential benefits of the use of a UAV for their own operation.**

This question is was used in determining how participants viewed the technology after learning a little more about what kind of information and data they could deliver. A majority of the participants are early adopters who are part of several social media groups that share information about these systems online, with roughly 42% of the respondents already owning a system. 32% were very interested in learning more after taking the survey and the remaining 26% were somewhat interested or felt it was interesting technology by not sure how it would benefit their operation.



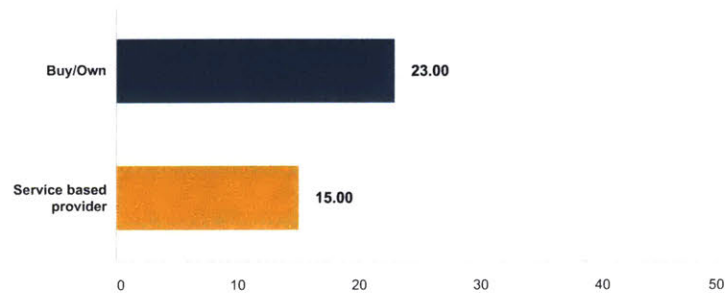
Answer Choices	Responses
I already own one	42.11% 16.00
I am very interested in learning more	31.58% 12.00
Somewhat interested	15.79% 6.00
Interesting tech, but not sure how it will benefit my operation	10.53% 4.00
Not interested	0.00% 0.00
<b>Total Respondents: 38</b>	
<b>Basic Statistics</b>	
<b>Minimum</b>	<b>Maximum</b>
1.00	4.00
<b>Median</b>	<b>Mean</b>
2.00	1.95
	<b>Standard Deviation</b>
	1.00

Figure 26: UAV Interest Following Survey

**5.4.2. Question #12: Regardless of cost would you prefer to buy and own a UAV crop monitoring system or would you prefer to hire a service provider for your crop monitoring needs?**

This question was used to understand the preference of the participants to own and operate their own system or hire a service provider to collect and process imagery for their field conditions. The concept of an Ag based service provider is not a new concept; for example the custom harvesting service were a company is hired by the farmer to harvest their crop. This saves the farmer the expense and hassle of managing complex equipment that is only used once a year. Sixty percent of the survey participants prefer owning their own system, and 39% reported that they would favor a service-based solution. Some respondents reported “I would prefer to have service contracts... its generally a problem to find a qualified service that is available

during initial start up of a new technology so we generally have had to purchase the technology and learn how to use it ourselves.”

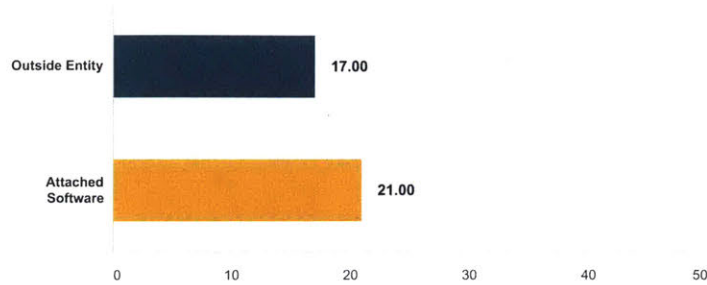


Answer Choices		Responses	
Buy/Own		60.53%	23.00
Service based provider		39.47%	15.00
<b>Total Respondents: 38</b>			
Basic Statistics			
<b>Minimum</b>	<b>Maximum</b>	<b>Median</b>	<b>Mean</b>
1.00	2.00	1.00	1.39
			<b>Standard Deviation</b>
			0.49

Figure 27: Buy/Own versus Service Based Provider

**5.4.3. Question #13: Regardless of cost would you prefer to have your crop imagery data analyzed by an outside entity or with software supplied by the UAV manufacture?**

The primary value that this system provides is not the imagery, but the analysis of that imagery. This question was included to determine if current lead users would prefer to have their data analyzed by an outside source or by an associated program that is provided by the UAV manufacturer. From the image below a majority of respondents would prefer to have the imagery data analyzed “in house”.



Answer Choices		Responses	
Outside Entity		44.74%	17.00
Attached Software		55.26%	21.00
<b>Total Respondents: 38</b>			
Basic Statistics			
Minimum	Maximum	Median	Mean
1.00	2.00	2.00	1.55
			Standard Deviation
			0.50

*Figure 28: Data Analysis Preference*

Once again this is a representation of the maturity of the technology and the developing industry. The difference in the methods of data analysis is much closer than the difference found in Question 12. As the industry matures and more data analysis capabilities are available it will be interesting to observe if the preference changes.

**5.4.4. Question #14: Do you have an Ideal System in mind? If, so please describe what “ideal” would be for you.**

This question was designed to gain insight into how lead users would improve their systems, and determine if there are any contradictions amongst their requirements. The participants shared many common desires for their ideal system; they primarily focused on operations, sensor type, resolution, and data analysis.

For operations they want a system that is efficient, easy to use, rugged and fast. They would like a system that provides fast field coverage, with long endurance. Several examples of ideal coverage time range from surveying a 200-acre field in thirty minutes to surveying a 600-acre field within an hour. A majority of the responses feel a fixed wing system would fit their

needs best, but several prefer a quad-rotor type for their ideal system. Many would like to see a vertical take off capability, but with endurance and speed of a fixed wing system. They would also prefer a system that is small and easily deployable with automatic planning, takeoff and landing that is capable of autonomous flight. Ease of use of the hardware and software is key for an ideal system. Multiple comments expressed the desire to quickly review the imagery collected while still in the field in order to save time and start ground truth.

There were several suggestions for the type of sensors and resolution in an ideal system. The sensor suggestions ranged from high definition cameras, multispectral, near infrared and thermal sensors. Resolution ranged from 4-10 centimeters with a specific request to identify individual plants. Data Analysis should be done quickly and ideally be available shortly after landing. The data should easily integrate with other precision Ag software and outside image processing programs. The NDVI imagery should be easy to understand and determine what it means for management choices.

The following comments from the question best summarize the ideal system the participants are looking for. “Farmers are not gentle people and we don’t have time to mess around with settings. We need a Throw and Go system. At the end of the day, pull out a data card plug it into the computer and show me what I need to know.” “Having the ability to see images while still in the field. Time is limited and spending time at night processing images, and then going back to the field the next day is a hassle.” “Current platforms are fairly good, work needs to be done on post processing and accuracy of the image, geo-referencing and integration into the on farm implements”

There were several noteworthy remarks and trends from the survey as a whole that contradicted the comments given for ideal system features. In product design and development

there are often times when differences between expressed needs and latent needs can be used to identify key areas of improvement. The biggest contradiction existed between the ideal systems characteristics for the time required to gather and process data, and the results from Question #12. In Question #12 the participants stated that their ideal system should quickly survey the field, and provide them with access to their data as soon as they land. “Time is limited and spending time at night processing images, and then going back to the field the next day is a hassle.” The paradox exists between their preference to own and operate their own systems and their desire not to spend a whole lot of time gathering information and processing it. This also exists with the information provide by Question #13 regarding data analysis and their desire to process the imagery with attached software. A service based provider could address this contradiction by surveying the field on a set schedule, collecting the imagery, processing it and providing the data to the farmer, allowing them to ground truth at their convenience.

**5.4.5. Question #15: Please describe how you would ideally use this type of system for the various phases of the crop cycle.**

This question allowed lead users to contemplate the crop cycle, and express how they would ideally utilize the system for each phase. Participants provided several examples of ideal use across the various phases, with a majority of the comments centered on the emergence and crop care phase.

For the planning phase, the ideal use case focused on determining field conditions such as terrace erosion and weed coverage. The data would be useful for early herbicide application and pesticide application. Preferably being able to use the information to develop variable rate mapping for the application. In the emergence phase, the lead users would use the system to determine stand counts and uniformity in emergence, allowing them to make decisions on

possible replant. They would also use the imagery to ensure proper irrigation flow and early water stress as well as to identify any equipment errors in planting, spraying, etc..

The crop care phase had more inputs for ideal use, focusing on the use of NDVI to make prescription maps for side dressing, or mid season application, of nitrogen to trouble spots. They would also use NDVI to adjust irrigation levels to optimize water usage and maximize plant growth. Ideal use would identify areas of plant stress and use that information to make precision inputs to improve the health of the crop. In the harvest phase, lead users would use the system to determine which field is the most ready for harvest. They would also like to use the system to provide a visual of what harvest potential will be.

Participants suggested a variety of timelines for how often they would ideally scout their fields. They ranged from weekly collection of field images to flying every three weeks to gather information on crop development. One participant gave a very detailed summary of how they would prefer to use this system across the crop cycle. “When farming new fields I clear in January/Feb and plant a cover crop in March-knock it down in July and prepare to plant a 15 acre plot of blueberries, I would observe the fields at least twice a week to make sure they are progressing the way they should. For regular blueberry growing, I would begin observing in March and continue through September, looking for plant health and color, water leaks, and hopefully changes in berry color.” The wide range of duration between revisit times suggest that the lead users are still experimenting/learning how to best utilize this technology.

#### **5.4.6. Question #16: If you currently own and use a UAV system, how do you currently utilize your UAV system?**

This question was used as an opportunity for lead users to explain how they actually use the UAV systems in their operations. The majority of responses were not surprising; several common themes focused on irrigation inspection, weed management, and visual scouting of



general crop conditions, and “evaluating crop health and looking for anything bad that may stick out.” One participant stated that they have used their system to for crop scouting gathering 4-6 scans of various fields during the growing season from emergence to harvest.

Less common responses focused on land management by tracking terrace erosion and post storm evaluation of field conditions. “I use the system to inspect blown down corn following large storms for better crop insurance adjustment.” Because this technology is still in the early adopter phase, the full capability of these systems is still being explored. Many lead users are still learning to how to integrate the data provided into their farming operations.

Several unique observations about current usage stood out from the rest of the comments. One user explained that they use their systems to create videos to communicate crop progress within the company and with landlords. The imagery provides a high level overview of the crop development for investors. Another comment that stood out clarified the importance of high definition imagery without the NDVI processing. “I believe that one of the greatest tools we have to offer is just video from a GoPro. Most farmers in my area have a hard time understanding the processed imagery but are more than happy to see a GoPro video and make their own conclusions based on that.” They go on to explain that they are big proponents of the NDVI processing and field mapping, but the high definition imagery currently provides a good introduction of this technology.

**5.4.7. Question #17: If you currently own and use a UAV system, do you use it for anything other than crop monitoring? If so how?**

Several participants acknowledged that they have used their systems for uses other than crop monitoring in support of their farming operations. Several “out of the box” unique and distinctive uses include: filming promotional videos for farm products, livestock scouting, livestock health inspection, forest land management (lightning strike and fire hazard GPS

location for forestry service), grain elevator leg inspection, and using thermal sensors for farm building efficiencies during winter months.

#### **5.4.8. Summary of Section III**

The purpose of Section III of the survey was to give the participants an opportunity to express how they would design their ideal system and how they would preferably utilize it. It also explored the lead user's interest in having a third party survey and analyze their field data. Finally it offered those who currently own and operate a system a chance to describe how they actually use the system for crop monitoring and if and how they use it for other purposes.

The preference of a majority of the participants is to own and operate their own system. A few would prefer to hire a service provider to collect and process imagery of their field conditions. There were several responses about how they would prefer to utilize a service provider, but the maturity of the technology and market limits that availability. The same general consensus occurs with data analysis; with a majority favoring to have the imagery data analyzed with system-attached software. The response from these two questions is contrary to many of the comments detailing their model platform.

The participants primarily focused on operations, sensor type and resolution, and data analysis when describing their ideal system. The general consensus is that the information provided could have better resolution and multiple sensors to more aggressively identify crop disease and infections. They also would like a system that is easy to use, rugged and fast. While many prefer to own, operate and analyze their imagery, there was a common request for quick data turnaround that was conflicting to their previous responses. The ideal use case focused on determining field conditions such as terrace erosion and weed coverage. It also concentrated on the use of NDVI to make prescription maps for side dressing, or mid season application, of

nitrogen to trouble spots. They would also use this imagery to adjust irrigation levels to optimize water usage and maximize plant growth. Over all, the ideal use would be to identify areas of plant stress and use that information to make precision inputs to improve the health of the crop. The ideal collection time ranged from weekly collection of field images to flying every three weeks to gather information on crop development.

When asked to describe their actual use the answers varied somewhat from the ideal case. Many use simple high definition standard images without NDVI for evaluation of field conditions. They also use their systems for irrigation inspection and weed management, but the use did not go beyond general crop condition surveying. The average revisit time for image collection was 4-6 times during the growing season; far less than the ideal use case scenario. The integration of imagery data into current precision agriculture software is still evolving and that may be the explanation for the difference between ideal and actual use. Some interesting uses beyond crop monitoring include livestock scouting, and building inspection for efficiencies in the winter months.

The responses to the questions in section III were very valuable in determining how accepting the lead users are of this technology and it also provided insight into how it could be improved for future use. While the proposed value of Ag UAV systems was high for the respondents of the survey, many of whom would be considered lead users with a high interest in this technology, the results may not be representative of the agricultural industry as a whole. The next section summarizes the research and proposes areas for further study with this technology.

## **6. SUMMARY/RECOMMENDATIONS**

This section contains the conclusions from the research conducted for this thesis and discusses future areas of study. It provides suggestions for further areas to explore to gain more insight into this technology and its use in improving farming techniques.

### **6.1. SUMMARY: THE VALUE PROPOSITION AND ACCEPTANCE OF UAV TECHNOLOGY IN AGRICULTURE**

Value Proposition is defined as: A promise of value to be delivered and acknowledged and a belief from the customer that value will be delivered and experienced (Barnes 2009). This thesis explored the value proposition that lead users believe Ag UAVs will provide for the various phases of the crop cycle. This technology is relatively new, and is still in the innovative and early adoption phase on the diffusion of innovation curve. Because of the maturity of the technology and current regulations, the adoption and market for this technology has been slow to expand. Once the proposed rules and regulations for commercial operation are in place and the value provided by these is recognized, the acceptance of this technology will grow.

The highest value for these systems centers around the emergence and crop care phases of the crop cycle. Decisions made during these two phases have the largest impact on crop health and potential yield. For the emergence phase the value is found in the capability to accurately evaluate stand count and stage growth development, water stress and rainfall impacts on young plants, as well as capturing imagery that displays weed development and insect infestations and the early signs of plant stress associated with them. The value derived for the crop care phase focused on the ability to recognize areas of fertilizer deficiency and determining locations for optimal fertilizer application, as well as the ability to realize the impact of irrigation and water stress on the crop. A secondary value is the ability to quickly identify pest and weed

infestations and make timely, accurate and efficient management decisions based on that information.

There was some value to be found during the planning phase to determine the field conditions that would impact the next crop. Specifically, focusing on conditions such as drainage, erosion and terrace damage as well as determining the amount of field residue related to the previous crop and/or weed cover concentration. The harvest phase had the lowest value of the four phases, primarily due to the fact that it is relatively easy to determine when a field is ready for harvest, and very little can be done to change the conditions of the field or impact the yield at this point in the crop cycle. The value associated with this phase was centered on the ability to understand the variation of crop readiness through out the field in order to determine how soon harvest can begin. This was extremely valuable when considering multiple fields and deciding which are ready and which may need more time to ripen.

While the lead users found the information provided by these systems valuable, there still remain areas for improvement. A common thread through out the responses was the need for ground truth. Many found the information useful, but feel that an onsite investigation was still required before making changes to their management decisions. Another shared concern is how well this data will integrate into existing farm technologies. Many lead users view the data provided to be useful, but are concerned how it can be used in relation to the data they already have through the use of yield maps. There still exists a need for a product that will tie the various data streams together that can be used with their current equipment. In order for this technology to reach its full potential future development must focus on ease of use, rapid turnaround on image processing and integration into available precision planning software. It must also focus on easier access to the data, a simple and efficient method of compiling data

from various sources and developing a plan that is feasible for the given farming operation to implement.

While the survey focused mainly on the lead users of Ag UAS it is important to understand how the average farmer will accept and utilize this technology. There are 2.1 million farms in the U.S. with an average size being 423 acres (USDA Census 2014). The adoption of precision farming techniques in the US has been growing, with some type of precision technology being used on 58 percent of wheat acres in 2009, up from 14 percent in 1999; on 49 percent of corn acres in 2005, up from 35 percent in 1999; and on 45 percent of soybean acres in 2006, up from 31 percent in 1999 (Schimmelpfennig 2011). The question remains on how to integrate precision Ag techniques into more farming operations, and how well the data provided by Ag UAVs will be implanted into those precision farming practices.

There are several factors that impact the adoption of precision Ag technology: cost of equipment, ease of gathering and understanding data, using the data to make management decisions, as well as the cost benefit implementing the technology and techniques. Precision Ag is both capital and information intensive has a low degree of compatibility, trialability and observability and a relatively high degree of complexity. Among corn producers the probability of precision agriculture adoption increased as farm size and farm income increased. Furthermore farm operators who were familiar with computers, more educated, used crop consultants as an information source, and were less than 50 years of age were more likely to adopt precision farming practices (Fernandes-Cornejo 2001). Taking these factors into consideration, it is not unreasonable to assume that Ag UAV technology will follow a similar path. The use of UAVs will require a change in farming practices similar to the early adoption of precision farming techniques.

This does not mean that Ag UAVs use will be solely limited to large farms with the capability, and knowledge to effectively utilize these systems. While it is true that adoption is more responsive to farm size at the innovator stage, the effect of farm size in adoption generally diminishes as diffusion increases. (Fernandes-Cornejo 2001) As precision farming continues to be adopted and will soon be utilized by a majority of farming operations, so too will Ag UAV technology. Not only will precision Ag techniques need to be adopted on a larger scale, there will also need to be a change in the mindset of farming operations with use of Ag UAVs. Current practices utilize yield maps, which are generated at the end of the growing season and used to make adjustments for the following year. Ag UAVs provide data throughout the crop cycle and gives the farmer more opportunity to adjust management practices over the growing season. However, this requires the data to be analyzed and acted up in a timely fashion in order for the suggested changes to make an impact. Because of this the farmer will be much more involved than they currently are during the course of the growing season to assure maximum performance of their crop. This additional involvement and time obligation will require an adjustment period to be accepted as a part of normal farming practices.

With the world's population expected to reach roughly nine billion by 2050 (United Nations 2013), the demand for food and fiber will require increasingly improved methods of agricultural production. There is movement afoot in Ag technology development as innovation and technology continue to explore new and more efficient methods for farming. The AgTech sector had a record-breaking year in 2014, with \$2.36 Billion invested across 264 deals (Leclerc 2014). This current trend in venture capital investing in Ag technology could be the start of a wave of innovation in agriculture that will be critical in meeting the challenge of feeding those nine billion people.

## **6.2. FUTURE RESEARCH OPPORTUNITIES**

Progress in understanding the true value these systems provide for crop management requires further field research. Focus should be given to developing in field experiments using the data provided by these systems to make management decisions across the crop cycle to determine if the benefits are worth the cost in terms of expense, time and material. Actual data needs to be collected to determine the data provided can actually reduce the amount of chemical applied while impacting yield.

Another area of research is to determine if UAV imagery is more cost efficient and more useful than conventional methods of remote sensing. This is important to developing better methods of integrating remote sensing data into modern precision agriculture techniques. As a better understanding of the value provided by these systems is developed, a more in-depth look is required to determine if different sensors are necessary to provide better inputs for various types of crops and geographical areas. For example is there an optimal sensor for blueberries and is it the same for corn? What types of information would be more useful and provide more value for drought stricken areas versus those areas with too much precipitation?

As the world's population continues to grow and the demand for food increases, improved methods of agricultural production will be required. The use of UAVs and the information they provide will play a role in developing more efficient farming practices. The role of technology in agriculture must continue to expand to meet the challenge of providing food to the world.



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## APPENDIX A – SURVEY INFORMATION SUMMARY

Surveyor: Tobias Walters

Purpose: Research gathering to fulfill thesis requirements of Massachusetts Institute of Technology System Design and Management Program

Survey Candidates: Lead Users: Farmers, Crop Consultants, and Manufacturers

Overview of Research: The thesis research focused stakeholder value proposition remote sensing using UAVs brings to various phases of the crop cycle

Time Required: Approximately 15 to 25 minutes.

Question Set: 18 Questions.

### SECTION I – Focus UAV familiarity and operations size

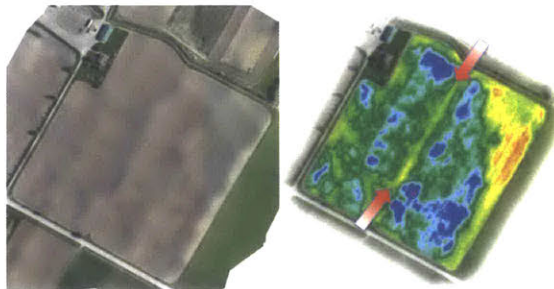
- 1) What is your familiarity level with Ag UAV technology?
- 2) What is the size of your farming operations (number of acres)?

### SECTION II – Focus on value position for crop cycle

- 1) What kind of information would you require form a UAV for the crop-planning phase? (includes the decisions for crop rotation, placing a field into fallow, crop cover, on farm research support, and variable rate applications)



This image is a picture of weed coverage quantified using an Agrobotix UAV with collected color and infrared images after image processing. The field has roughly 16% of its surface covered by weeds.



Swinglet CAM imagery show areas with higher or lower organic matter. Below, the yellow- green line in the photo's center is an old fence row and yellow-red areas indicate silty soils with higher organic matter.

- 2) After reviewing the images above, how valuable might this information be in making management decisions during the planning phase?
- 3) What kind of information would you require from a UAV system for the emergence phase? (includes early crop development, crop sprouting progress and thickness, re-seeding)

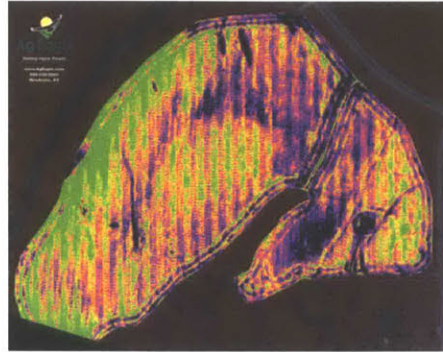
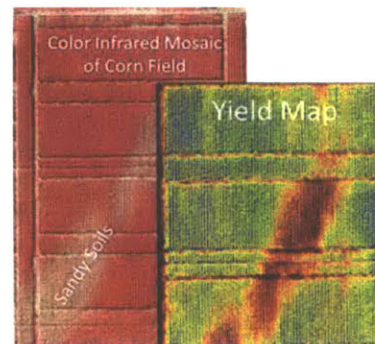


Image of corn in the early development phase, courtesy of AgEagle, colors correspond to various crop density.

- 4) After reviewing the image above of a field shortly after planting, how valuable might this data be in making field management decisions?
- 5) What kind of information would you require from a UAV for the crop care phase? (chemical/fertilizer application, irrigation, pest management)

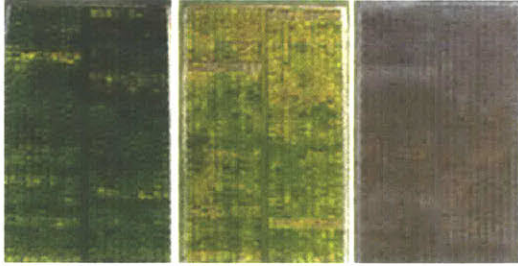


Image from an Agribotix UAV showing the impact of a blocked pivot spray head.



Comparison between UAV IR imagery and yield maps for a corn field. Notice the area of sandy soil corresponds to low yield area.

- 6) After reviewing the images above, how valuable might this data be in making crop care management decisions?
- 7) What kind of information would you require from a UAV for the harvest phase? (decisions on field readiness)



Images of a field over the course of the growing season: mid-season, late-season, and, pre-harvest. Indicating overall field readiness in preparation for harvest. Courtesy of Precision Hawk

- 8) After reviewing the above image, how valuable might this information be in making management decisions for harvest?

### SECTION III – Focus on Stakeholder use

- 1) After reviewing the above images, how likely are you to investigate the potential benefits of the use of a UAV for your operation?
- 2) Regardless of cost would you prefer to buy and own a UAV crop monitoring system or would you prefer to hire a service provider for your crop monitoring needs?
- 3) Regardless of cost would you prefer to have your crop imagery data analyzed by an outside entity or with software supplied by the UAV manufacturer?
- 4) Do you have an ideal system in mind? If so, please describe what "ideal" would be for you. (For example, what is your ideal platform type, resolution, endurance, and how important is ease of use and data analysis capabilities?)
- 5) Please describe how you would ideally use this type of system for the various phases of the crop cycle.
- 6) If you currently own and use a UAV system, how do you currently utilize your UAV system?
- 7) If you currently own and use a UAV system, do you use it for anything other than crop monitoring? If so how?



## **APPENDIX B - LIST OF ABBREVIATIONS**

Above Ground Level (AGL)  
Agricultural (Ag)  
Agriculture and Resource Inventory Surveys through Aerospace Remote Sensing (AgRISTARS)  
Association for Unmanned Systems International (AUVSI)  
Automatic section control (ASC)  
Earth Observing 1 (EO-1)  
Federal Aviation Administration (FAA)  
Geographical Information Systems (GIS)  
Global Positioning System (GPS)  
Gross Domestic Product (GDP)  
Ground Sampling Distance (GSD)  
Land Remote Sensing Satellite (LandSat)  
Large Area Crop Inventory Experiment (LACIE)  
Long-wave Infrared (LWIR)  
Massachusetts Institute of Technology (MIT)  
National Aeronautics and Space Administration (NASA)  
National Airspace (NA)  
Near Infrared (NIR)  
Normalized Difference Vegetative Index (NDVI)  
Object Process Diagrams (OPD)  
Object Process Language (OPL)  
Object Process Methodology (OPM)  
Precision Farming (PF)  
Single lens reflex (SLR) camera  
System Diagram (SD)  
United States Department of Agriculture (USDA)  
United States Geological Survey (USGS)

Unmanned Aerial System (UAS)

Unmanned Aerial Vehicle (UAV)

Variable Rate Application (VRA)

Variable Rate Technology (VRT)

Visual line-of-sight (VLOS)