Private grain storage technology considerations and location optimization

by

Kinzey Janae Cott

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Major Professor
Dr. Elizabeth Yeager

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Abstract

Farming operations looking to invest in private grain storage as a long-term investment to increase potential profits often face difficulty when deciding the best location to fulfill current storage needs and future expansion options. This thesis aims to combine the knowledge and desires of current farm operations to create optimization models for the optimal location for a private storage facility. Combining the use of technology and storage data in the precision agriculture realm allows agriculturalists to manage farm efficiency to better plan storage construction.

Interviews were conducted with various farmers across the Midwest. Data was then accumulated on what factors of storage decision processes are most important as well as different types of technologies used in the agriculture industry. The operations varied in size, storage capabilities, technology implementation and storage expertise. All interviewees stated that technology was imperative in data management and grain monitorization in their farming processes.

A concept farm was created to protect interviewee's confidentiality. This creation was attainable using base knowledge gained through the interview process. The concept farm consisted of multi-year yield data as well as satellite imagery to show acreages and field boundaries. A 90/10 storage percentage of corn to soybeans was realized as well as three potential storage location options. A transportation minimization model was then created and solved to find the least time required for hauling to a potential storage facility. Furthermore, a cost minimization model was created to find which location had the least cost associated with infrastructure requirement and freight costs. Results indicated that through both model processes, out of a selection of three feasible sites, Location 1 is the desired location.

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This project relied heavily upon farmers throughout the Midwest and the interviews conducted with them regarding the private storage industry. Relationships were developed with each farm operation, and I truly appreciate the knowledge you have through real life experiences and the willingness to share successes and failures. Being able to see what real producers find valuable in the agriculture industry made this thesis possible.

Finally, I would like to credit both my family and Megan Hill for helping to keep me on track through my graduate school experience. My family has been able to provide much needed agriculture knowledge and support during this time and Megan was instrumental in helping to work out the fine details of the optimization process as well as being a constant friend and cohort in the program. My graduate journey would not be the same without their presence in my life during this experience.

Chapter 1 - Introduction

When farmers make the decision to invest in long term private storage options for their operations, there are many aspects that play into making the right decision. Not only do farmers have to think about feasibility with budget constraints, but also how to meet the list of necessary requirements such as power requirements that are customized to fulfill their needs. Financial requirements and access to financing should also be considered before making an investment into a long-term asset.

Considering the desired benefits and outcomes of a storage facility for a farming operation will determine many of the financial and operational decisions made in the construction process. Having a value of $2.737 billion in 2020 for global grain bin value lends the private grain storage industry to be a significant factor in the agriculture industry (MarketWatch, 2021). Learning from past basis data allows farmers to see the benefits of holding grain for periods of time in order to capture profits later in the year. By wanting to take advantage of increased profit, potential farmers make the decision to invest in private storage. Some operations might find that having an optimal location for the facility is most important while others would determine the availability of power sources to be the most valuable factor. Establishing potential benefits while meeting all necessary desires is imperative for an operation before advancing the construction of a non-liquid asset.

In the current precision agriculture realm, technology plays a significant role on how optimal results will be ascertained. Without the implementation of technology in agriculture, accurate data would be much more difficult to collect and manipulate. Technology allows farmers to oversee moisture sensor levels, bin monitorization, yield data, application rates, and more. With complete and factual data, comes the ability to create a well-managed farm ready to increase profit potential. Through the expansion of data implementation and awareness, farms can be informed and positioned to achieve the desired goals set in place.

This thesis will examine feasibility of adding privately owned grain facilities while optimizing different criteria. This optimization will take place in multiple parts in order to minimize miles required to haul to the storage facility. One part will include a linear optimization minimization problem solved in relation to location for construction. This will allow the farmer to decrease the amount of time needed to truck grain from different harvest locations to a storage facility. Having multiple location options will also be implemented in order to give robustness to the model and account for real-world decisions being made on farming operations.

Another part of the optimization process will include a linear optimization cost minimization problem. The goal of this model is to choose the least cost location for the farming operation to feasibly construct a private grain facility. Conclusions will then be drawn on how, through the optimization process, farmers can choose the location best suited for themselves ranging on various desires and requirements. In order to develop an optimization problem and keep farmer's information confidential, a concept farm will be developed. The concept farm will be based off of various interviews with farm operation owners in the Midwest in order to solve the problem and achieve feasible results.

The goal of this thesis is to provide an increase in understanding on what requirements and planning are required to construct a privately owned grain storage facility on a technologically advanced precision agriculture farm. Additionally, an optimization model process will be illustrated so that a farmer, with proprietary data, can optimize potential location or minimize the cost of construction processes.

Chapter 2 - Literature Review

2.1 Background

Metal bins, most commonly constructed from steel, have been a primary method of storage for farmers since the early 1900's (McKenzie, & Fossen, n.d.). By constructing a reinforced cylindrical steel structure, grain moisture levels can be maintained. The cylindrical design improves air circulation which is the most important factor in a grain bin. With the implementation of dryer fans, moisture levels can be dropped by multiple percentage points as well. Due to temperature differences throughout the year, it is important that the crop sitting in long-term storage maintains a consistent reading. Air is ushered through the top of the spout of each bin where a convection current forms and is then pulled down around the edges of the metal structure to aerate the bottom. As the air travels from the top of the structure to the bottom, the air temperature increases which leads to a decrease in density. Through this temperature increase, moisture is added to the air helping to regulate the grain. As the moisture laden air rises through the center of the bin the grain on top is breached with warmer temperatures and higher moisture. This air circulation process allows for a consistent moisture migration pattern which decreases the chances for grain to develop bacteria and overall spoilage. When building a private grain facility of size, steel bins are most commonly used in order to mediate costs and allow for compatibility with dryers and additional sensors added to the system throughout expansion processes (McKenzie, & Fossen, n.d.). Figure 2.1 below shows what potential private grain facilities can look like and shows how steel bins can be added in a modular pattern for additional storage options.

Source: (Cott, 2021)

Figure 2.1 - Grain Storage Facility Visual

Cost is an important factor when it comes to building a storage facility. Therefore, planning for storage must include developing an enhanced appreciation of the total cost and its components. Deciding upon whether to invest in storage that will fit the personal needs of the operation or building additional storage as a rental option to other farmers in the area is crucial as well. Calculating cost per bin and the average period it will take to pay off the bin as it depreciates, should also be calculated before the purchase is made. When building a larger storage facility, steel bins and dryers are the most commonly sourced materials due to cost. Steel bins allow for costs to be lowered while still maintaining the structural integrity of the bin system itself. Pricing private storage facilities is highly dependent upon relationships held with local bin sellers, desired technology to be installed, and raw material prices at the time. Location also plays a significant factor upon pricing of different materials required in the construction of a private facility. In 2009 the cost to construct a stand-alone steel bin averaged $2.15 per bushel, but as the economy has experienced inflation, the prices have increased as well (Miller, & Jose, 2009).

In addition to the steel bins being the choice of building material for private facilities, demand for structures themselves must be taken into account as well. Demand for private grain storage seems to have increased over the past twenty years. After conducting interviews with farmers across the Midwest a conclusion of overall increased investment into on-site private storage could be found. Many reasons as to why an increased demand seems to be occurring as time goes on were discovered. Current farm operations when compared to previous decades, have grown in size immensely. Total acreages have increased for farms that are still in the industry. The number of farms is decreasing by thousands per year which allows the average farm size to increase on a yearly basis too. In the United States, the average farm size is roughly 444 acres (USDA, 2020). In Figure 2.2, the total number of farms varying over a range of eight years can be seen.

Number of Farms, Land in Farms, and Average Farm Size – United States: 2012-2019

Year	Number of farms	Land in farms	Average farm size
	(number)	(1,000 acres)	(acres)
2012	2,109,810	914,600	433
2013	2,100,350	911,720	434
2014	2,082,440	908,920	436
2015	2,063,890	905,790	439
2016	2,055,340	902,680	439
2017	2,042,000	900,370	441
2018	2,029,200	899,500	443
2019	2,023,400	897,400	444

Source: Farms and Land in Farms 2019 Summary (February 2020) USDA, National Agricultural Statistics Services

Figure 2.2 - Number of Farms, Land, and Size in US 2012-2019

2.2 Motivation

When an individual is faced with the decision of whether to invest a substantial amount of money into a private storage facility, many forces are affecting the decision. One motivating reason behind storing grain privately is to capture potential price increases at different points of the year. If grain is held for multiple months after harvest, higher profits can be gleaned when the cash price increases after the harvest season. On average, according to AgManager.info, basis data has the general trend of narrowing the longer after harvest a farmer stores grain (AgManager.info, n,d.a.). This is due to the increased demand from the industry as grain becomes harder to source the further time progresses from harvest. Figure 2.3 shows the basis data for corn over the past five years with a noticeable decrease happening in basis values once harvest starts around week 33. However, after harvest a small strengthening in basis begins to build and on average grows over the next nine months, thus allowing farmers to capture this increase directly to profits (AgManager.info, n,d.a.).

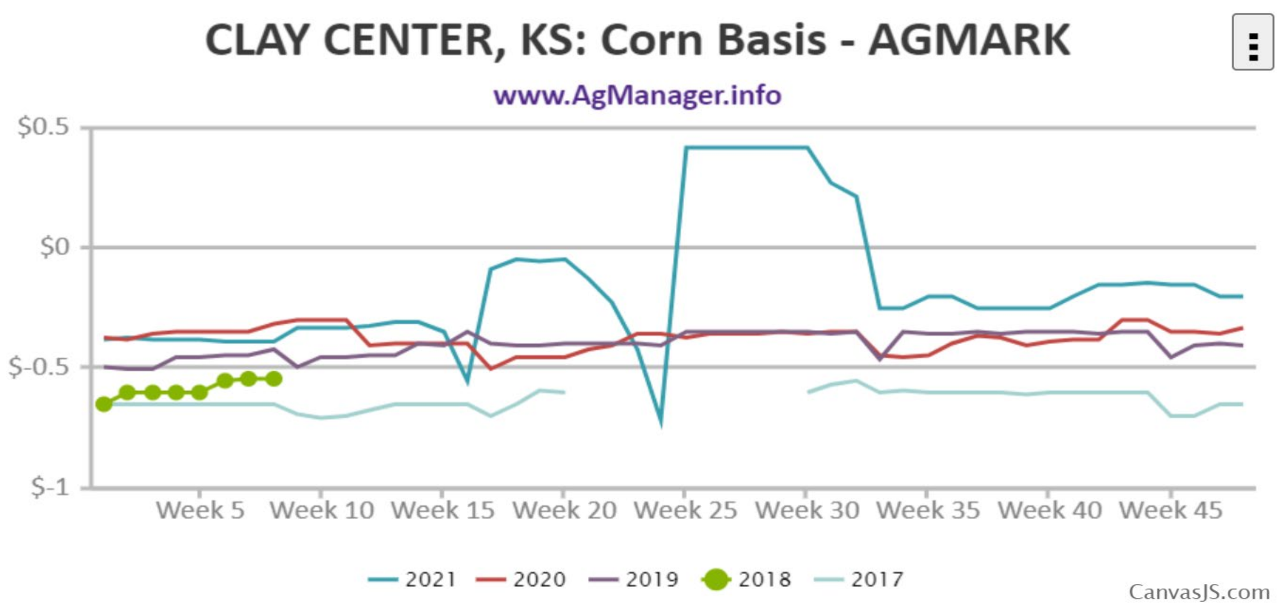


Figure 2.3 - Corn Basis (Clay Center, 2017-2021)

Furthermore, soybean prices are historically seen to have the same relationship with basis if held for longer periods of time. Figure 2.4 shows the trends from the last five years regarding soybean trends (AgManager.info, n.d.b.). By week 33 at the start of fall harvest, the basis prices decrease as the supply of soybeans in the market increases. Yet as time progresses small increases are made to basis values which often peak around the weeks of 25-30 which is the time of year just before fall harvest begins. If farmers have the ability to hold their grain in private storage for extended periods of time, they can take advantage of stronger basis values which can bring higher profits to the operation instead of selling the grain at harvest (AgManager.info, n.d.b.).

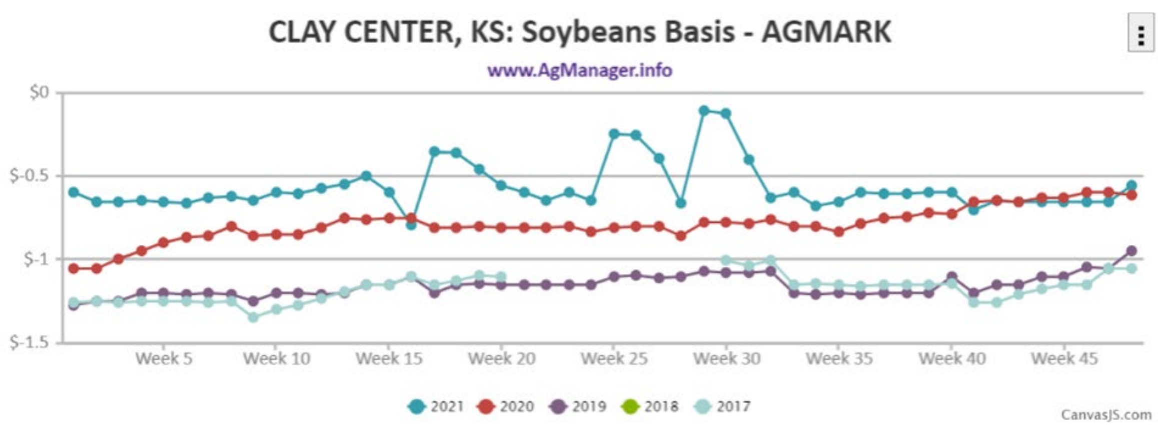


Figure 2.4 - Soybean Basis (Clay Center, 2017-2021)

When comparing the two charts, corn is oftentimes found to have narrower basis values on average than beans. This might lead farmers to make the decision to store more corn throughout the year than other commodity crops. Facilities that are constructed with grain dryers might also be able to capture the stronger basis values just before the start of harvest season by harvesting earlier and drying to desired moisture contents. Capturing the strong corn basis by storing and drying allows farmers with private grain storage facilities to arguably make more profit than farming operations without. This is further illustrated through crop indexing for corn. In view of the seasonal patterns of price changes, if possible, corn would bring back the highest return if placed in storage after harvest and sold on the market in the summer months. Figure 2.5 shows a visual representation of corn price changes over a twelve-month span. This data is the averages of price changes from 1996 to 2015 (Nebraska, 2015). When comparing the basis figures with the index figures the same results are shown that if grain is stored through the year, higher profits can be obtained.

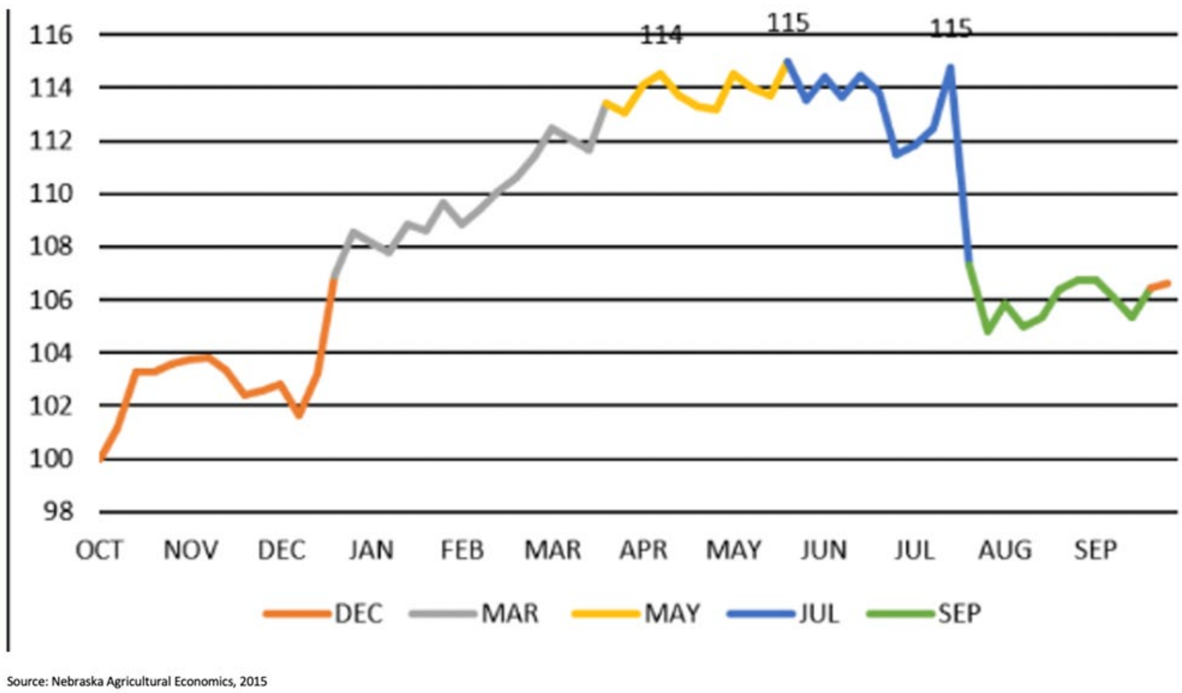


Figure 2.5 - Corn Index Price Changes (1996-2015)

Producers have other motivations to invest in private storage as well; a main source of which, is control over their product. Having a private grain storage facility allows farmers to transport grain in and out of the facility at all times of the day. This ability contrasts with public storage options as public facilities keep normal business hours which constrains harvest delivery to a certain segment of day fixed by the storage company instead of the farmer. Furthermore, traceability of grain is assured as all the bushels are being stored in-house which provides ease in marketing and bushel tracking. By capturing the ability to transport grain 24 hours per day, opportunities to increase profits by lowering harvest times and increasing transportation efficiency are also experienced.

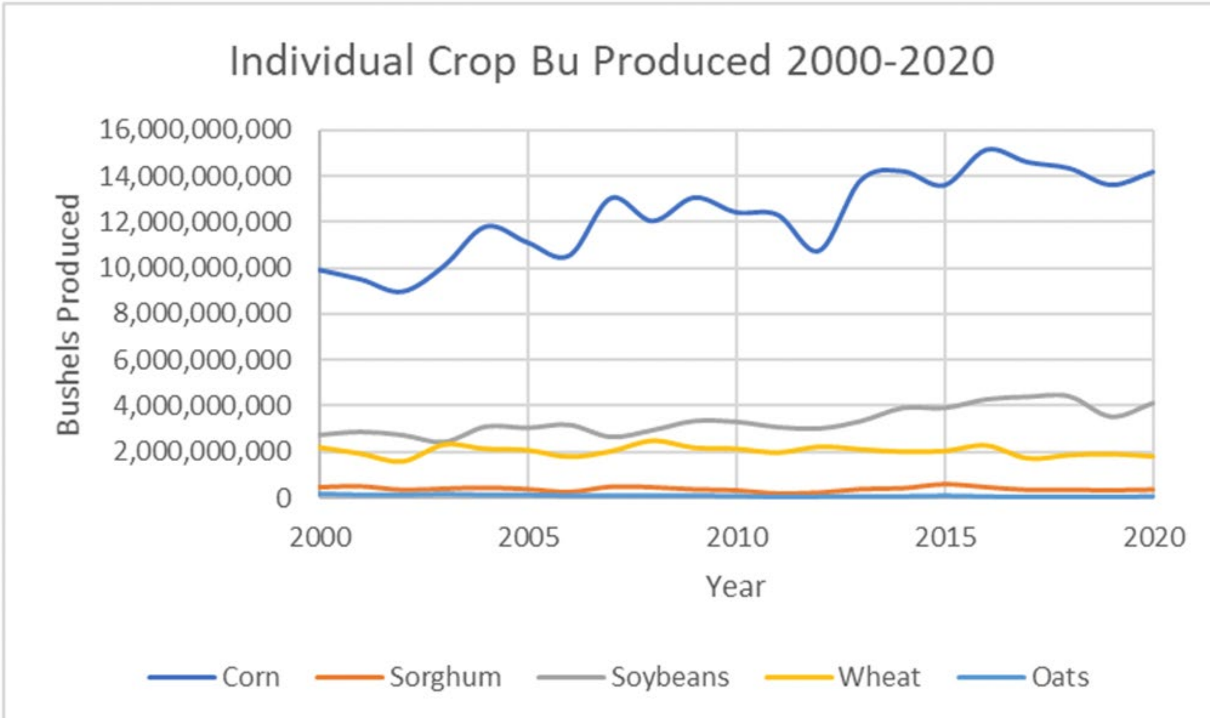
Private storage also lends itself to a variety of marketing options that can be negotiated and set by the producer instead of the public storage lender. Greater profit potential can be experienced by in-house marketing through leveraging product integrity and traceability. However, with the potential of increasing profits comes the opportunity cost of time and liquid capital. Another option to obtain liquid capital immediately after harvest would be to sell the grain at market price in order to bring immediate profits to the operation. This use of working capital allows the farm operation to payoff outstanding loans, payoff input purchases from the current growing season, or purchase new inputs for the next growing season immediately. These purchase requirements might be a reason a producer would opt to use public storage methods or direct market selling instead of holding grain privately for extended periods. Producers must weigh the importance of potential increased profits over an extended period of private storage time, or immediate monetary reimbursement of selling directly after harvest and decide which is best for their individual operation.

In summary, farm operations have many motivations behind why the decision to invest in private grain storage would be beneficial to their operations. Having the ability to take advantage of basis on a profitable year is an advantage but having direct control over one's product is an attribute that should not be overlooked. Finally, opportunity cost must be noted as the process of holding private storage can impede the acquisition of liquid capital for an operating entity

2.3 Markets

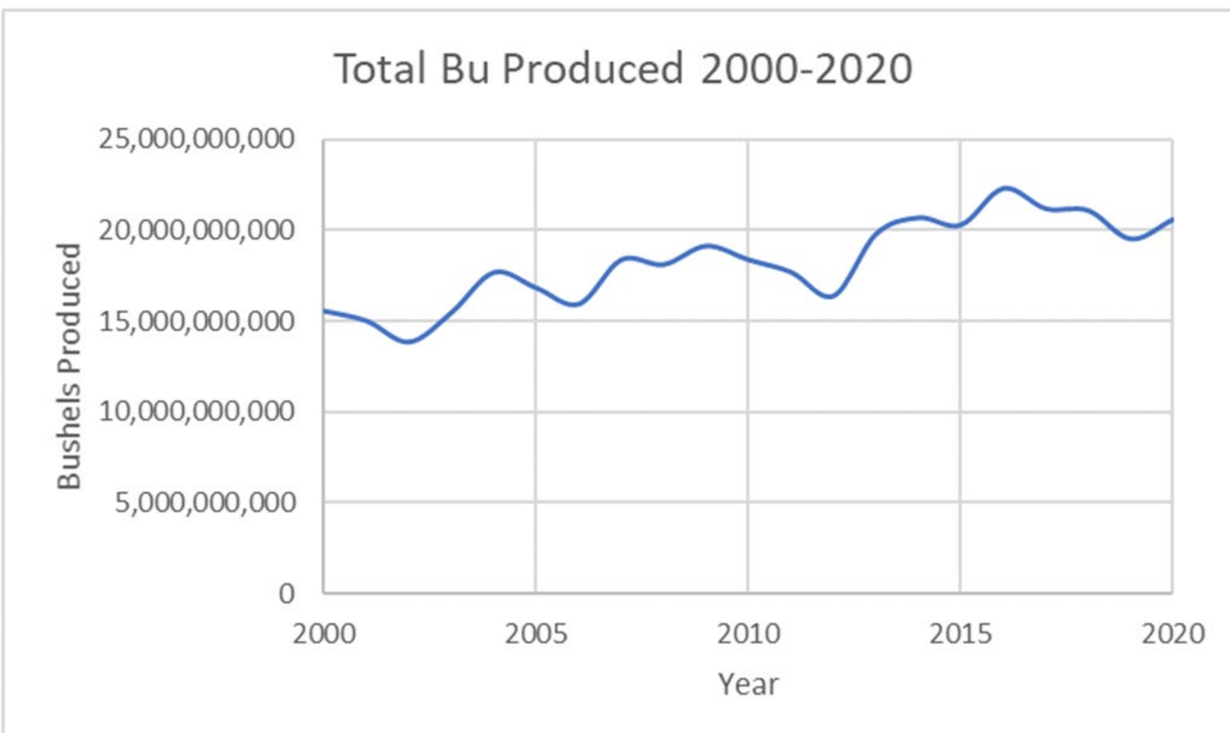
2.3.1 – Market Demand

Each year, farms are declining in number while increasing in overall acreage. As each farmer increases acres to the operation, more storage options are required, or alternate forms of sale and movement of grain are necessary to accommodate the gain of overall acres and bushels. Bushels produced using these increased farm acres per operation are also driving up the demand for private grain storage. Due to increased annual yields as a result of soil structure conservation, as well as the implemented use of genetic modification, farmers have seen improvements in operational output (Oliver, 2014). This increases the overall bushels produced in the United States from previous decades. Figure 2.6 shows in one chart the combination of the crops that are most often stored in private storage from overall bushel production. It can be seen that corn is the highest bushel bearing crop, but other crops make serious impacts in storage necessities too. The total bushel numbers produced in the United States in the past twenty years can be seen in Figure 2.7. With an upward trend in produced bushels, the demand for grain storage to handle the grain from harvest to distribution has increased in kind (USDA, 2020).



Data Source: (USDA, 2020)

Figure 2.6 - Crop Production in Bushels (2000-2020)



Data Source: (USDA, 2020)

Figure 2.7- Total Bushels Produced (2000-2020)

2.3.2 – Market Supply

Ultimately each farmer needs to consider their own operation and decide if investing in more grain storage is feasible. Factoring in yields, overall farm acreage, and available funds to invest are all important aspects when considering if a large infrastructure purchase should be made. Farmers must also consider how long they will find the storage option to be necessary. If they are planning for long-term expansion, steel or concrete bins would be a recommended method. The worldwide market value for grain bins is placed at $2.737 billion in 2020 (MarketWatch, 2021). In the US, storage capacity for crop production has steadily increased at a similar rate to the increase in total bushels. Shown below in Figure 2.8, the storage capacity has stayed above the total amount of bushels produced consistently. Although off-farm storage has grown at a faster rate than on-farm storage, on-farm storage reigns dominant in corn being stored privately. Supply of grain bins available to farms has stayed consistent in the past twenty years and there has always been enough supply to provide for the demand from farmers. In recent years, the demand for storage capacity has slowed but is still increasing as a whole. It is projected, given the data, that market supply will follow the industry demands from farm owners and continue to provide the necessary amount of storage facilities requested from operations wanting to expand their infrastructure (Janzen & Swearingen, 2020).

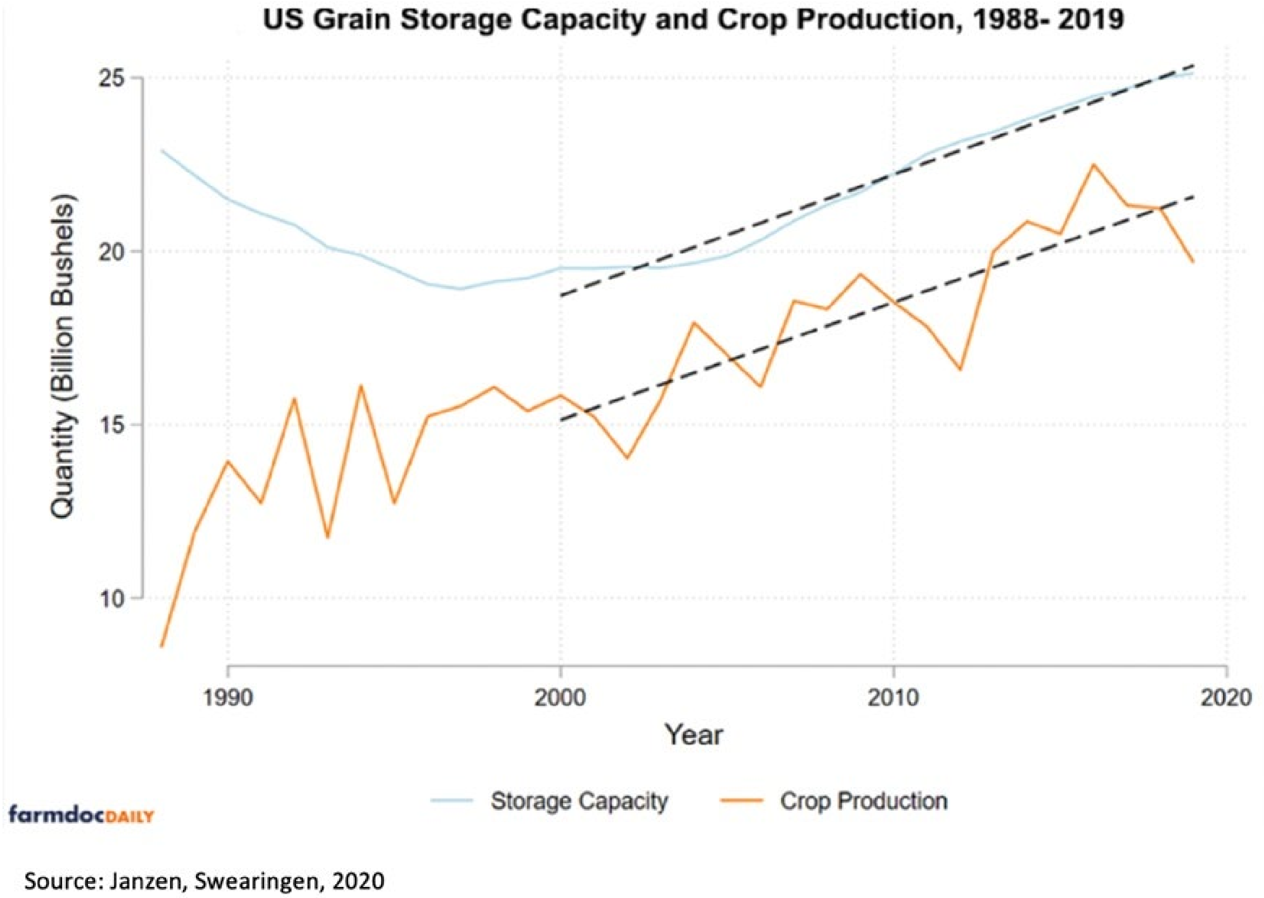


Figure 2.8- US Grain Storage Capacity & Crop Production (1988-2019)

Competition from public vendors plays a role into the private storage sector for farms of varying sizes. This can be a challenge for construction of new private facilities for smaller scale farmers due to the direct competition with the copious public storage options available nationwide. If farmers are local COOP members at elevators in town, public storage might be an appealing option if funds are not readily available for private structures. Dropping commodity prices has made it harder for smaller farmers to grow their on-site storage and are forced to look at public storage options as an alternative. Profitability is what both public storage companies and private entities are most concerned about. The question of "Will storage increase at a similar rate that yields increase?" is constantly being asked by producers in the industry. If producers cannot handle the rates of change in storage options, whether public or private, the individual will have to sell grain during peak harvest time and possibly take a hit on potential profit (Gleason, 2018).

Antonio Martin (2014), a grain storage expert in the industry, points out that while there are plenty of advantages to building private storage facilities, an operation still needs to consider all aspects before construction. A vital decision is made when deciding the location where the facility will be constructed. Each storage facility is rooted to the original placement so margin of error needs to be essentially eliminated. Construction is a serious investment, decisions must be made regarding logistical requirements, energy availability, and sizing of the site before breaking ground with construction.

If these aspects are considered into the design and flow of the private facility before pricing potential costs, changes can be made without causing havoc on the construction process. With optimal decisions made at the forefront of the process, farming operations can achieve higher control of grain storage for their harvest process, obtain improved shipping rates, and gain the ability to customize and differentiate their farm where others cannot. Martin (2014) also mentions the ability to take advantage of the markets through holding grain in private storage in order to receive maximum returns when selling throughout the year. This process allows for price flexibility and manipulation of grain stored. By having the personalization capability, farmers can also mix their grain to achieve the grading they desire when it is shipped to market.

Through careful monitorization and wise investment and planning, an operation can make the choice to invest in a profit returning private storage facility. However, if proper precautions are not taken and decisions are rushed or made from convenience, disaster can strike that can create serious financial burdens on an investor. Taking the time to slow down and pick the right option for a permanent fixture is imperative (Martin, 2014).

2.4 Logistics

LCDM Corporation is an industry leader in customizable grain storage planning and sourcing. The company works with customers to plan their private grain facility long before any ground is broken on the build site. Making sure the facility is constructed correctly on the first attempt is what LCDM strives to obtain for their customers. Their website allows farm operations to design their own storage facility with professionals to make sure the plan is feasible and economical. A list of criteria is given to an operation owner to decide upon before setting any money aside for the long-term investment. The key decision to make according to LCDM is the location and layout of the facility. Often private storage facilities are sizeable enough that moving locations is impossible, so planning out the best location prior to construction is imperative. LCDM recommends the operation choose a location that gives available access to all parties who might need to frequent the location, ability to source power such as natural gas, propane, and three-phase power, and finally to construct it a reasonable distance from farm ground (LCDM, 2021).

LCDM also recommends talking with various other farmers in the area and asking for advice to learn from possible mistakes. Choosing the right location for each operation is crucial to creating an economical and profitable grain storage option that will pay for itself in a shorter amount of time while fulfilling the requirements the operation owner has for the facility. The processes of planning ahead and looking to the future for possible expansion is strongly advised. Building a facility to meet current grain storage demands might work in the short-run but having a plan in place for expansion options through the years will save logistical problems down the road. Having blueprints and plans in place for future investments into the facility can save overhead costs, time, and stress. Placement and power requirements should be thought about and planned accordingly prior to the start of construction in order to prevent additional costs of electrical, infrastructure, and power sourcing during the expansion process. If decisions are made considering future options, a logistically superior private facility can be created outright (LCDM, 2021).

2.5 Conclusion

When investing in private grain storage, farm operations must weigh criteria that will be most important for their specific operation and choose the most logical option for themselves. It has been found that steel bins make the best building material for operations to efficiently and economically construct a facility of size and keep up with farm growth rates. As more operations are continuing to gain acres every year, the amount of storage required for those choosing to store privately also increases.

Technology increases in importance as the desire for accurate data collection and interpretation is desired by grain system managers each year. With the expansion in precision agriculture comes the necessity of accurate information in the moment in order to create profit maximizing decisions for the operation as a whole. By making the decision to invest in private grain storage, operation owners are also deciding upon future expansion options. Picking the right location that offers ease of maneuverability, access to multiple power sources, and has room for future growth is vital.

Overall, when choosing to build grain storage privately, a myriad of other decisions and possibilities have to be planned for too. This thesis strives to add to the miniscule amount of literature available to farmers regarding how to best choose the optimal location for their private grain facilities based on the recommended criteria found in the literature.

Chapter 3 - Data Collection

3.1 Introduction

Data collection is imperative when deciding where to place a grain facility. Without knowing every aspect of the farm operation, a manager might fail to see where possible options for construction could occur. By having a well informed and analyzed farm, the farmer can make educated decisions regarding what factors are most important to consider when making the investment into private grain storage.

Agriculture technology is expanding and is constantly becoming further advanced and customizable. Agriculturalists can link machines, databases, and get visual readouts of data in an efficient manner from a myriad of sources. The purpose of this chapter is to explore different data capturing platforms and processes in order to compile methods to create a concept farm. Finding what is most important to farmers who are actively building storage facilities and learning the data programs leading their decisions, allows for a realistic conceptual farm to be created.

Through discussion with individual farmers, knowledge can be gained to determine what types of technology should be utilized when developing a farming operation as well as the necessary requirements to store grain in the most efficient manner. As the agriculture sector has become more advanced, precision ag is becoming the normality. Personal interviews with farmers in the precision agriculture sector allow for insight into what requirements are needed to create a farm from the ground up.

3.2 Personal Interviews

3.2.1 – Operation 1

When interviewing the manager of this farming operation, he consistently stressed the importance of technology as a necessity to daily life. In fact, it was stated, "The cell phone was the number one most important ag technology since the 1950's, with the smart phone being the second most important (Kastens, 2021)". As precision ag has developed, the smart phone has become a necessary addition to control and monitor equipment in the agriculture industry. Other types of technology utilized in Operation 1 are autosteer systems, row-unit shutoffs, and drones. From a recordkeeping and managerial standpoint, Operations Center by John Deere is the most used platform for handling and manipulating yield data as well as tracking equipment. AGI SureTrack is also implemented for grain facilities to monitor fans, measure moisture content, and monitor storage levels. OPI Blue is another technology form of grain system management that Operation 1 is in the process of phasing in at their grain storage locations.

Operation 1 has approximately 700,000 bushels of private grain storage on site. The manager also expressed interest in doubling that capacity in the coming years if opportunities arise. Grain is seldom transported over 35 miles to a private grain storage site as the more distant fields are hauled to public elevators. When asked the maximum distance Operation 1 would be willing to travel to haul to a private storage facility the response was what they are currently working with, a 35-mile span. However, the manager noted that if further fields are experiencing high moisture contents, the operation would rather haul farther to their own storage facility than pay the moisture fees at the public elevator.

When asked about the importance of private grain storage being used in Operation 1, the manager was focused on how profitable the grain facility would be in the long-run. When constructing storage, it was stated that location was the number one factor relating to profitability. Decisions were always being made regarding where to place new grain bins, if additional storage should be added to established grain storage facilities, or if new grain storage facilities should be erected in a different area. Operation 1 is most concerned about the ability for as many trucks to flow through the facility as possible during the harvest season. Logistics and trucking efficiency are the biggest profitability aspects of this operation thus making optimal location of grain storage essential.

The manager of Operation 1 stated interest in expanding existing storage facilities but would be willing to consider constructing a new facility if the location is near their farming area, as well as a paved road. Increased costs in erecting a new facility are not a concern for this farmer if the long-term profitability will provide a higher return than the current investment (Kastens & Cott, 2021).

3.2.2 – Operation 2

Although Operation 2 does not currently have private grain storage, knowledge about the subject was abundant and the potential desire for private storage in the future was expressed if the right circumstances arose. The owner of Operation 2 expressed that technology is a fact of life that is essential in today's farming environment. It is imperative for technology to be easily interpreted and for records to be accurate. Information is what the owner of this operation uses to guide everyday decisions. Since Operation 2's owner does all the planting, through having accurate plant population information, precise reactive and proactive decisions while planting will be attainable.

Operation 2 expressed the importance of having access to information at all points of the farming process. Being able to have individual monitors in tractor cabs to capture output operation progress while planting the crops is imperative from a managerial standpoint. This allows the operator of the equipment to monitor all stages of the farm from the cab. Examples being, moving pivots, turning on fans in grain bins, and checking moisture sensors. When asked what aspects are most valuable when considering investing in private grain storage, the owner of Operation 2 said that location in proximity to farmland is essential.

During harvest, all potential locations would have to be able to handle the heavy truck traffic and be as close to the owned farm ground as possible. Not having the location housed on a dirt road is also a key aspect when faced with the decision of picking a storage location. Since Operation 2 doesn't have private storage in place at the current time, expansion is not an option, thus making the initial decision of placement even more important. After discussing how far Operation 2 would be willing to haul harvested grain to a private location, 20 miles was the optimal distance for the owner. However, if feasible the establishment of a facility within a ten-mile radius of the current farm ground would be the best case scenario (Schroeder, & Cott, 2021).

3.2.3 – Operation 3

Implementation of more traditional farming methods is what Operation 3 relies upon. The only types of technology utilized are the Green Star GPS systems for John Deere tractors, and the use of autosteer. Although this operation is smaller scale, the importance of private grain storage is paramount. An employee of Operation 3 stated that a myriad of decisions must be made before construction. The most important aspect to consider when investing in storage is proximity to fields. Having the site on already owned land was also a requirement for this operation as additional funds weren't allotted for new land purchases. Availability to well maintained roadways is also a significant factor to be considered.

This operation currently has 20,000 bushels of storage on-site with a maximum of 40 miles of travel necessary to reach the facility. Although this distance is larger than the optimal distance of 30 miles for this operation, transport is still done if grain is unable to be hauled directly to market. When discussing expansion options for storage, the employee explained that growing substantially wouldn't be financially feasible at the current time but a goal of adding an additional 15,000 bushels per year would be optimal to keep up with current crop yields. If additional storage was attainable, the ability to hold grain and take advantage of higher market prices throughout the year would be a new option for Operation 3 in which they are not experiencing currently (Miller & Cott, 2021).

3.2.4 – Operation 4

The owner of Operation 4 is in possession of ground and desires to hold grain in private storage but doesn't do all of the farming and field work himself. For this reason, the only technologies the farm uses daily are GPS and Autosteer for smaller fieldwork projects. Seeing as most of the ground is rented to surrounding area farmers, the technology is handled by their expertise in precision agriculture where the owner of Operation 4 is more concerned with private holdings of grain after harvest. When comparing to other interviews, this farm is unique as the land in ownership spreads across multiple states. Because of the extreme distances between large tracts of land purchased, Operation 4 is constantly aware of logistical needs and finding opportunities to cut costs. Therefore, private storage has been invested in to hold all of Operation 4's share of the harvest each season.

When asked what the most important qualities might be when investing in private storage, the owner stressed the importance of location chosen as well as the cost per bushel stored. Having the best possible location to erect a storage facility was dependent upon multiple factors for this operation. The need for accessibility throughout all the seasons was topmost priority. Tractor-trailer semis must be able to enter and leave the facility in an efficient and clean manner. Proximity to power sources is another aspect to consider when faced with the task of choosing a potential location. If no power source is immediately available, the owner recommended pricing different power options if the tract of land was the best possible option fulfilling the other criteria. Strategic building layout was also important to consider after finding the initial construction site. Although a location might be chosen, deciding what direction the facility should face, and the most efficient route for the graincarts and semis to take have to be decided upon as well.

Since Operation 4 has land spread over many states, having close on-site storage is a priority. There is less than three miles between every field and a private storage location for this landowner. It would be optimal to have smaller storage options with a higher frequency in location, than to have one large grain facility and pay freight to haul the large distance. When asked how far the operation would ideally like to have their storage locations distanced from one another, the answer averaged to roughly one mile. At the current period, Operation 4 has 125,000 bushels of private storage and plans to construct new facilities on each new piece of property purchased. During the current economic climate, the owner of this operation has been able to expand storage capacity by 12,000 bushels per year. However, the figure is dependent upon availability of new land to purchase and supplies of grain facility construction materials. In the conclusion of the interview, the owner of Operation 4 expressed the desire to continue to add storage as fast as possible when new land is acquired regardless of cost of construction (Hamadah & Cott, 2021).

3.2.5 – Operation 5

Precision and diversified agriculture is this operation's specialty. They are quick to adopt new technologies and merge technology with traditional farming practices to get personalized efficient results. A manager of Operation 5 expressed the importance emerging technology has in the farming industry and how the farm relies on technology to become more efficient. The smartphone is used consistently throughout the day to keep track of equipment locations, monitor sensors and check employee locations. This operation has irrigated ground, so a program called AgSense is used to monitor irrigation status and application rates. GPS, variable rate application during planting season, and yield monitors are all used at various times throughout the year too. Operation 5 also handles all their own chemical application so having pulse width modulation on the sprayer booms allows them to better control the rate of application. However, the most used technology for Operation 5 would be Operations Center powered by John Deere, in conjunction with Conservis. Operations Center allows the managers of this farm to monitor equipment, track yield and application rates, and manipulate data from prior years. This information is gathered by each John Deere machine and is then sent to the Operations Center account. Conservis is then implemented to add pricing information for all application processes throughout the year. Using both together allows the operation to optimize the best application rates to minimize cost per acre in order to maximize overall profit levels.

Grain storage is greatly valuable to Operation 5 and having a grain facility ready to store year-round is of utmost importance. A recent new storage facility has been constructed using the latest technologies which allow for customization of grain moisture levels and optimization of overall grain storage conditions. With the addition of storage comes the adoption of remote grain dryer monitoring which is a capability of controlling the grain dryer from any location with a smartphone. Moisture sensor cables are also used in each bin to monitor storage conditions and alert the manager if moisture levels or temperatures are out of the optimal range.

When constructing a new storage facility, Operation 5's manager stressed the importance of choosing an optimal location. The highest valued assets of location for this farm were the ability to obtain 3-phase power to fuel the facility, be erected near roads that are user friendly in all weather conditions, and be centrally located to the farming area. To go along with these requirements, thoughts about drainage, sourcing of natural gas, and logistics of bin layout should also be considered before making the long-term investment. After discussion on possible expansion options for Operation 5, it was concluded that the farm would like to not only expand their current capacities at multiple locations, but also consider erecting new facilities in different areas. When thinking about constructing a facility of this magnitude, the manager stressed the importance of always thinking about future opportunities. He also recommended planning a new construction site with the idea that more storage will be added in the coming years. When picking a location, think about relation to current markets being used as well as potential new markets. Although having the storage site centrally located to the current farm ground is essential, considering where possible new opportunities can arise, is also significant.

The furthest distance Operation 5 is currently hauling harvest grain to their own storage facility is 47 miles as the crow flies, or 60 trucking miles. The manager expressed that this distance is often too far to be the most profitable, so oftentimes trucks are sent directly to market unless moisture levels prohibit the ability to do so. A desirable trucking distance for this operation would be about 15 miles depending on the size of the field in proximity to storage location. Although the manager was willing to haul around 30 miles to the private storage, anything over that would be a hinderance and the preference would be to haul to the elevator instead. This operation currently has over 900,000 bushels of private storage available and is looking to build more as temporary storage methods such as grain bags are currently in use every year. A target of 30,000 bushels of private storage would be the desired rate of increase for Operation 5 (Cott, R., & Cott, K., 2021).

3.2.6 – Operation 6

Operation 6 is a larger scale commercial operation which relies heavily on technology and precision to run efficiently. The owner is constantly using applications that update him on all aspects of the operation from employee location, to fuel levels in equipment. My Operations by John Deere is used many times per day to track field data and manage field operations. MiFleet is then utilized to track the location and optimize shipping routes from the harvest field to different storage and selling locations. The owner of Operation 6 also stressed the importance of everyday organization applications such as email, text messaging, and group messaging software to manage groups of employees. With the implementation of data management systems, and system sharing, Operation 6 has been able to manage groups of employees with minimal stress while achieving high efficiency. Although this farm uses various forms of technology every day, when asked what types of technologies are used most, the answer was all of the Cloud based options. This is due to the ability to have all employees see updates and instructions anytime during the workday. Managers also use these platforms to coordinate work schedules, send out daily tasks, and manage the harvest schedule for various crews.

When tasked with storing grain at an operation this size, Operation 6 must plan for massive expansion in the future. Discussion of the importance of location to field was top priority for this business. However, being located near well-constructed roadways, and near convenient avenues to reach the buyers in the market is also key. Their trucks must be able to easily reach the dump pits year-round and quickly load and unload to keep the operation profitable. Access to power is also vital when constructing a site and the requirements for 3-phase power, and natural gas are non-negotiables for this operation. The owner of Operation 6 also mentioned the importance of doing the research and having a well thought out plan before constructing in order to minimize costs, which will in-turn, maximize potential profits in the future. Aspects to think through when planning a new bin site would be to consider drying the grain using a grain dryer, or if the normal aeration on steel bins is adequate. Speed of conveyance of grain is also vital. Choosing the right materials to convey the grain in and out of the bins will need to be considered when erecting a new site. Remembering the small details can make a major impact in the final result of the facility.

Operation 6 is spread out over a range of 555 miles total which is why the importance of choosing an optimal location for a grain facility is vital to the owner of this farm. With their over 1.7 million bushels of private storage already constructed, the operation is looking to continue to erect new storage facilities in the coming years. A goal of 125,000 bushels additional storage per year has been created with hopes that it will be financially and logistically attainable. A key goal for Operation 6 in the current economic climate is the decision of whether to expand their current large private facility that is centrally located. Another option would be to create a whole new grain facility with top-of-the-line technology and logistical layouts. With the new technologies of remote dryer controls, moisture sensors, and aeration controls now available, the owner of Operation 6 has more power to control an entire facility from a different geographic location than ever before. In order to fulfill the goal of optimal location for Operation 6, the owner has begun looking into new construction sites that would be optimal for the farm's circumstances and financial standing (Vulgamore, & Cott, 2021).

3.2.7 – Operation 7

Located in the corn belt, Operation 7 combines emerging technology and precision agriculture to accrue the highest yields per acre. Having the ability to consistently monitor field operations and store data for efficient interpretation is vital to this farm. An extensive amount of data storage is needed in this operation, so additional software is used in tandem with one another such as My Operations management from John Deere, grid mapping and soil testing trackers, and scale data. This allows for Operation 7 to constantly keep track of cost per field and the amount of bushels harvested per year. Accurate data keeping is required at this operation due to farming being done for additional landowners, and for precise contract records. At their grain facility the owner of Operation 7 uses a programmable logistic controller to run the site which he can then manage from monitors in the scale house, dump building, and from a smartphone. Moisture sensors, fan control, auger control, and dryer power can all be changed with a touch of a button. Having access to this type of technology allows the owner of the farm to be off-site and still manage the facility in order to maximize work levels.

Operation 7 has just constructed a new private storage facility and was adamant that the location of the site was the most important aspect to consider before funding the investment. Choosing a location that is centrally located to the headquarters as well as owned fields is a requirement for this operation. Luckily, Operation 7 has all the farmed acres withing fifteen square miles which allows for an optimal location to be placed in the center of the area in order to minimize trucking time. The owner also expressed that having a strong foundation and layout can prevent catastrophic events from happening in the future as a natural disaster had recently destroyed all previous storage used in the operation. Drainage, power, and layout configurations are likewise vital to ponder before constructing any facility of magnitude. Having a nearby airport was an issue for this operation as the grain leg would have been too high in the air and posed a problem for the local air traffic so a new construction site had to be found. Finally, Operation 7 emphasized the need for thinking to the future when constructing a new private storage facility of size. Leaving room for growth and making sure the current configuration can be expanded with additional dryers and bins is imperative. Although finding new construction sites is always an option, the owner has found that expanding the current site might be the best option for the operation given the centrality of the location.

Through careful consideration and prior planning, the new facility constructed on this farm was able to minimize the trucking time required for harvest. The owner of the operation stated that an optimal amount of feasible trucking miles would be around 10 miles and their facility is within that range so it would make the most sense to continue to expand their current location. However, if additional farm ground was added a further distance from the facility, a new construction site for storage would be considered. Operation 7 currently has 423,000 bushels of storage available, which is higher than the bushels produced at the current period. This farm doesn't have plans to expand more storage in the next five years but will consider adding more bins to the current location if yields continue to improve or if additional land is rented from landowners in the area. A final piece of advice from the owner of Operation 7 was to always plan for the worst to happen, consider logistics, and to never get to the point where additional payment is made because storage is not available (Mann, & Cott, 2021).

3.2.8 – Personal Interview Conclusions

To show which attributes of grain storage are the most important to each farm operation, Table 3.1 shows the ranked preferences of criteria for the construction of a private storage facility. Some operations ranked the criteria from prior expertise in the field, while other operations ranked the options based on possible future investments into the storage sector.

Table 3.1 - Importance of Storage Attributes (Ranked 1-7, 1 being most important)

Importance of Storage Attributes (Ranked 1-7)

	Access to Energy	Location in Relation to Owned Fields	Access to Technology/ Better Power Source	Ease of Access for Trucks	Amount of Land for Expansion	Location in Relation to Railway	New Location: Not Near Current Bin Location
Operation 1	2	3	2	1	2	5	4
Operation 2	3	1	5	2	4	5	5
Operation 3	1	3	5	2	4	7	6
Operation 4	2	1	6	3	4	7	5
Operation 5	1	4	6	3	2	7	5
Operation 6	1	3	4	2	7	6	5
Operation 7	3	1	5	2	4	6	6

*Key: 1-7 in order of importance with 1 being the most important. Duplicate numbers have equal importance

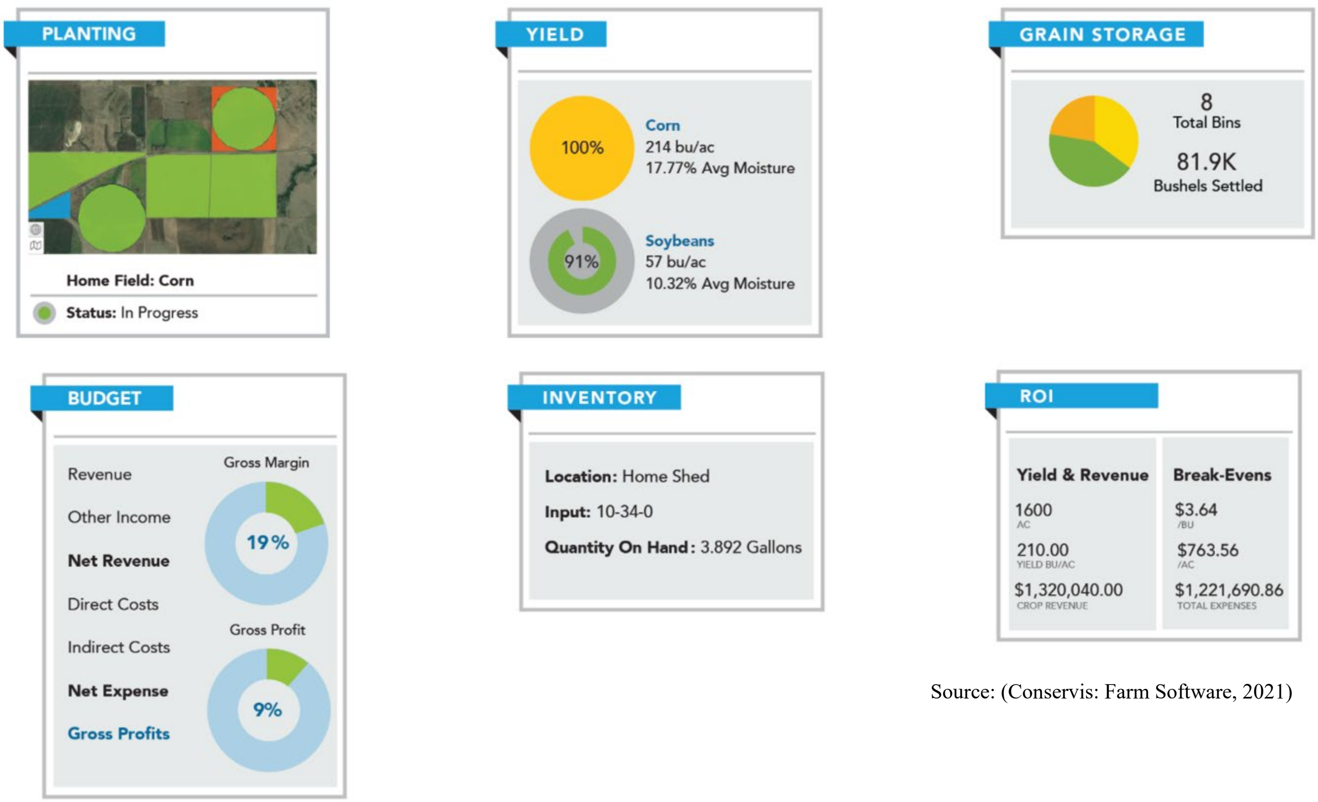
3.3 Data

3.3.1 - Conservis

Conservis is a data managing platform developed in 2008 by a group of farmers who wanted a database that would make harvest data user-friendly and give efficient readouts. Their location in the Midwest allows them to not only work jointly with farmers to solve up-and-coming problems in the industry, but also provide one-to-one support if needed. The company's focus is the management of large amounts of data which can then be easily interpreted and stored for later use or manipulation (Conservis, 2021). If a farmer is growing row crops, they can implement Conservis from pre-planting season to after harvest. Having one database to plan and hold all data allows for efficient monitoring and updating throughout the season. There are capabilities to insert an operation's budget per year as well as see visuals of quick statistics regarding acres planted and locations of infrastructure. It can link records with the John Deere Operations Center app to track progress of individual tractors in fields which is an attraction for many Deere users. With this capability, producers can monitor all machines at once while having an overview of different locations and field averages all from one screen in the database.

Since Conservis is web-based, it can be accessed from a computer in a managerial office or via the smartphone of an operator in the field. This compatibility over different platforms allows the farmer to customize as well as maximize the benefits the program has to offer. During planting season, Conservis allows the user to see satellite views of each field and uses color coordination to show which fields are planted to different seed varieties as well as variable rate application. Applicators can see what seed variety is in each row of the field as well as see an overall farm summary. During harvest, if Conservis is connected to the My Operations application from John Deere, there are visual readouts that show each field's bushel per acre yield as well as the moisture level average through all the machines (Conservis: Farm Software, 2021). After conducting interviews with various farmers, Kyle Cott said he appreciated how he can use the program to store grain logs throughout the year. This has helped him to constantly be aware of how many bushels are in private storage and what contracts to third parties are being fulfilled. Having the ability to inventory all the grain at every storage location his operation uses, has been extremely valuable. Cott also pointed out he uses the database to log all the purchased inputs from various other companies such as total fertilizer, seed, and chemical (Cott, K. & Cott, 2021).

Conservis offers multiple packages to potential customers for each operation to get the attributes they need for their specific operation. Every plan offered includes Data Management software, Harvest Management, Production Management, and Total Analytics. Various other attributes and systems get added into the software until reaching the Enterprise option which supplies Input Management, Financial Management, customized Management Dashboards and Corporate Reporting. Having various system management capabilities through one database can help the farmer analyze high volumes of data and information in a user friendly and eye-catching format. Figure 3.1 below shows the dashboard screenshot of the mobile version of the app from the manager status. (Conservis: Farm Software, 2021).



Source: (Conservis: Farm Software, 2021)

Figure 3.1 - Conservis Dashboard View

3.3.2 – AgSense

AgSense is a web-based program that helps farmers regulate their resources and make quick economical decisions by the day. AgSense is a hardware company that installs components onto center pivot irrigation towers, has grain bin sensors, and soil moisture sensors. Through the implementation of AgSense on center pivot irrigation, the farmer can see the location of the pivot in a specific field, as well as what direction it is going. On some pivots the farmer can turn the irrigation sprinklers on and off using an app. Additionally, on newer models, a farmer can change the direction of the pivot from a smartphone without being in the general area or standing next to a pivot panel. The technology stores data on how many acre inches are applied, the auxiliary relay status, as well as flow rates, end gun status, recent rainfall amounts and more. All the information is funneled through the website which can also be accessed by app, so data is readily available for the farmer (Valmont Industries, 2021). Robert Cott says "I like how I can manage all my pivots at once and if any of them break down an alert is sent to my phone. This helps me fix machines in a more efficient manner (Cott, R., & Cott, 2021)." Irrigation: AgSense Applications has the capability to send an email or phone alert whenever the machine incurs a problem. The program will send a text to the user if any sensor reaches a level above a certain threshold or if any malfunction occurs. Terry Kastens states that AgSense is the first piece of technology he looks at in the morning. "…I first check my texts – because I will have been sent a text from AgSense had something gone wrong." On top of using the center pivot information and alert system, Kastens has placed pressure monitor systems in his wells to be informed of ground water levels and if each pump system is turned on or off (Kastens, T., Cott, K., 2021).

With an interactive and user-friendly mobile app, a farmer can quickly see application reports and get yearly/seasonal totals of application rates. Alarms for cable theft are also built into the system so the producer is alerted if the span cable is being stripped or manipulated with, from the pivot itself. Each span cable sends electricity to the pivot which is comprised of eleven wires, encased in rubber which is laid on top of the pivot and is connected to each tower control box. Many safety precautions are embedded in the system as well. Collision protection is valuable if there is more than one pivot making rotations in a field at a time. If traveling at different rates, the collision prevention technology would measure the speed of each pivot and make sure multiple irrigation systems won't collide. Stop in Slot options are also available to be implemented if a farmer wants the system to stop at a certain degree or amount of a rotation in a field. This would be ideal during the harvest season when the pivot might need to be at 180º in order to fully harvest the field without driving into a span. By using Stop in Slot, the system can be set prior to entering the field through the app so no individual would need to be present in the field.

Having the ability for each farmer to customize the AgSense platform system allows for every pivot to run independently of one another. When setting up the pivot, the producer inputs the tire size for each span, how long the center pivot is, and what kind of motor drives are installed. For additional information which can further be customizable, well or water source pumping availabilities of gallons/hour can also be programmed into the system. With this information, AgSense can utilize a range of options that help producers make the highest yields possible. When making the decision of how much water to apply per field, a farmer has a variety of options to decide upon using the interactive capabilities. The first option being choosing a percentage of moving time over an interval of ten. To explain, if the system was set at 30% the pivot would be in motion for three minutes out of ten. Or if the system was set to 100% the pivot would be constantly in motion. A second option would be for a specific value to be input into the system and AgSense would use the information programmed at the original setup to calculate how fast the pivot needs to travel to accomplish the desired application rate. If a farmer wanted to apply 80/100, AgSense can figure the exact percentage the pivot would have to travel to get a consistent application rate. The final option is the Variable Rate Irrigation Application which is a newer intuitive system designed to be extremely accurate with application rates.

When deciding to implement the variable rate application system, it begins with soil tests or an analysis of the topography of the land the system is going to be set on. A producer can then choose how much moisture is applied to certain areas in the cycle of the system. If a producer had a system set up to make a full rotation through both a row-crop field as well as a hay meadow, the producer might choose to run the system at 30% during the row-crop section and 100% over the hay meadow. If programmed correctly, the producer can save money by only watering sections of the field most valuable per rotation. Since all of these specifications are set up through the AgSense platform and controlled remotely, a person doesn't have to go to the field itself and manually adjust the control panel. It also allows for a user to adjust and set all the pivots owned at one time and monitor them from afar. Furthermore, if producers decide to upgrade pivot systems or switch pivots, the control panels can stay in place through the upgrade process. This means that no rewiring or electrical work will have to be done when making changes, saving the farmer money, time, and permit costs (Valmont Industries, 2021).

3.3.3 – AGI Suretrack

AGI Suretrack is a grain bin monitoring system which also provides information on conditioning. Having the ability to trace grain storage conditions in order to increase value of crops is the ultimate goal of the Suretrack technology. If a producer made the decision to invest in Suretrack, they would have access to soil probes in order to monitor soil conditions before the grain is harvested. The information gathered through the growing season is made available to the producer in a concise format for ease of understanding. Weather conditions, rainfall, and windspeeds are also monitored through the same sensors.

When it comes to storing the grain in bins, Suretrack embeds sensors into each bin that tracks fan speeds, heat readings and air quality. The purpose of tracking these three criteria is for the producer to be able to make an instant decision on when to turn the fans of the bin on or off depending on the temperature of the grain and the air quality in the structure. The BinManager component of Suretrack monitors grain moisture content in each bin and can be programmed for the fans and dryer to automatically run in order to achieve desired moisture levels throughout the unit. In addition, if a grain dryer is part of the grain facility, air pressures and temperatures are monitored with updates sent to the farmer using a preferred method of text message or email. When it comes to powering the grain dryer, Suretrack has safeguards in place for the use of natural gas as well. Tank Manager is an additional sensor system connected to the Suretrack database that monitors stores of natural gas or diesel and will automatically order more of a fuel if needed (Johnson, 2019).

Suretrack uses internet connection to connect each bin's sensor system to the database which can be accessed through the app or from the website where the farmer can look at colored temperature readings of every part of the bin. The visual 3-D view uses thermal imaging to show how air flow traveling through the grain is affecting the temperature in all areas. As long as the sensor system is connected to an internet source, data is being collected by the database. The user can open the app on their smartphone or visit the website to see the visual readouts and make adjustments accordingly. With the capability of seeing temperature changes through the entirety of every bin, a manager can set the Suretrack system to only operate when air would be most productive for cooling or heating. All the fans and heating elements can be directly connected to the sensors too, so the operator won't have to be physically present at the bin to monitor the moisture progress.

AGI's technology promises consumers that Suretrack will pay for itself in roughly two years. This savings comes from reduced energy costs, and extremely low spoilage rates. According to Brad Berk, a new investor in the BinManager technology, "The BinManagers paid for themselves the first year they were installed" (AGI Suretrack, n.d.). One of the highly desirable selling points of the Suretrack technology is that every aspect of the sensor system, fans, and dryers can be controlled remotely. This allows farmers who are developing grain storage away from their main hub to keep an accurate account of what is happening at their storage site miles away (AGI Suretrack, n.d.).

3.3.4 – OPI Blue

OPI Blue is an entity of the OPI Systems Incorporated company. Their software is meant to help farmers better monitor grain storage levels to lower costs and lower spoilage. Some of the product attributes of OPI Blue are the consistency of informing the producer with status updates of each grain storage facility. Through moisture monitoring from nodes hanging down from the top of the bin, specific moisture content can be measured at any given time from all parts of the structure. Temperature monitoring is also embedded in the Blue system as hot spots are being searched for and handled with automatic fans. With the link of the temperature monitoring system as well as fan control, the user can set the system to automatically cool the grain and circulate air when specific temperatures and moisture contents are hit. Having a consistent neutral temperature below 50 degrees helps reduce the number of hot spots which create an appealing atmosphere for mold and insect growth (OPI Systems, 2021).

Producers are often looking for a low stress option when it comes to monitoring their grain stores and OPI Blue offers that. Through the constant monitorization of weather surrounding each bin, humidity and temperatures are factored in the system and the decision for the lowest cost option to aerate grain is already decided. By having the system decide when aeration occurs, the producer isn't having to be present on property to start the fans or worry about external weather factors. All these decisions are made by OPI in the background and updates are sent to the producer in order to minimize manpower and time spent on grain monitoring.

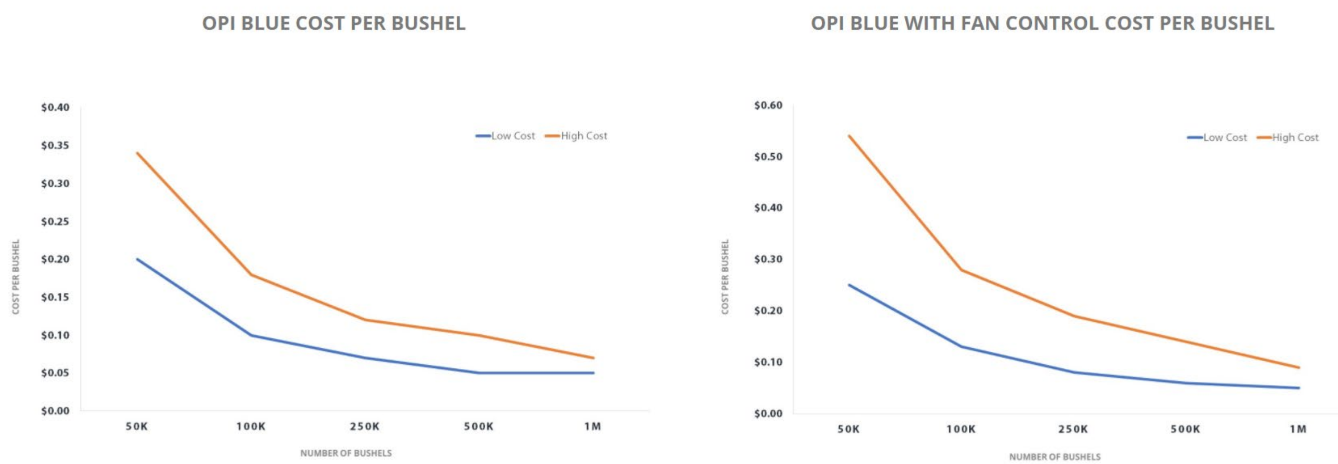
Along with having moisture and fan controls, each OPI System includes sensors to provide an accurate reading of how many bushels of grain are in each bin. This can also be seen visually on the mobile app which is shown below in Figure 3.2. The only requirements of the OPI Blue system are the need for internet access and the ability to support the power necessities for the fan controls and sensors. Since OPI uses the cloud to house data, a producer never has to worry about the information not being readily available. If there is internet connection, digital readouts and monitor systems are available to be changed and manipulated around the clock (OPI Systems Inc, 2021).

Source: (OPI Systems Inc, 2021)

Figure 3.2- OPI Blue App Display

OPI Blue strives to make grain monitoring a simple process for the user. The company is trying to reduce stress on the producer and make grain storage less worrisome. In order to eliminate confusion, OPI's database and mobile app have a user-friendly interface that primarily relies upon pictures and color usage to correspond with temperature and measurements. This tracking is mapped through moisture cables dropped from the top of the structure. With the implementation of moisture cables, grain can be constantly conditioned which will allow for higher payoffs at the end of the storage period. When constructing the bin, it is imperative the farmer has a proper aeration system for grain to stay safe, hygienic, and last for extended durations of time. With the sensors and cables installed with OPI Blue, a producer can use natural aeration in order to minimize the cost of storage as well as conserve energy usage.

From a financial perspective farmers and producers are always looking for the rate of return on investment. OPI Blue markets their system as a low-cost option that will pay for itself in a timely manner. By having constant monitorization, shrinkage rates will be reduced and spoilage percentages would decrease which offsets the initial investment and creates profitable returns in a shorter amount of time. Looking at Figure 3.3, it is shown that a farm averaging 200,000 bu in storage would only pay \$0.10-\$0.30 per bushel for a constant monitoring system making it a feasible technology option for producers growing their private storage (OPI Systems Inc, 2021).



Source: (OPI Systems Inc, 2021)

Figure 3.3- Cost Breakdowns per Bushel for OPI Blue System

3.3.5 – MiFleet

Logistical management is a necessity when it comes to transferring and hauling grain to storage locations or fulfilling contracts. MiFleet is a Fleet Management Platform that helps users combine unit tracking, efficiency data, and maintenance needs all from one program. There are many types of tracking options available to consumers ranging from individual driver tracking through phones, to tractor and trailer systems.

MiFleet markets their products to be user friendly and easy to install on all types of transportation equipment and materials. Tracking can be as easy as following the three simple steps they advertise on their website. If a semi is desired for tracking, the user will first plug in the diagnostic device onto the tractors diagnostic port, mount the tracker on the trailer, or install the app onto a mobile device. The diagnostic device then measures driving patterns, captures speed fluctuation, and provides constant location tracking to administrators. The third step of the process is monitoring the data captured through the website or application on a mobile device. MiFleet allows administrators to get updates on fuel costs, fuel efficiency of the vehicle, track drive time, record driver behavior and more. A unique capability offered through the fleet software is the ability to geofence boundaries. If a driver takes their tractor-trailer outside of a set boundary an alert is sent to the administrator alerting them of the situation and location (*Heavy Duty – MiFleet*, 2021).

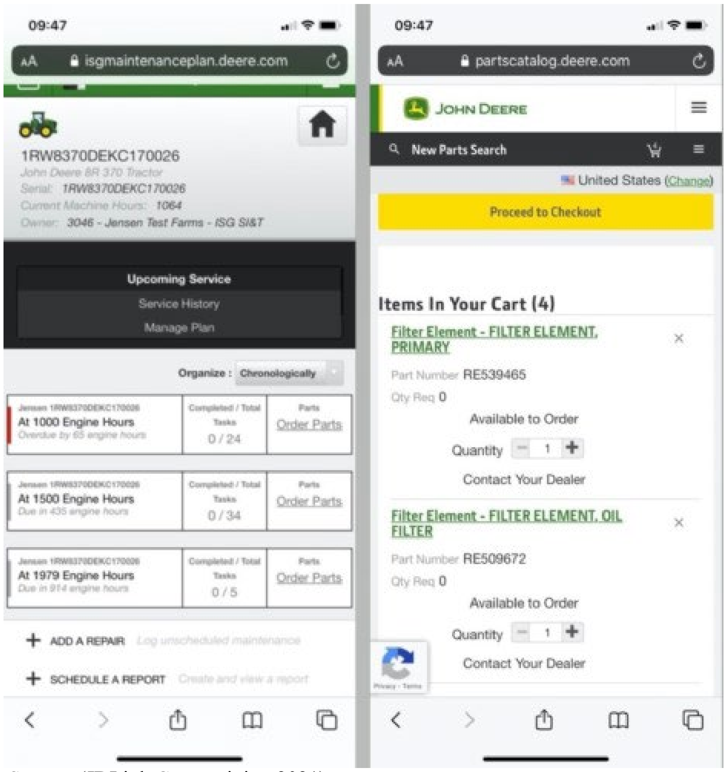
With administrator access, multiple portals through the app and website can be personalized for the business. Having mapping software embedded into the program allows for a manager to see a precise location of every asset associated in the MiFleet system. If the geofence boundaries are used, the tractor-trailer operator will know that if they decide to take their vehicle "out of bounds" an administer will get an alert and the individual will be tracked and monitored for suspicious behavior. MiFleet is equipped to send alerts in multiple ways in order to best inform the administrator. Options include, text message updates, banners for notifications through the app that show up on the user's home screen, and email alerts.

Additional features can also be added on to the basic software that the fleet tracking system provides. Driver logs can be added to each tractor to monitor drivers' performance and collect data on engine hours, and record of hours logged per employee. Speedometers are optional installations for managers who are concerned about safety habits of drivers or are wanting to find the most efficient and economical speeds to offset fuel costs. The speedometer won't set a limit of the speed the specific driver can drive, it will just collect information about driving speeds and combine the data in the app for simple interpretation. A final example of an addition to MiFleet would be weather tracking software. An OpenWeather option shows drivers and managers the driving conditions on a global scale so all drivers can be prepared for the setting they're entering. OpenWeather shows pressure systems, precipitation levels, radar displays, temperature readings, and wind speeds. This information is often useful for operators to stay as safe as possible and avoid dangerous situations by choosing different routes if necessary. MiFleet markets their software to be a comprehensive way to keep track of all aspects of logistics through the trucking industry and more (MiFleet Software solution, 2021).

3.3.6 – Operations Center: John Deere

Operations Center is a database that John Deere equipment users can use to manage their operation from equipment details to field averages and satellite imagery. The database is aimed to provide instant information to the user at any point in time from any location. According to their website, Operations Center is built in four steps in order to bring maximum returns to the user. Step one is to setup the farm itself into the system. By inputting the base information such as location of each field, and establishing all machinery in the system, it allows for an accurate account of inventory and minimizes mistakes such as data errors in the future. Step two is the planning of work that needs to be done during a specific time period. This step allows all the users of the Operation Center platform to see what needs to be accomplished for the business and allows for cohesive communication from an employee standpoint. Another benefit of step two is that when using machinery in the field, the screens in the tractor will connect to Operations Center and provide all the notes and planning at the touch of a button. Step three is monitoring the farm; this can be attained through multiple methods. Monitor tools are embedded in the database so managers can always be up to date on equipment, employees, as well as the progression of harvest, planting, and more. The final step is the analyzing of performance. After a season is complete, Operations Center will provide the user with trends, specific field data, and a summary report for the entire operation which can be broken down by category. With this information at the operation's disposal, they can make informed economic decisions for the next growing season (Deere & Company, 2021).

JD Link is another aspect of Operations Center in which users can get information on each piece of equipment in order to keep informed of investments at all points in time. JD Link uses Green Star GPS to locate each piece of machinery and keep its location current on the Operations Center app. When tapping or clicking on a specific piece of machinery in the database, readouts will appear that allow informed decisions to be made. Maintenance schedules can be shown, required parts are listed, and links for individual parts to repair an issue are all available through the app. In Figure 3.4 the screenshot shows that there are multiple pages giving supplemental information for every piece of machinery. Quick information that can be found when tapping a tractor are the location, current activity, engine hours, fuel and diesel exhaust fluid levels, alerts and more. Administrators also have the capability to give location tracking and machine level information to specific members of the Operations Center group. This allows for confidential information to be kept secure and locational data hidden if a manager doesn't want all employees to have access to this information (JDLink Connectivity, 2021).



Source: (JDLink Connectivity, 2021)

Figure 3.4 - JD Link - Mobile Parts Order In-App Display

Data sharing is a large part of why Operations Center is available on the inside of each tractor cab. With in-field data sharing, operators can share field maps in order to coordinate guidance lines for auto-steer, match machine speeds, and coordinate field harvest layout patterns. Grain carts can also use the location and bin capacity readouts to see which combine will need to unload first, thus allowing the operator to make informed and efficient decisions in the moment. This sharing ability also allows each user to see yield averages of the other machines in the same field, or in a completely different field. Product placement can also be improved upon through data sharing over different seasons by monitoring application patterns of planting, spraying, fertilizing and more (In-Field Data Sharing, 2021).

Connect Mobile, and Harvest Mobile are other options that can be used to monitor performance of different types of machinery through the My Operations portal. These platforms are jointly connected and provide supplemental information regarding yield quality, yield history, and alerts to the operator.

3.3.7 – Data Conclusions

All farm operations agreed that technology is a vital part of the precision agriculture realm and is essential for day to day farm management. All operations implemented some form of technology into the operation and utilized it daily. There is also a myriad of technologies available to agriculturalists to increase efficiency, manage the operation, and lower production costs. Table 3.2 below, shows a breakdown of each farm operations data management systems implemented by each farming operation.

Table 3.2- Operation Overview: Storage, Freight, & Technologies Implemented

Operation Overview: Storage, Freight, and Technologies Implemented

	Amt of Storage (bu)	Miles willing to travel to Grain Facility	Optimal Travel Time	My Operations	OpiBlue	AGI Suretrack	GPS	AutoSteer	Conservis	AgSense	MiFleet
Operation 1	700,000	35	<16	1	1	1	1	1	0	0	0
Operation 2	0	20	10	1	0	0	1	1	0	0	0
Operation 3	20,000	30	15	1	0	0	1	1	0	0	0
Operation 4	125000	27	1	0	0	0	1	1	0	0	0
Operation 5	985,000	30	15	1	0	0	1	1	1	1	0
Operation 6	1,700,000	40	20	1	0	1	1	1	0	0	1
Operation 7	423,000	15	10	1	0	0	1	1	0	0	0

Chapter 4 - Methodology

4.1 Overview

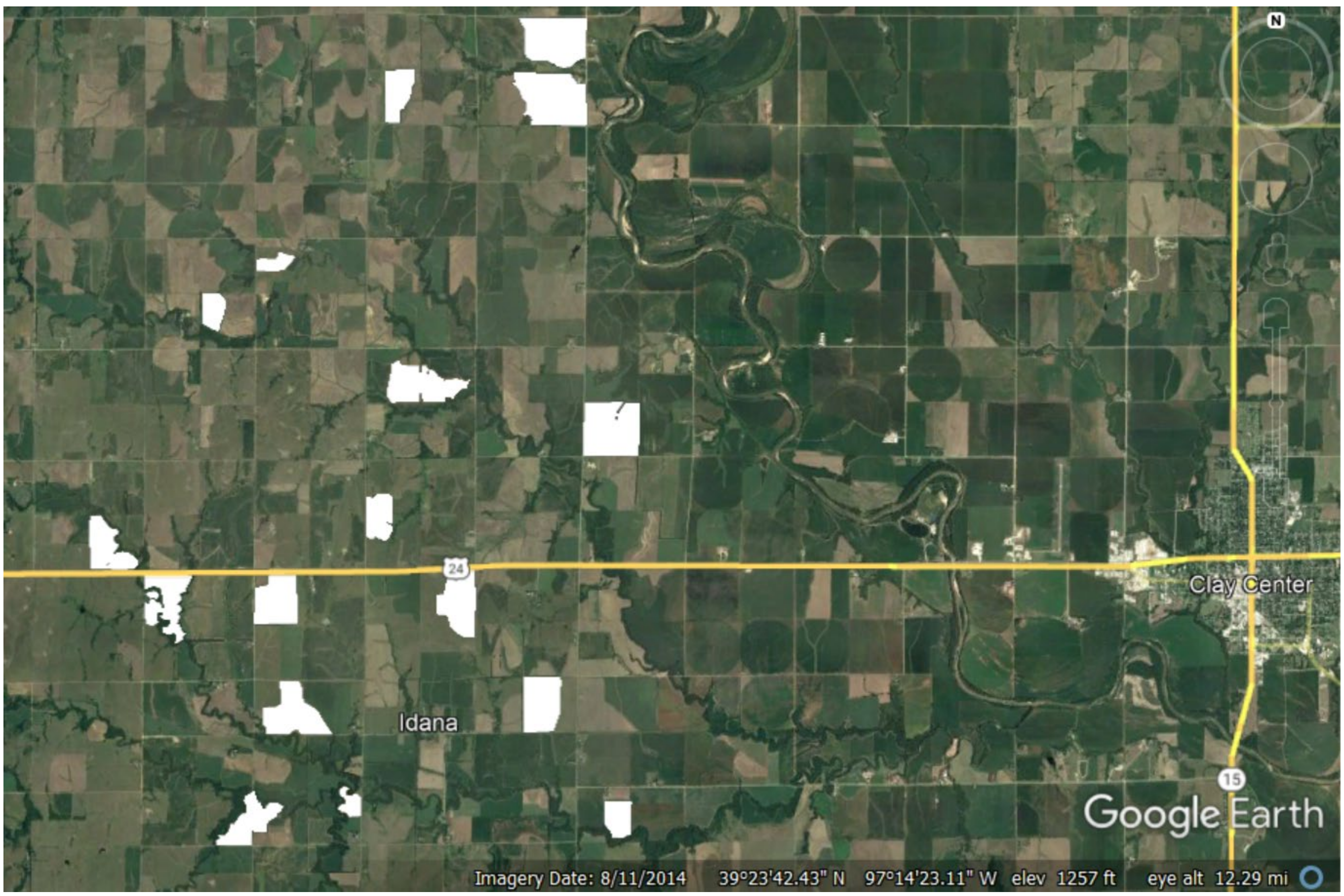
In order to respect privacy and data, a concept farm will be developed in order to run simulation models and predict various outcomes for linear minimization models. Development of a concept farm is conducted to implement both the technology considerations found through the interview process and combine those considerations together to create a precision agriculture concept farm to run optimization models with. This concept farm will draw on knowledge gained through the interviews with different farming operation owners as well as types of technology available to the current agriculture industry. By having a concept farm, the data interpreter can see how differing yield levels, location, and technology implementation factor into the optimal placement for a private grain storage facility.

Individual pieces of land owned by the concept farm are crucial to getting realistic results that can coincide with operational farms today. Keeping land acquisition and holdings practical is crucial in the development processes. Furthermore, after deciding which plots of land are going to be acquired for the conceptual farm, data will be found to give credibility for an average yield output for the area. Types of technology used in the growing process plays a significant factor on the yield during harvest, as well as the location, soil type, and irrigation patterns. Because of these factors, the concept farm will utilize multiple types of precision agriculture technologies currently on the market. An ultimate goal is to have a conceptual farm that is not only realistic when it comes to production data numbers, but easily interpreted by farmers in the industry.

4.2 Conception of Farm

4.2.1 – Geographical Area

In order to fall within the range of experience for development, ground was chosen utilizing Google Earth Pro around the area of Idana, Kansas. This specific location was chosen as options for irrigation implementation are available in this area. Data regarding road quality is also posted for this area and can be easily seen on Google Earth Pro as well. Fields were chosen in a realistic pattern with space between field boundaries. A total of 19 fields were selected with a total of 304 irrigated acres and 1,153.9 dryland acres. This data selection can be shown on a satellite view in Figure 4.1 below as the white fields. To further summarize the geographical data in acres per field selected, Table 4.1 can be utilized (Google Earth Pro, n.d.).



Source: (Google Earth Pro, n.d.)

Figure 4.1 - Satellite Imagery of Selected Fields

Table 4.1 - Field Acreages

Field Number	Acreage	
1	101	
2	45.4	
3	31.2	
4	44.3	
5	113	
6	46.3	
7	53.6	
8	36.3	
9	23.7	
10	111	
11	79.7	
12	163	irrigated
13	141	irrigated
14	58.7	
15	100	
16	85.4	
17	148	
18	54.9	
19	21.4	
	1457.9	Total

Percentage distributions of crops for storage at the proposed facility are 10% of space for soybeans and 90% of facility space for corn. This is due to past trends from the yield data collected which was decided originally from a basis standpoint using historical basis data. It was found that if grain is stored through the year, a stronger basis can be obtained in the months before harvest rather than during the harvest season or directly after. Since on average the basis for corn lends to higher profits, a much higher percentage of corn will be stored at the facility. This decision also lends itself to being able to take advantage of starting corn harvest multiple weeks ahead of surrounding farmers with the dryer at the storage facility. Now the concept farm can harvest high moisture corn and dry into the desired moisture and sell to customers before the basis drops during the regular harvest season. By having a storage facility that allows for the drying of grain as well as for extended lengths of time for storage, the increased basis rate that occurs before harvest can be captured and profited upon.

4.2.2 – Technologies

Having accessibility to data is crucial for any farm operation to make logical decisions and keep track of past choices. In the current technological environment, copious technologies are made available to the producer in order to manage each farm intensively. This concept farm will be implementing multiple types of precision agriculture technologies in order to achieve realistic data readouts and control managerial activities from a smartphone. By utilizing these forms of management, yield data can be tracked which will provide a weighted scale of importance of potential optimal location of a private grain facility in relation to highest yields being produced per acre.

The concept farm has 304 irrigated acres in the ground selected. In order to manage this ground and see application rates of water, AgSense pivot management will be used. This application will allow the concept farm manager to track pivot progress in the field, move the implement if it happens to be in an inconvenient location during harvest, and manage water application rates which will affect yields produced. AgSense is already in use on the concept farm currently and the farm manager is adept at customizing the program to achieve peak results for the acres it is correlated with.

Another type of technology currently in use by the concept farm would be Operations Center by John Deere. Seeing as the farm is running John Deere equipment, Operations Center comes standard on the newer equipment currently being operated. With the usage of this software, comes the data collection that the farm manager uses to look at various application rates, historical yield data, and visual imaging. This concept farm also takes advantage of the guidance systems and machinery monitorization software included.

In the future, the manager of this concept farm would ideally use AGI Suretrack or OPI Blue to monitor levels in the new private storage facility being built. With this addition of storage, comes the necessity of monitoring grain moisture levels, drying speeds, and temperature throughout the bins. Although both AGI Suretrack and OPI Blue are potential options for this farm owner, the bins being selected to be manufactured will be the deciding factor on what grain monitor technology will be chosen. However, AGI Suretrack is only able to be implemented on AGI steel bins which makes the technology harder to obtain. Luckily a manufacturer of AGI bins is near the geographical location of the concept farm so this bin brand will most likely be the lowest cost option making the AGI Suretrack technology most likely to be chosen.

With the addition of bin monitoring technology on this farm, the location of the private storage facility doesn't have to be close to the farm's headquarters. Minimal amounts of manpower are needed at the facility itself to make the storage operational year-round. Due to this reduction of manpower and attention, a facility of size can be monitored from any location on a smartphone using either the AGI Suretrack technology or the OPI Blue. These capabilities add flexibility to location placement options for the concept farm which allows for other desires to be met in terms of permanent location.

4.2.3 – Yield Data

For the purposes of this optimization process two crops have been chosen, corn and beans, and information about each field's yield history are listed in Table 4.2 below. As is commonly known in the agriculture industry, irrigated ground gives higher yields per field on average than dryland. This concept farm has a mix of both types of ground in operation, so these differences are accounted for in the yield outputs as well as total bushels produced per field. A timespan of the past 5 years has been accounted for with the average being used in the optimization process. This data was found using the Operations Center by John Deere technology that is currently being utilized on the concept farm.

Table 4.2 - Yield Data per Field (5 Year Span)

Yield Data (bu/acre)

	Year 1		Year 2		Year 3		Year 4		Year 5	
Field Number	Corn	Soybeans	Corn	Soybeans	Corn	Soybeans	Corn	Soybeans	Corn	Soybeans
1	139		142		129		143			57
2	136		131		135		145		145	
3		61	143			57	131		127	
4	129		138			63	125		137	
5	143		142		132		127		133	
6	138			55	137		141		140	
7	139		136		142		141			65
8		58	137		126		130		122	
9		64		56	134		142		129	
10	141			58	139		136		127	
11		57	141		138		142		133	
12	197		214		227			64	189	
13	205		220		221			62	201	
14		57	129			60	117		140	
15	127			56	118		135		138	
16	129			57	124		133			58
17	119		129			59	137		119	
18		56	134		140		136			62
19		62	124			57	139			57

With the current planting configuration to conform to the concept farm's decision of 90/10 desired storage ratios, the storage facility will follow the same pattern as previously stated. With this yield data, averages will be used in the optimization problem from the five-year data set in order to find realistic production allotments per field to find the best location to minimize miles transported.

4.2.4 – Location Options

The concept farm manager has found three potential location options to construct a private grain storage facility. Each potential option has different requirements needed in order to house a private storage facility. A satellite view with the highlighted options is shown in Figure 4.2 (Google Earth Pro, n.d.).

Source: (Google Earth Pro, n.d.)

Figure 4.2 - Potential Location Options 1-3

Location 1 is located on the Northeast corner of Field 7 which is already owned. No cost would be associated with attaining this property and the cost of converting the necessary amount of acres it would require to build the facility would be negligible. This location is on a blacktop highway and has ease of access for trucks to maneuver and enter the roadway. Natural gas is also an option at this facility and would cost an amount of $12,000 for installation on the nearest gas line (Cott, 2021). Power requirements are easily attainable at this location as well with 3-phase power already in place. If additional power sources are required or if propane is acquired to keep on site an additional cost of $60,000 would be incurred (Cott, 2021). A reason for having both propane and natural gas as fuel options would be to power the grain dryer that is constructed at the storage facility.

Location 2 lies along the boundary of Field 12 which is one of the irrigated properties. The location is equipped with propane storage already and has access to 3-phase power. Propane will be the main source of fuel at this location as natural gas lines are not in the vicinity thus eliminating gas as an option. This property is located along a gravel road and has a circle drive already in place for trucks to maneuver easily.

A final location has been decided by the manager to be placed on the Southeast corner of Field 5. This location is on a dirt road 0.3 miles from a county blacktop surface. This location would have to be equipped with propane as well as 3-phase power in order to make it functional. Natural gas is not available as no lines run along the boundary of property. The cost of installation of propane would be the same as Location 1 with an amount of $60,000 with an upgrading of power from single-phase to 3-phase which costs approximately $10,000 from quotes of local professionals (Cott, 2021).

All location options are already owned by the concept farm so purchase prices for properties have not been included. Each location requires different costs in order to make the location viable for a private grain facility, and each location lies on varying types of road qualities. The concept farm manager is looking to find the best possible location to store grain in order to minimize trucking time and costs required. The farm manager has chosen these specific locations as options due to the area of location placement in relation to other markets the farm has contracts with or normally sells to. All three options are located less than five miles from a major highway which can be taken to fulfill these grain contracts with buyers. This prior thinking allowed the farm manager to choose locations more apt to be logistically friendly for the long run as well as the current time period when deciding location options.

4.3 Conclusions

To calculate where the optimal location of construction for the storage facility should be, the following chapter will examine various models and methods used to result in the optimized outcome. These models will factor in the yield data, and location desires in the decision. A model will then find the location that will minimize the amount of trucking time required in order to maximize efficiency. Furthermore, a minimized cost model will be used to inform the concept farm manager of where the least cost location for construction would be. In a perfect world these two locations would align but oftentimes is not the case. However, utilizing the models provided, the concept farm will be exposed to different optimized outcomes. Then the decision can be made to either minimize the cost of making the location feasible or to minimize trucking time which would lead to maximum efficiency during the harvest process.

Chapter 5 - Model

5.1 Overview

The concept farm aims to store its grain on-site in order to minimize the costs of paying storage fees at local coops as well as to maximize potential profits by holding grain in order to sell at higher prices in the future and controlling storage costs. The problem faced is where to place the site in order to fulfill desired goals. For example, the concept farm would like to build one storage facility of size instead of building multiple smaller bins at different locations. Having to decide where the optimal location to place a sizable grain facility can be an issue of large proportions when dealing with hundreds of thousands of bushels of storage and operations spread out across several counties.

By building an optimization model, the concept farm can pick an optimal location for the placement of the grain facility in order to minimize cost and minimize total travel time required. The concept of minimizing time required from harvest to facility is the focus of the concept farm but additional aspects of facility to venders can also be considered. Other farms might weigh the importance of efficiency from storage facility to final sale location more important than time consumed from field to storage facility. The model can be customized based on each farm through the constraints, including cost of freight per mile, cost of getting natural gas to the location, cost of having three phase power, and willingness of freight travel distance in order to provide a personalized result. One of the biggest nightmares the farm can have is to make a large financial decision and not benefit from the investment. By constructing an optimization problem, the information for the concept farm will be input to provide a personalized result, which pertains to the issues they would like to resolve. This would allow them to locate the best feasible area to build the new facility. By personalizing the model for specific farm operation needs, these models will help provide the information necessary to make an economical decision on the optimal grain storage location for the concept farm.

5.2 Methods

Two different models will be solved to determine the optimal location for a grain storage facility for the farm. A unique aspect of the concept farm is that monetary investment is not the chief concern of the operation, instead the concept farm is aiming to find the most efficient transportation route and use the cost model as supplemental information to look at other possible avenues. For this reason, four transportation models were constructed to find the fastest feasible route from each farm to the potential three grain storage facilities. Then four cost minimization models were run to find which location has the lowest cost. The results can be used to inform the concept farm which location is best to choose in order to minimize transportation times during harvest that will not only help with efficiency of trucking but also meet the needs of location placement for fulfilling contracts throughout the year.

In order for the model to be feasible, averaged yield data will be used with the most recent year 5 planting configuration. The average yield per crop output is figured from the yield data of the previous five years. Although the truckload numbers from each field will change as the crop rotation changes, with the desired 90/10 planting configuration, in all the truckload total would equalize in the long run. If the potential locations were further separated in geographic location, the result might vary to the point where multiple optimization models would need to be accounted for. However, since the land owned by the concept farm is not separated by a distance that would make trucking infeasible, a general planting configuration will be input into the model.

Three properties were chosen by the concept farm manager for potential location options and will be implemented in the minimization models. These locations are explained thoroughly in the previous chapter with the necessary costs associated with each property and additions required to make the property feasible for construction of a facility. Google Earth Pro was implemented to visualize field boundaries and specify accurate acre size (Google Earth Pro, n.d.). However, in order to find the time to reach one field to a possible storage facility location, Google Maps was used in conjunction with the “drive” feature to pick the fastest possible route (Google Maps, n.d.). This time was then used as the arc length in the model for each field to destination. The transportation model has a total of 54 arcs, with three potential destinations and 18 fields. However, it should be explained that the figures below are showing the path ‘as the crow flies’ but the specified arc length in minutes are accurate for real-world drive time. For reference see Table 5.1 for the arc length values below.

Table 5.1- Arc Value Definitions for Transportation Models

Arc Values: Minutes to Transport Truckload from Field (i) to PotentialStorage Location		Potential Storage Location		
		Location 1	Location 2	Location 3
Field (i)	Field 1 (i=1)	3	11	4
	Field 2 (i=2)	6	12	6
	Field 3 (i=3)	7	17	4
	Field 4 (i=4)	7	15	4
	Field 5 (i=5)	5	12	0
	Field 6 (i=6)	3	10	6
	Field 7 (i=7)	0	10	5
	Field 8 (i=8)	7	9	8
	Field 9 (i=9)	8	9	9
	Field 10 (i=10)	4	7	5
	Field 11 (i=11)	4	12	5
	Field 12 (i=12)	9	0	11
	Field 13 (i=13)	11	0	13
	Field 14 (i=14)	7	6	8
	Field 15 (i=15)	4	12	4
	Field 16 (i=16)	4	12	6
	Field 17 (i=17)	5	5	8
	Field 18 (i=18)	2	9	3
	Field 19 (i=19)	4	12	3

5.3 Transportation Model

5.3.1 – Objective

The objective of the transportation models is to minimize the total time required to transport both soybeans and corn from each field to the potential storage locations. The constraint under consideration in these problems, are that the truckloads of soybeans supplied have to be equal to the truckloads produced at each field. Because the storage location options are private, there are no demand constraints to take into consideration. These models attempt to find which storage location would be the best place to build given the amount of time required for transportation.

5.3.2 – Data Calculations

The following formulas were used to calculate the Right Hand Side (RHS) values of the constraints for the transportation problems. Table 5.2 below provides and summarizes the data used to make the following calculations.

Total Bushels/Field:

Field Size (Acres): See Table 5.2

Average Bu/Acre: See Table 5.2

$$\text{'Field Size (Acres)'} * \text{'Average Bu/Acre'} = \text{'Total Bushels/Field'} \tag{5.1}$$

Truckloads/Field Soybeans:

Average Bu/Truckload Soybeans: 850 bu soybeans/truck (Miller, & Cott, 2021)

Total Bu/Field: calculated above. See Table 5.2

$$\text{'Total Bu/Field'} / 850 = \text{'Truckloads/Field Soybeans'} \tag{5.2}$$

Truckloads/Field Corn:

Average Bu/Truckload Soybeans: 1000 bu corn/truck (Miller, & Cott, 2021)

Total Bu/Field: calculated above. See Table 5.2

$$\text{'Total Bu/Field'} / 1000 = \text{'Truckloads/Field Corn'} \tag{5.3}$$

** Truckloads/Field for both soybeans and corn were rounded up in Table 5.2 because regardless of how full the truckload is, the travel time to the potential storage facility would be the same.**

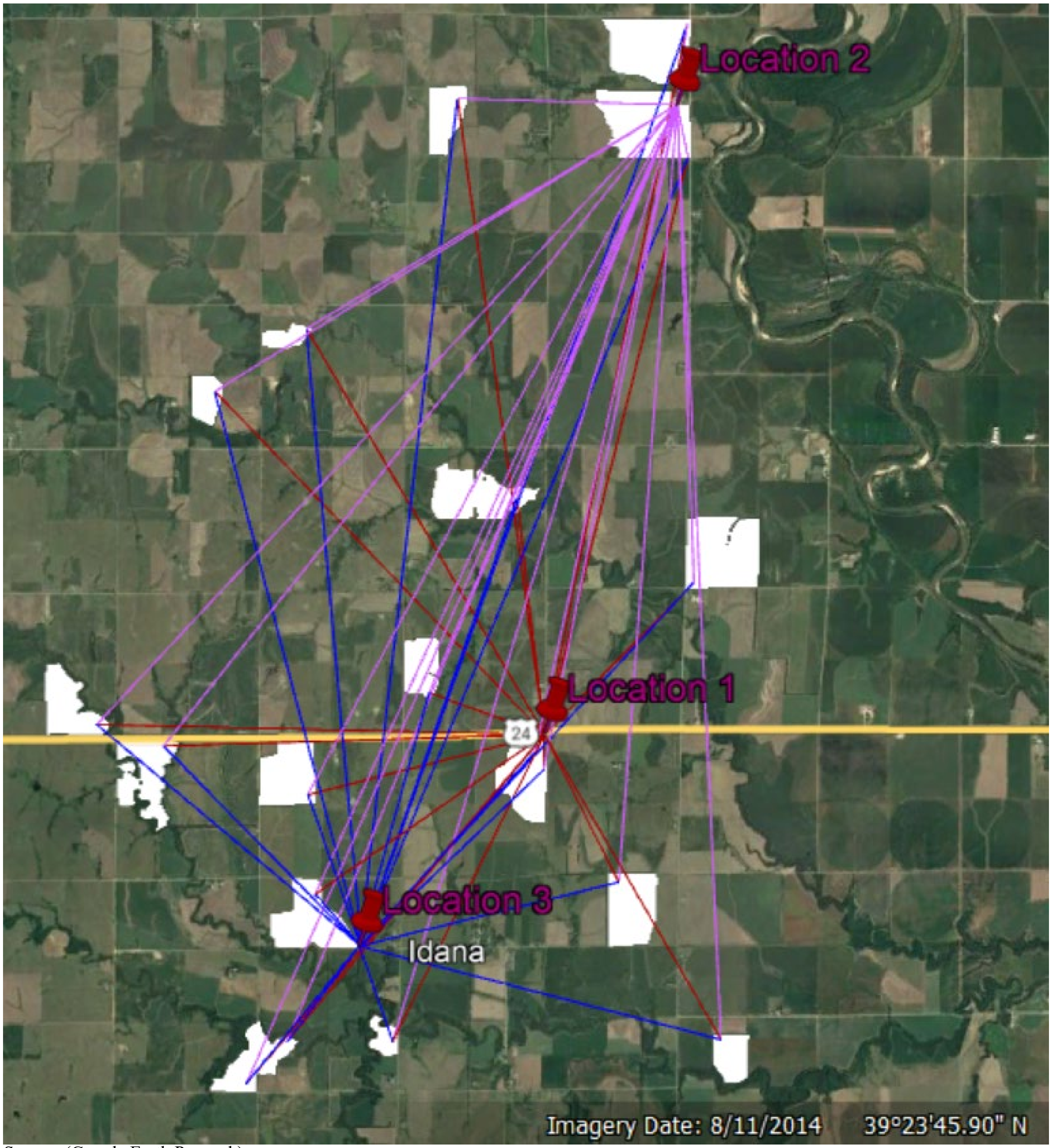
Minutes to transport each truckload (the arc values) were used as the technical coefficients and the Truckloads/Field were calculated to be used as the right hand side (RHS) values on the following transportation models. The decision variables for these models are the number of truckloads being sent from each field to potential storage locations. This data is summarized in Table 5.2 below.

Table 5.2 - Data Calculations for Transportation Models

Field	Field Size (Acres)	Crop Grown	Average Bu/Acre (5 year data)	Total Bu/Field	Av Bu/Truckload	Truckloads/Field	Rounded up Truckloads/Field
1	101	Beans	57	5757	850	6.773	7
2	45.4	Corn	138.4	6283.36	1000	6.283	7
3	31.2	Corn	133.67	4170.504	1000	4.171	5
4	44.3	Corn	132.25	5858.675	1000	5.859	6
5	113	Corn	135.4	15300.2	1000	15.300	16
6	46.3	Corn	139	6435.7	1000	6.436	7
7	53.6	Beans	65	3484	850	4.099	5
8	36.3	Corn	128.75	4673.625	1000	4.674	5
9	23.7	Corn	135	3199.5	1000	3.200	4
10	111	Corn	135.75	15068.25	1000	15.068	16
11	79.7	Corn	138.5	11038.45	1000	11.038	12
12	163	Corn	206.75	33700.25	1000	33.700	34
13	141	Corn	211.75	29856.75	1000	29.857	30
14	58.7	Corn	128.67	7552.929	1000	7.553	8
15	100	Corn	129.5	12950	1000	12.950	13
16	85.4	Beans	57.5	4910.5	850	5.777	6
17	148	Corn	126	18648	1000	18.648	19
18	54.9	Beans	59	3239.1	850	3.811	4
19	21.4	Beans	58.67	1255.538	850	1.477	2

5.3.3 – Transportation Model 1 (Total)

The first transportation model was constructed using Location 1, Location 2, and Location 3 as the destination nodes, and the 19 fields as the supply nodes. There are 57 arcs total, with one arc from each field to the three destination nodes. The arcs between the supply and destination notes represent the time required to travel from each field to each potential storage location. Figure 5.1 provides a satellite view of the transportation model diagram used to solve this model. The white shaded space shows the 19 fields owned by the concept farm. The red lines represent the arcs from each field to Location 1, purple lines represent the arcs from each field to Location 2, and blue lines represent the arcs from each field to Location 3.



Source: (Google Earth Pro, n.d.)

Figure 5.1 - Transportation Model 1 Diagram

Table 5.1 can be used for reference to further explain the time in minutes required to travel from each field to the three potential grain storage facilities. Furthermore, Table 5.3 shows the variable label between each field and storage location. For example, A_1 represents the variable label between Location 1 and Field 1 below.

Table 5.3- Decision Variable Definitions for Transportation Models

Decision Variable Chart for Transportation Models		Potential Storage Location		
		Location 1	Location 2	Location 3
Field (i)	Field 1 (i=1)	A_1	B_1	C_1
	Field 2 (i=2)	A_2	B_2	C_2
	Field 3 (i=3)	A_3	B_3	C_3
	Field 4 (i=4)	A_4	B_4	C_4
	Field 5 (i=5)	A_5	B_5	C_5
	Field 6 (i=6)	A_6	B_6	C_6
	Field 7 (i=7)	A_7	B_7	C_7
	Field 8 (i=8)	A_8	B_8	C_8
	Field 9 (i=9)	A_9	B_9	C_9
	Field 10 (i=10)	A_{10}	B_{10}	C_{10}
	Field 11 (i=11)	A_{11}	B_{11}	C_{11}
	Field 12 (i=12)	A_{12}	B_{12}	C_{12}
	Field 13 (i=13)	A_{13}	B_{13}	C_{13}
	Field 14 (i=14)	A_{14}	B_{14}	C_{14}
	Field 15 (i=15)	A_{15}	B_{15}	C_{15}
	Field 16 (i=16)	A_{16}	B_{16}	C_{16}
	Field 17 (i=17)	A_{17}	B_{17}	C_{17}
	Field 18 (i=18)	A_{18}	B_{18}	C_{18}
	Field 19 (i=19)	A_{19}	B_{19}	C_{19}

The LP model for Transportation Model 1 has an objective function for time minimization and supply constraints since each farm has a certain number of truckloads they must send to one of the potential grain storage locations. Other constraints include nonnegativity and integer decision variables. The final LP Model including the objective function and constraints can be found next in Figure 5.2.

Figure 5.2 - LP Model for Transportation Model 1 (Total)

The LP Problem used was:

Minimize Z =

$$\left[\sum_{i=1}^{n=19}(t_{iA} * A_i)\right] + \left[\sum_{i=1}^{n=19}(t_{iB} * B_i)\right] + \left[\sum_{i=1}^{n=19}(t_{iC} * C_i)\right]$$

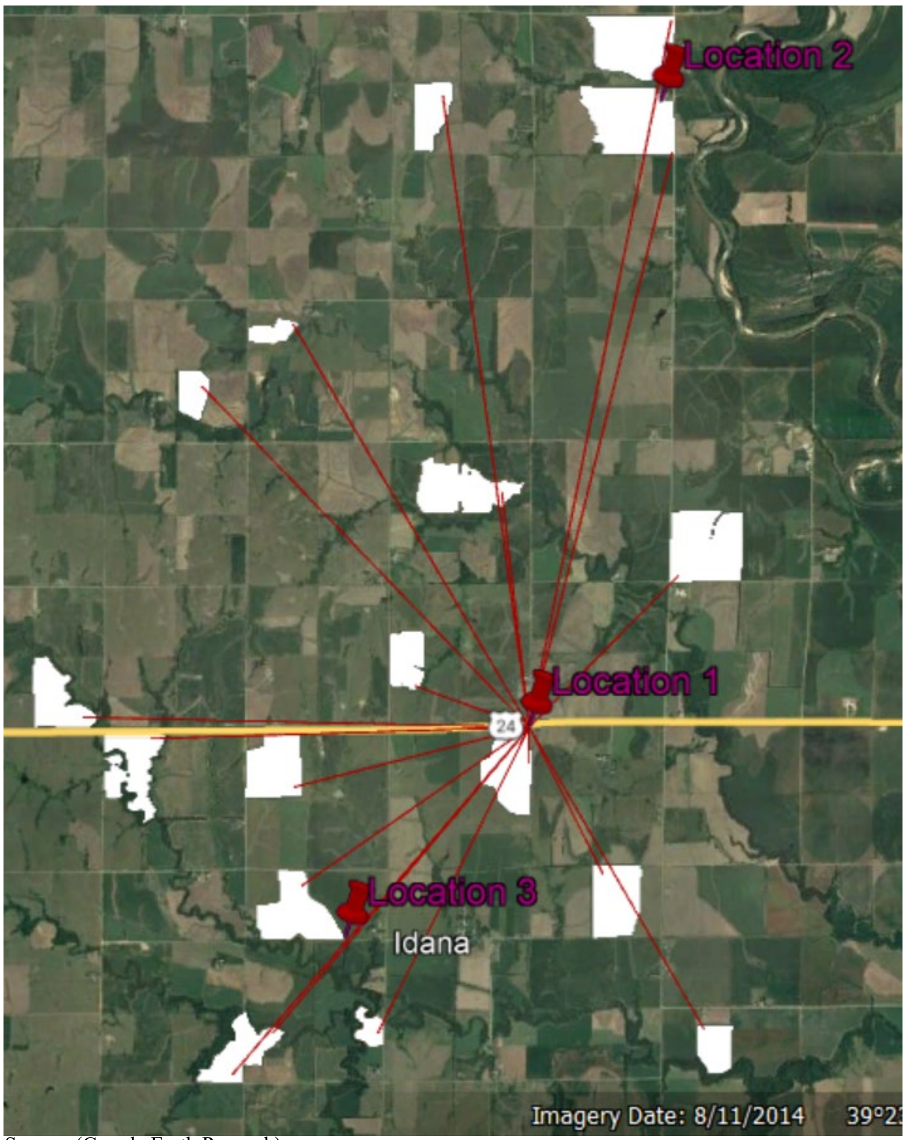
Subject To:

$A_1 + B_1 + C_1 = 7$
$A_2 + B_2 + C_2 = 7$
$A_3 + B_3 + C_3 = 5$
$A_4 + B_4 + C_4 = 6$
$A_5 + B_5 + C_5 = 16$
$A_6 + B_6 + C_6 = 7$
$A_7 + B_7 + C_7 = 5$
$A_8 + B_8 + C_8 = 5$
$A_9 + B_9 + C_9 = 4$
$A_{10} + B_{10} + C_{10} = 16$
$A_{11} + B_{11} + C_{11} = 12$
$A_{12} + B_{12} + C_{12} = 34$
$A_{13} + B_{13} + C_{13} = 30$
$A_{14} + B_{14} + C_{14} = 8$
$A_{15} + B_{15} + C_{15} = 13$
$A_{16} + B_{16} + C_{16} = 6$
$A_{17} + B_{17} + C_{17} = 19$
$A_{18} + B_{18} + C_{18} = 4$
$A_{19} + B_{19} + C_{19} = 2$
$A_i, B_i, C_i \geq 0$ (for all i=1,…19)
A_i, B_i, C_i = integer (for all i=1,…19)

Variable Definitions:
t_{iA} is the minutes required to transport a truckload from Field (i, i=1,...,19) to Location 1 **(Values from Table 5.1: Arc Value Definitions for Transportation Models)**
t_{iB} is the minutes required to transport a truckload from Field (i, i=1,...,19) to Location 2 **(Values from Table 5.1: Arc Value Definitions for Transportation Models)**
t_{iC} is the minutes required to transport a truckload from Field (i, i=1,...,19) to Location 3 **(Values from Table 5.1 Arc Value Definitions for Transportation Models)**
A_i is the number of truckload trips from Field (i, i=1,…,19) to Location 1
B_i is the number of truckload trips from Field (i, i=1,…,19) to Location 2
C_i is the number of truckload trips from Field (i, i=1,…,19) to Location 3

5.3.4 – Transportation Model 2 (Location 1)

This transporation model was solved using the same methods from Transportation Model 1, except only the potential storage facility of Location 1 was considered. This was done to calculate the amount of time required to transport all soybeans from each Field (i, i=1,…,19) to the potential storage facility of Location 1. Figure 5.3 provides a satellite view of the transporation model diagram used to sovle this model. This diagram only takes into consideration the arcs from each field to Location 1.



Source: (Google Earth Pro, n.d.)

Figure 5.3 - Transportation Model 2 Diagram (Location 1)

The LP model for Transportation Model 2 has an objective function for time minimization and supply constraints since each field has a certain number of truckloads they must send to Location 1. The final constraint is nonnegativity. The final LP Model including the objective function and constraints can be found in Figure 5.4.

Figure 5.4 - LP Model for Transportation Model 2 (Location 1)

The LP Problem used was:

$$Minimize\ Z = \sum_{i=1}^{n=19} t_i A_i$$

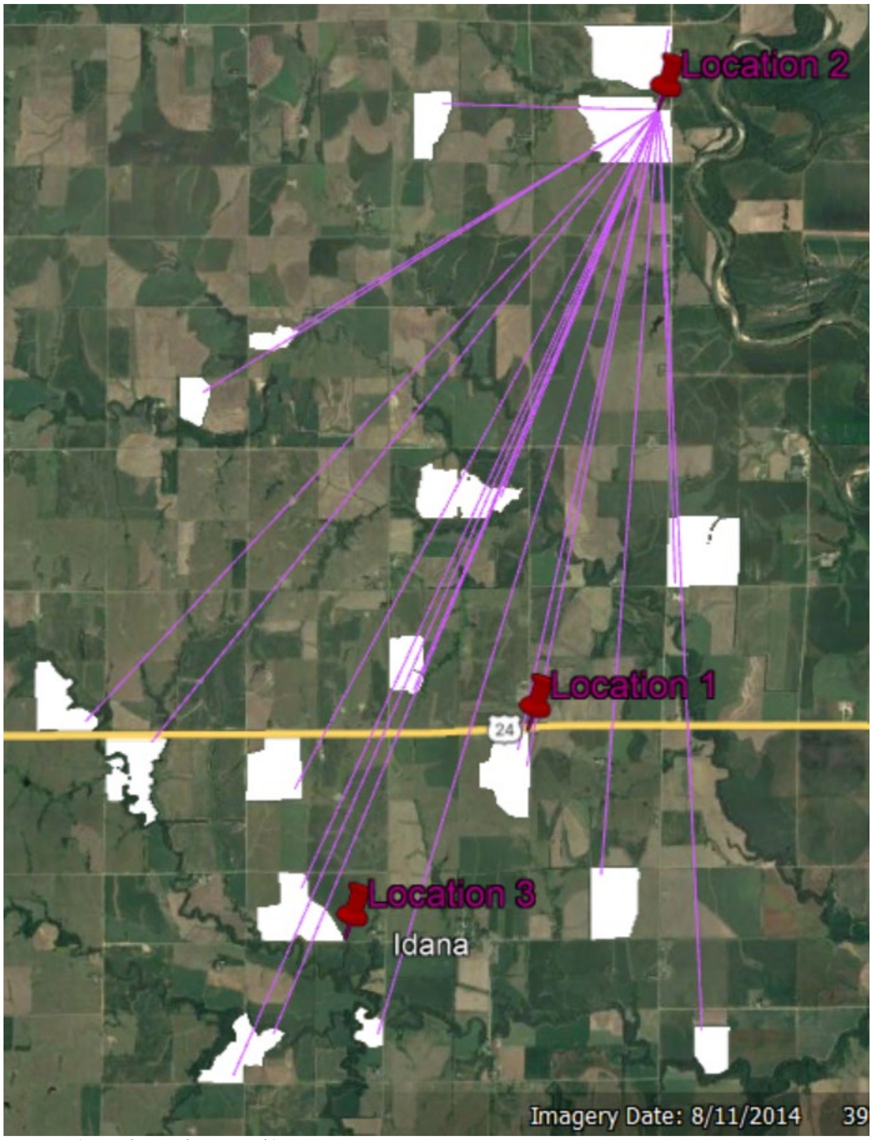
Subject to:

$A_1 = 7$
$A_2 = 7$
$A_3 = 5$
$A_4 = 6$
$A_5 = 16$
$A_6 = 7$
$A_7 = 5$
$A_8 = 5$
$A_9 = 4$
$A_{10} = 16$
$A_{11} = 12$
$A_{12} = 34$
$A_{13} = 30$
$A_{14} = 8$
$A_{15} = 13$
$A_{16} = 6$
$A_{17} = 19$
$A_{18} = 4$
$A_{19} = 2$
$A_i \geq 0$ (for all $i=1,\ldots,19$)

Variable Definitions:
t_i is the minutes required to transport a truckload from Field (i, $i=1,\ldots,19$) to Location 1 **(Values from Table 5.1: Arc Value Definitions for Transportation Models)**
A_i is the number of truckload trips from Field (i, $i=1,\ldots,19$) to Location 1

5.3.5 – Transportation Model 3 (Location 2)

This transporation model was solved using the same methods from Transportation Model 1, except only the potential storage facility of Location 2 was considered. This was done to calculate the amount of time required to transport all soybeans from each Field (i, i=1,…,19) to the potential storage facility of Location 2. Figure 5.5 provides a satellite view of the transporation model diagram used to sovle this model. This diagram only takes into consideration the arcs from each field to Location 2.



Source: (Google Earth Pro, n.d.)

Figure 5.5 - Transportation Model 3 Diagram

LP model for Transportation Model 3 has an objective function for time minimization and supply constraints since each field has a certain number of truckloads they must send to Location 2. The final constraint is nonnegativity. The final LP Model including the objective function and constraints can be found in Figure 5.6.

Figure 5.6- LP Model for Transportation Model 3 (Location 2)

The LP Problem used was:

$$Minimize\ Z = \sum_{i=1}^{n=19} t_i B_i$$

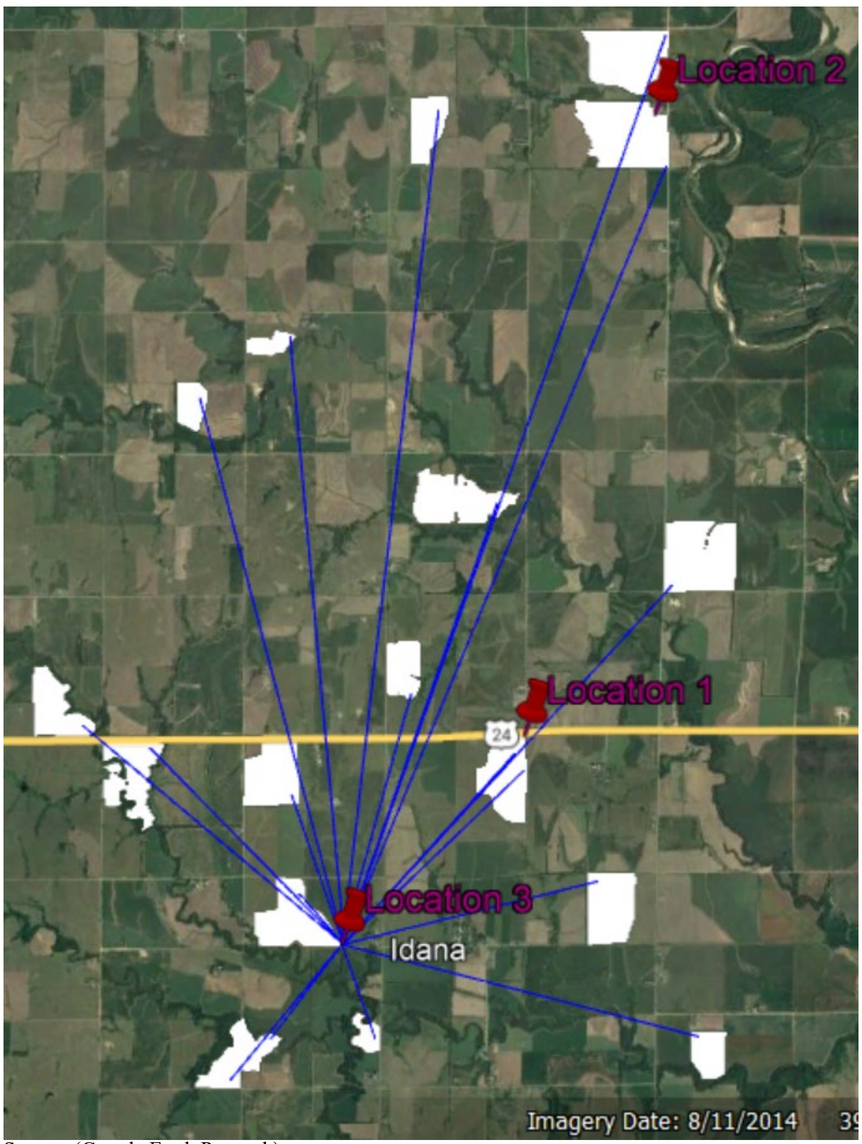
Subject to:

$B_1 = 7$
$B_2 = 7$
$B_3 = 5$
$B_4 = 6$
$B_5 = 16$
$B_6 = 7$
$B_7 = 5$
$B_8 = 5$
$B_9 = 4$
$B_{10} = 16$
$B_{11} = 12$
$B_{12} = 34$
$B_{13} = 30$
$B_{14} = 8$
$B_{15} = 13$
$B_{16} = 6$
$B_{17} = 19$
$B_{18} = 4$
$B_{19} = 2$
$B_i \geq 0$ (for all i=1,…,19)

Variable Definitions:
t_i is the minutes required to transport a truckload from Field (i, i=1,…,19) to Location 2 **(Values from Table 5.1: Arc Value Definitions for Transportation Models)**
B_i is the number of truckload trips from Field (i, i=1,…,19) to Location 2

5.3.6 – Transportation Model 4 (Location 3)

This transporation model was solved using the same methods from Transportation Model 1, except only the potential storage facility of Location 3 was considered. This was done to calculate the amount of time required to transport all soybeans from each Field (i, i=1,…,19) to the potential storage facility of Location 3. Figure 5.7 provides a satellite view of the transporation model diagram used to sovle this model. This diagram only takes into consideration the arcs from each field to Location 3.



Source: (Google Earth Pro, n.d.)

Figure 5.7 - Transportation Model 4 Diagram

The LP model for Transportation Model 4 has an objective function for time minimization and supply constraints since each field has a certain number of truckloads they must send to Location 3. The final constraint is nonnegativity. The final LP Model including the objective function and constraints can be found in Figure 5.8 below.

Figure 5.8 - LP Model for Transportation Model 4 (Location 3)

The LP Problem used was:

$Minimize\ Z = \sum_{i=1}^{n=19} t_i C_i$

Subject to:

$C_1 = 7$
$C_2 = 7$
$C_3 = 5$
$C_4 = 6$
$C_5 = 16$
$C_6 = 7$
$C_7 = 5$
$C_8 = 5$
$C_9 = 4$
$C_{10} = 16$
$C_{11} = 12$
$C_{12} = 34$
$C_{13} = 30$
$C_{14} = 8$
$C_{15} = 13$
$C_{16} = 6$
$C_{17} = 19$
$C_{18} = 4$
$C_{19} = 2$
$C_i \geq 0$ (for all i=1,…,19)

Variable Definitions:
t_i is the minutes required to transport a truckload from Field (i, i=1,…,19) to Location 3 **(Values from Table 5.1: Arc Value Definitions for Transportation Models)**
C_i is the number of truckload trips from Field (i, i=1,…,19) to Location 3

5.4 Cost Minimization Models

5.4.1 – Objective

The objective of the Cost Minimization Models is to find which potential storage facility has the lowest cost associated with making the location available for use as a grain storage facility and the transportation required. This model is looking only at the time taken from harvest location to storage facility and does not consider time taken for shipment from storage facility to market. The constraints under consideration in Cost Minimization Model 1 are the number of truckloads required from each field, binary decision variables for the required fixed costs at each location, an accounting constraint for each field, and nonnegativity. The constraints under consideration for Cost Minimization Models 2, 3, and 4 are the number of truckloads required from each field to the respective potential storage location.

5.4.2 – Data Calculations

All the following equations were used to calculate the technical coefficient values for each field to storage option. Tables 5.4, 5.5., and 5.6 provide and summarize the data used to make the calculations below.

<u>Cost/Mile:</u>

Price of Road Diesel: \$3.34

Average Mile per Gallon for Semi: 6 (Miller, & Cott, 2021)

$$\$3.34 / 6 = \$0.56/\text{mile} \tag{5.4}$$

<u>Fuel Cost/Location:</u>

Cost/Mile: \$0.56 (calculated above)

Round Trip Multiplier: 2

Miles to Location: varies, see Tables 5.4, 5.5., and 5.6

$0.56 * 'Miles to Location' * 2 = 'Fuel Cost/Location' (5.5)

<u>Minute Wage/Trucker:</u>

Wage/Hour (including average overtime allotment): $18

Minutes/Hour: 60 Minutes

$18 / 60 = $0.30/minute wage (5.6)

<u>Minutes/Load:</u>

Minutes to location (arc lengths): varies, see Tables 5.4, 5.5., and 5.6

Round Trip Multiplier: 2

Unload a facility time: 10 minutes (figured from concept farm's average unload time)

(2* arc length for A_i's, B_i's, and C_i's) + 10 = 'Min/Load' (5.7)

<u>Wage/Load:</u>

Minute Wage: $0.30 (figured above)

Min/Load: (figured above) See Tables 5.4, 5.5., and 5.6

$0.30 * 'Min/Load' = 'Wage/Load' (5.8)

<u>Cost/Load:</u>

Wage/Load (figured above): see Tables 5.4, 5.5., and 5.6

Cost/Mile (figured above): $0.56

Minutes to Location: see Tables 5.4, 5.5., and 5.6

'Fuel Cost' + 'Wage/Load' = 'Total Cost/Load' (5.9)

Cost/Load is used as the technical coefficients and Loads Required/Field are used as the RHS values in all four Cost Minimization Models. The decision variables for these models are the number of truckloads being sent from each field to potential storage locations. Tables 5.4, 5.5., and 5.6 are shown below including all the data calculations and necessary data.

Table 5.4 - Data Calculations for Location 1 Cost Minimization Model

	Cost/ Mile	Miles to Location 1	Fuel Cost Location 1	Minute Wage per Trucker	Minutes to Location 1	Min Unload Time at Location 1	Min/ Load	Wage/ Load	Cost/ Load	Loads Required/Field
Field 1	0.56	1.9	2.128	0.3	3	10	16	4.8	6.928	7
Field 2	0.56	3.4	3.808	0.3	6	10	22	6.6	10.408	7
Field 3	0.56	4.3	4.816	0.3	7	10	24	7.2	12.016	5
Field 4	0.56	4.5	5.04	0.3	7	10	24	7.2	12.24	6
Field 5	0.56	2.8	3.136	0.3	5	10	20	6	9.136	16
Field 6	0.56	0.2	0.224	0.3	3	10	16	4.8	5.024	7
Field 7	0.56	0	0	0.3	0	10	10	3	3	5
Field 8	0.56	4.5	5.04	0.3	7	10	24	7.2	12.24	5
Field 9	0.56	4.9	5.488	0.3	8	10	26	7.8	13.288	4
Field 10	0.56	2.9	3.248	0.3	4	10	18	5.4	8.648	16
Field 11	0.56	3.4	3.808	0.3	4	10	18	5.4	9.208	12
Field 12	0.56	5	5.6	0.3	9	10	28	8.4	14	34
Field 13	0.56	5.7	6.384	0.3	11	10	32	9.6	15.984	30
Field 14	0.56	5.3	5.936	0.3	7	10	24	7.2	13.136	8
Field 15	0.56	2.5	2.8	0.3	4	10	18	5.4	8.2	13
Field 16	0.56	3.1	3.472	0.3	4	10	18	5.4	8.872	6
Field 17	0.56	2.4	2.688	0.3	5	10	20	6	8.688	19
Field 18	0.56	1.4	1.568	0.3	2	10	14	4.2	5.768	4
Field 19	0.56	3.1	3.472	0.3	4	10	18	5.4	8.872	2

Table 5.5 - Data Calculations for Location 2 Cost Minimization Model

	Cost/ Mile	Miles to Location 2	Fuel Cost Location 2	Minute Wage per Trucker	Minutes to Location 2	Min Unload Time at Location 2	Min/ Load	Wage/ Load	Cost/ Load	Loads Required/Field
Field 1	0.56	6.5	7.28	0.3	11	10	32	9.6	16.88	7
Field 2	0.56	6.9	7.728	0.3	12	10	34	10.2	17.928	7
Field 3	0.56	9.9	11.088	0.3	17	10	44	13.2	24.288	5
Field 4	0.56	11.2	12.544	0.3	15	10	40	12	24.544	6
Field 5	0.56	9.5	10.64	0.3	12	10	34	10.2	20.84	16
Field 6	0.56	5.5	6.16	0.3	10	10	30	9	15.16	7
Field 7	0.56	5.3	5.936	0.3	10	10	30	9	14.936	5
Field 8	0.56	4.9	5.488	0.3	9	10	28	8.4	13.888	5
Field 9	0.56	4.6	5.152	0.3	9	10	28	8.4	13.552	4
Field 10	0.56	5.8	6.496	0.3	7	10	24	7.2	13.696	16
Field 11	0.56	10	11.2	0.3	12	10	34	10.2	21.4	12
Field 12	0.56	0	0	0.3	0	10	10	3	3	34
Field 13	0.56	0	0	0.3	0	10	10	3	3	30
Field 14	0.56	3.9	4.368	0.3	6	10	22	6.6	10.968	8
Field 15	0.56	9.1	10.192	0.3	12	10	34	10.2	20.392	13
Field 16	0.56	8.4	9.408	0.3	12	10	34	10.2	19.608	6
Field 17	0.56	2.9	3.248	0.3	5	10	20	6	9.248	19
Field 18	0.56	7.3	8.176	0.3	9	10	28	8.4	16.576	4
Field 19	0.56	9.7	10.864	0.3	12	10	34	10.2	21.064	2

Table 5.6 - Data Calculations for Location 3 Cost Minimization Model

	Cost/ Mile	Miles to Location 3	Fuel Cost Location 3	Minute Wage per Trucker	Minutes to Location 3	Min Unload Time at Location 3	Min/ Load	Wage/ Load	Cost/ Load	Loads Required/Field
Field 1	0.56	1.7	1.904	0.3	4	10	18	5.4	7.304	7
Field 2	0.56	3.2	3.584	0.3	6	10	22	6.6	10.184	7
Field 3	0.56	1.6	1.792	0.3	4	10	18	5.4	7.192	5
Field 4	0.56	1.8	2.016	0.3	4	10	18	5.4	7.416	6
Field 5	0.56	0	0	0.3	0	10	10	3	3	16
Field 6	0.56	3	3.36	0.3	6	10	22	6.6	9.96	7
Field 7	0.56	2.8	3.136	0.3	5	10	20	6	9.136	5
Field 8	0.56	5.3	5.936	0.3	8	10	26	7.8	13.736	5
Field 9	0.56	5.6	6.272	0.3	9	10	28	8.4	14.672	4
Field 10	0.56	3.7	4.144	0.3	5	10	20	6	10.144	16
Field 11	0.56	4.1	4.592	0.3	5	10	20	6	10.592	12
Field 12	0.56	7.8	8.736	0.3	11	10	32	9.6	18.336	34
Field 13	0.56	8.5	9.52	0.3	13	10	36	10.8	20.32	30
Field 14	0.56	6.1	6.832	0.3	8	10	26	7.8	14.632	8
Field 15	0.56	1.7	1.904	0.3	4	10	18	5.4	7.304	13
Field 16	0.56	3.9	4.368	0.3	6	10	22	6.6	10.968	6
Field 17	0.56	5.2	5.824	0.3	8	10	26	7.8	13.624	19
Field 18	0.56	2.2	2.464	0.3	3	10	16	4.8	7.264	4
Field 19	0.56	1	1.12	0.3	3	10	16	4.8	5.92	2

5.4.3 – Cost Minimization Model 1 (Total)

Cost Minimization Model 1 was constructed looking at all three potential grain storage locations simultaneously and was solved using truckload requirements, cost of shipping each truckload and fixed costs of necessary infrastructure to build the grain storage facilities at each location. The model was created to account for the fact that all grain had to be shipped to one facility and used binary variables to include the fixed costs only when relevant to the storage facility being used. This was done to calculate which potential grain storage location has the lowest cost.

The LP for Cost Minimization Model 1 has an objective function to minimize the cost of shipping soybeans and corn. The constraints are the maximum amount of truckloads from each field to potential grain storage facility, binary variables for the potential fixed costs, required truckloads to be shipped from each field, accounting constraints, and non-negativity. Figure 5.9 on the following page shows the LP model implemented.

Figure 5.9 - LP Model for Cost Minimization Model 1

LP Problem Used:

$$Minimize\ Z = [\textstyle\sum_{i=1}^{m}(X_{iA} * A_i)] + [\sum_{i=1}^{m}(X_{iB} * B_i)] + [\sum_{i=1}^{m}(X_{iC} * C_i)] + (F_G * Y_A) + (F_P * Y_B) + (F_P * Y_C) + (F_W * Y_C)$$

Subject to:	$A_1 \le 7$	$B_1 \le 7$	$C_1 \le 7$	$\sum_{i=1}^{m} A_i \le M*Y_A$ (Natural Gas Location 1 Binary)	$A_1 + B_1 + C_1 = 7$
	$A_2 \le 7$	$B_2 \le 7$	$C_2 \le 7$		$A_2 + B_2 + C_2 = 7$
	$A_3 \le 5$	$B_3 \le 5$	$C_3 \le 5$		$A_3 + B_3 + C_3 = 5$
	$A_4 \le 6$	$B_4 \le 6$	$C_4 \le 6$		$A_4 + B_4 + C_4 = 6$
	$A_5 \le 16$	$B_5 \le 16$	$C_5 \le 16$	$\sum_{i=1}^{m} B_i \le M*Y_B$ (Propane Location 2 Binary)	$A_5 + B_5 + C_5 = 16$
	$A_6 \le 7$	$B_6 \le 7$	$C_6 \le 7$		$A_6 + B_6 + C_6 = 7$
	$A_7 \le 5$	$B_7 \le 5$	$C_7 \le 5$		$A_7 + B_7 + C_7 = 5$
	$A_8 \le 5$	$B_8 \le 5$	$C_8 \le 5$		$A_8 + B_8 + C_8 = 5$
	$A_9 \le 4$	$B_9 \le 4$	$C_9 \le 4$		$A_9 + B_9 + C_9 = 4$
	$A_{10} \le 16$	$B_{10} \le 16$	$C_{10} \le 16$	$\sum_{i=1}^{m} C_i \le M*Y_C$ (Propane Location 3 Binary)	$A_{10} + B_{10} + C_{10} = 16$
	$A_{11} \le 12$	$B_{11} \le 12$	$C_{11} \le 12$		$A_{11} + B_{11} + C_{11} = 12$
	$A_{12} \le 34$	$B_{12} \le 34$	$C_{12} \le 34$		$A_{12} + B_{12} + C_{12} = 34$
	$A_{13} \le 30$	$B_{13} \le 30$	$C_{13} \le 30$		$A_{13} + B_{13} + C_{13} = 30$
	$A_{14} \le 8$	$B_{14} \le 8$	$C_{14} \le 8$	$\sum_{i=1}^{m} C_i \le M*Y_C$ (3-Phase Power Location 3 Binary)	$A_{14} + B_{14} + C_{14} = 8$
	$A_{15} \le 13$	$B_{15} \le 13$	$C_{15} \le 13$		$A_{15} + B_{15} + C_{15} = 13$
	$A_{16} \le 6$	$B_{16} \le 6$	$C_{16} \le 6$		$A_{16} + B_{16} + C_{16} = 6$
	$A_{17} \le 19$	$B_{17} \le 19$	$C_{17} \le 19$		$A_{17} + B_{17} + C_{17} = 19$
	$A_{18} \le 4$	$B_{18} \le 4$	$C_{18} \le 4$		$A_{18} + B_{18} + C_{18} = 4$
	$A_{19} \le 2$	$B_{19} \le 2$	$C_{19} \le 2$		$A_{19} + B_{19} + C_{19} = 2$
					(Required Truckloads)
					$A_i, B_i, C_i \ge 0$ (for all i=1,...19)

Variable Definitions:

X_{iA} is the Cost per Load for each Field (i, i=1,…,19) to Location 1 (Table 5.4: Data Calculations for Location 1 Minimum Cost Model)

X_{iB} is the Cost per Load for each Field (i, i=1,…,19) to Location 2 (Table 5.5: Data Calculations for Location 2 Minimum Cost Model)

X_{iC} is the Cost per Load for each Field (i, i=1,…,19) to Location 3 (Table 5.6: Data Calculations for Location 3 Minimum Cost Model)

A_i is the number of truckload trips from Field (i, i=1,…,19) to Location 1

B_i is the number of truckload trips from Field (i, i=1,…,19) to Location 2

C_i is the number of truckload trips from Field (i, i=1,…,19) to Location 3

F_G is the fixed cost value of power installation for Natural Gas

F_P is the fixed cost value of power installation for Propane

F_W is the fixed cost value of power installation for 3-Phase Power

Y_A is the binary variable for fixed costs associated with Location 1

Y_B is the binary variable for fixed costs associated with Location 2

Y_C is the binary variable for fixed costs associated with Location 3

M is a very large number that exceeds the largest feasible value of A_i, B_i, C_i

5.4.4 – Cost Minimization Model 2 (Location 1)

Cost Minimization Model 2 was solved by imposing that Location 1 is the grain storage location. This was done to calculate the absolute minimum cost requirements of transporting all soybeans and corn from each Field (i, i=1,…,19) to the storage facility of Location 1. Fixed costs did not require binary variables because in this model, it was assumed that Location 1 was used as the storage facility, therefore the fixed costs had to be included in the objective function. This also negated the need for non-negativity constraints. See Figure 5.10 for the model breakdown.

Figure 5.10 - LP Model for Cost Minimization Model 2 (Location 1)

LP Problem Used:

$$Minimize\ Z = [\sum_{i=1}^{m}(X_i * A_i)] + F_G$$

Subject to:

$A_1=7$
$A_2=7$
$A_3=5$
$A_4=6$
$A_5=16$
$A_6=7$
$A_7=5$
$A_8=5$
$A_9=4$
$A_{10}=16$
$A_{11}=12$
$A_{12}=34$
$A_{13}=30$
$A_{14}=8$
$A_{15}=13$
$A_{16}=6$
$A_{17}=19$
$A_{18}=4$
$A_{19}=2$

Variable Definitions:
X_i is the Cost per Load for each Field (i, i=1,…,19) to Location 1 (Table 5.4: Data Calculations for Location 1 for Minimum Cost Model)
A_i is the number of truckload trips from Field (i, i=1,…,19) to Location 1
F_G is the fixed cost value of power installation for Natural Gas

5.4.5 – Cost Minimization Model 3 (Location 2)

Cost Minimization Model 3 was solved by imposing that Location 2 is the grain storage location. This was done to calculate the absolute minimum cost requirements of transporting all soybeans and corn from each Field (i, i=1,…,19) to the storage facility of Location 2. Fixed costs did not require binary variables because in this model, it was assumed that Clifton Top was used as the storage facility, therefore fixed costs had to be included in the objective function. This also negated the need for non-negativity constraints. See Figure 5.11 for the model breakdown.

Figure 5.11 - LP Model for Cost Minimization Model 3 (Location 2)

LP Problem Used:

$$Minimize\ Z = [\ \sum_{i=1}^{m}(X_i * B_i)] + F_P$$

Subject to:

$B_1=7$
$B_2=7$
$B_3=5$
$B_4=6$
$B_5=16$
$B_6=7$
$B_7=5$
$B_8=5$
$B_9=4$
$B_{10}=16$
$B_{11}=12$
$B_{12}=34$
$B_{13}=30$
$B_{14}=8$
$B_{15}=13$
$B_{16}=6$
$B_{17}=19$
$B_{18}=4$
$B_{19}=2$

Variable Definitions:
X_i is the Cost per Load for each Field (i, i=1,…,19) to Location 2 (Table 5.5 Data Calculations for Location 2 for Minimum Cost Model)
B_i is the number of truckload trips from Field (i, i=1,…,19) to Location 2
F_P is the fixed cost value of power installation for Propane

5.4.6 – Cost Minimization Model 4 (Location 3)

Cost Minimization Model 4 was solved by imposing that Location 3 is the grain storage location chosen. This was done to calculate the absolute minimum cost requirements of transporting all soybeans and corn from each Field (i, i=1,…,19) to the storage facility of Location 3. Fixed costs did not require binary variables because in this model it was assumed that Location 3 was the storage facility, therefore the fixed costs had to be included in the objective function. This also negated the need for non-negativity constraints. See Figure 5.12 for the model breakdown.

Figure 5.12 - LP Cost Minimization Model 4 (Location 3)

LP Problem Used:

$Minimize\ Z = [\sum_{i=1}^{m}(X_i * C_i)] + F_P + F_W$

Subject to:

$C_1=7$
$C_2=7$
$C_3=5$
$C_4=6$
$C_5=16$
$C_6=7$
$C_7=5$
$C_8=5$
$C_9=4$
$C_{10}=16$
$C_{11}=12$
$C_{12}=34$
$C_{13}=30$
$C_{14}=8$
$C_{15}=13$
$C_{16}=6$
$C_{17}=19$
$C_{18}=4$
$C_{19}=2$

Variable Definitions:
X_i is the Cost per Load for each Field (i, i=1,…,19) to Location 3 (Table 5.6 Data Calculations for Location 3 for Minimum Cost Model)
C_i is the number of truckload trips from Field (i, i=1,…,19) to Location 3
F_P is the fixed cost value of power installation for Propane
F_W is the fixed cost value of power installation for 3-Phase Power

5.5 Results and Discussion

5.5.1 – Transportation Models

Transportation Model 1 (Total)

Using the combination of truckloads from each field to the potential storage facilities, the minimum time found in this model would be 534 minutes or 8.9 hours. These location results are what would be expected from the model but the length of time for transport was lowered immensely. The route between each field and potential storage facility with the shortest arc length was the route used for all shipments. The following three transportation models were run to find out which potential storage facility would have the shortest transportation time if all truckloads were sent from each field to the single storage facility of interest. These models will show us which building site is actually feasible for construction as the concept farm is only desiring to build one facility in this specific geographical area to store the grain. However, if in the future funds were not of concern and all power requirements were fulfilled making all three options usable, this model gives the minimum amount of time required. The results from Transportation Model 1 can be seen below in Table 5.13 on how many truckloads should be transported from each field to all potential storage locations.

Table 5.7 - Transportation Model 1 Decision Variable Results

Field to Storage Facility	Number of Truckloads
Field 1 to Location 1	7
Field 6 to Location 1	7
Field 7 to Location 1	5
Field 8 to Location 1	5
Field 9 to Location 1	4
Field 10 to Location 1	16
Field 11 to Location 1	12
Field 16 to Location 1	6
Field 17 to Location 1	19
Field 18 to Location 1	4
Field 12 to Location 2	34
Field 13 to Location 2	30
Field 14 to Location 2	8
Field 2 to Location 3	7
Field 3 to Location 3	5
Field 4 to Location 3	6
Field 5 to Location 3	16
Field 15 to Location 3	13
Field 19 to Location 3	2

Transportation Model 2 (Location 1)

If Location 1 is chosen as the location for the new storage facility, the amount of time it would take to transport all the soybeans and corn from each field to Location 1 is 1291 minutes or 21.517 hours.

Transportation Model 3 (Location 2)

If Location 2 is chosen as the location for the new storage facility, the amount of time it would take to transport all the soybeans and corn from each field to Location 2 is 1392 minutes or 23.2 hours.

Transportation Model 4 (Location 3)

If Location 3 is chosen as the location for the new storage facility, the amount of time it would take to transport all the soybeans and corn from each field to Location 3 is 1477 minutes or 24.617 hours.

Results/Summary

According to these results, the optimal way to minimize the time required to haul the truckloads of soybeans and corn to storage would be to have facilities built at all three locations. This value was drastically lower than the results of the three individual locations figured separately. A total time of 534 minutes if transporting to all three locations provided a difference of 757 minutes efficiency gained when compared to the next best option which was Location 1 with a value of 1291 minutes. However, having storage facilities of size in as small of a geographic area as the concept farm is using is not feasible nor practical. The concept farm desired one location to construct the facility and strives to find the lowest transportation time possible which is achieved through Transportation Model 2 using Location 1. This outcome would result in a total transportation time of 1291 minutes which saves 101 minutes in relation to Location 2 and 186 minutes in relation to Location 3.

5.5.2 – Cost Minimization Models

In order to provide the concept farm with a variety of options regarding the best location for the potential grain storage facility, the minimum cost model was also conducted to check if the most efficient location would also be the least cost option. Four models were run in order to see how much each location would cost to construct.

Cost Minimization Model 1 (Total)

The results from this model show that Location 1 is the least cost storage facility when factoring in the costs to make the location feasible to build a grain storage facility and the associated transportation costs. This minimum cost would be $14,240.76 when sending all the soybeans and corn produced to Location 1.

Cost Minimization Model 2 (Location 1)

If Location 1 was picked as the location for development of the construction, the minimized cost value was $14,240.76 which reinforces that Cost Minimization Model 1 solved correctly. The amount was calculated by using the required amount of truckloads per field and the cost of shipment per load with the addition of the necessary fixed costs. The total shipment costs would have a total of $2,240.76 with an additional $12,000 value for the installation of natural gas giving a combined amount of $14,240.76.

Cost Minimization Model 3 (Location 2)

If Location 2 was picked as the location of construction, the minimized cost value was $62,572.82. This model was solved in the same way as Cost Minimization Model 2 with the same data calculation methods. Total shipment costs valued $2,572.82 with an additional $60,000 added to account for installation of propane at the location.

Cost Minimization Model 4 (Location 3)

A final minimized value for Location 3 was $72,593.64. This minimization model was solved the same way as the previous two models by finding the shipment costs and then factoring in the necessary fixed costs based on the location requirements. Location 3 shipment costs have a value of $2,593.64 with an additional $10,000 and $60,000 added to account for installation of 3-phase power and propane respectively.

Results/Summary

When interpreting the results of Model 1, it was concluded that Location 1 would give the overall lowest cost value if imposing that all bushels of soybeans and corn need to be transported to one facility. This is then confirmed when solving Cost Minimization Models 2-4 as the value of Location 1 gave the overall lowest cost value of $14,240.76. This value provides a potential cost savings of $48,332.06 when compared to building at Location 2 and a potential savings of $58,352.88 when compared to building at Location 3.

It can be seen that the greatest influx in costs at each of the potential locations was due to the fixed cost values of sourcing power or making construction alterations at each location. Although the result of the cost minimization final value would ultimately still be Location 1, a smaller price difference is experienced if all locations had been equipped with the necessary power requirements from the onset. However, this is not a reality for agriculturalists or the concept farm and the large fixed cost values created the increased difference in price for each potential storage location.

In the long-run, the initial cost of inserting power options such as propane and natural gas seems quite high but the construction cost would equalize out over a span of 15-20 years. However, since the concept farm was considering both the fastest transportation time and the lowest cost option, Location 1 would continue to be the optimal location. However, the payoff period for the two higher cost power options at Location 2 and 3 would eventually payoff in the long-run but not change the model results finding the optimal location.

Cost Minimization Model Sensitivity Analysis

In order to validate the robustness of the model, a 10% increase in cost was applied. The resulting minimized total cost value stayed consistent with a 10% overall increase in cost. This incremental increase in cost had a final value of $15,664.84 which made a difference in total cost of $1,424.08 which is a 10% price difference. These results validated the model in the fact that it is robust and percentage price changes would not affect the final outcome of the optimized result.

Location in relation to potential markets is also a factor to consider when planning for the future. Although at the current time, the potential locations are all relatively close to a major highway that is on the way to multiple markets located East and West of the farm operation, Location 1 is the closest. If additional markets were acquired to the North of the operation, the final result has the potential to change the optimal placement to Location 2. However, at the current point in time for the concept farm, there is no prospects of gaining entry to new markets to the North of the operation, with the only potential new market entries lying to the West.

Additionally to the transportation and minimum cost models have the result be Location 1, the specific site has other attributes that would be desirable for construction too. One specific attribute that would greatly benefit the concept farm is Location 1's proximity to a paved road. This site lies along the highway making logistics optimal for trucks entering and exiting the facility whereas the other two locations are located on gravel. The width of the roadway and ability to build it on the corner of the field also allows for less congestion for incoming and outgoing trucks to maximize unload times.

Chapter 6 - Summary and Conclusions

Optimizing the best location to construct a private grain facility for farmers who are wanting to minimize trucking time or lower costs with infrastructure placement is essential. As agriculture advances into the technological innovation realm, private grain storage can become more customized to suit the needs of the agriculturalist. By having a location that fits not only the current needs of the farmer, but building with the idea of future expansion, long-run costs can be lowered.

Current literature addresses potential benefits farmers can obtain by investing in private grain storage using basis pricing. If grain can be stored for extended periods of time or be harvested earlier than the normal growing season, an increased basis price can be captured. Literature also addressed the infrastructure requirements it would take to build a private facility of size and stature. The implementation of steel circular bins with the addition of a grain leg and grain dryer are the most common options in the agricultural industry. However, literature was found to be lacking with guidance for farmers on where geographically to build their facility.

After conducting interviews with grain producers throughout the Midwest the biggest concern from each producer before investing into a long-term asset such as grain storage was where to build the facility. Producers are willing and able to spend the money required in order to capture potential increases in profit by storing grain but are wanting to make strategic decisions that will last for generations when it comes to choosing the location. Additionally, as producers continue to adopt new technological practices into their farming operations and yields continue to increase, expansion must be planned for. Farmers also expressed the necessity to utilize what emerging technology can offer to a farming operation. Yield maps, record keeping on the cloud, and moisture readouts available to the producer at all times has been a way for producers to receive higher yields with the same manpower. Having the capability to manage multiple aspects of the farming operation from a cellphone not only lowers transportation time for the manager, but also allows for better monitorization of the operation.

After finding what technologies are most utilized in the production agriculture realm by Midwest producers, a concept farm was created to solve multiple optimization problems. Historical crop data was provided and utilized as well as satellite imaging to lower the potential transportation time for each grain storage facility option provided by the concept farm manager. This data was then input into the formulated optimization problems to find what location would be best suited for the desired criteria of fastest transportation time or minimum cost for construction. It was found that Location 1 would be the best decision for both the desired problems in minimizing transportation time as well as costs.

Further recommendations and changes could be made in the model to make the optimization process more diverse if desired. Incorporating more crops such as sorghum and wheat production if grown on the farm can be factored in along with the varying crop rotation patterns over an extended period of time. This thesis solved the optimization problem with a desired storage configuration of 90/10 in terms of corn to soybeans with the most recent planting configuration of the concept farm. However, these percentages and planting configurations can be altered and give varying results depending on the decisions of the farm owner. Additional crops can also be added into the storage and planting configuration if desired.

Another consideration for the research would be the importance of haul-out scenarios. Although this thesis was primarily concerned with finding the most efficient scenarios of hauling grain from field to facility another aspect of hauling from facility to vendor is an aspect to consider. If the most efficient location for harvest transportation happens to lie in a location opposite from current markets, revisiting the location placement decision is imperative. Picking the right location to not only coincide with current land ownership but also vender fulfillment is a balance that must be kept. Furthermore, if partnerships can be made with haul-out facilities that can increase profit potential or efficiency exponentially, a cost-benefit analysis must be conducted. An example being access to rail facilities. Although building a storage facility close to a rail line might not be the most efficient for harvest, the potential profits that can be obtained through fulfilling contracts have the possibility to outweigh the lost efficiency during harvest. Designing models that address haul-out scenarios could be added if further research was conducted.

Various limitations existed in this thesis, one of which was the availability of land information to the public. Field yields and acreage amounts are often times proprietary information held confidential by the landowner, so satellite imagery had to be used to figure field boundaries and acreages. Furthermore, yield values were created using average yields for the geographic area of the concept farm, not actual yield information as none was to be found. Crop rotation was also created to fulfill the 90/10 desire for storage. However, with certain fields having corn planted year after year, different fertilizers and cover crops might have to be applied to keep consistent soil health in check.

Interviewing producers throughout the Midwest provided its own limitations as multiple producers expressed the desire to stay anonymous and for specific storage and size information to remain confidential. This posed difficulties in explaining the magnitudes of decision making from one farm to another. Implementation of technology from one farm size to another was also hard to portray although the consensus was made that technology adoption is a requirement for a precision agriculture industry.

In the optimization model, numbers used as constants and multipliers change on a more frequent basis in the real world. Examples being the price of diesel fuel and the bushels able to be hauled in the truck. If a truck has a triple axel trailer with additional tags will be able to haul more bushels than the standard trailer. These values were chosen in the model whereas they are likely to fluctuate based on the national economy and state laws.

Finding an optimal location for private grain storage ultimately depends on what technologies each farm operation currently implements, the desired attributes of the facility itself, and the capital the operation wants to invest. These characteristics can change the result of whether a private grain facility is a feasible long-term investment for a farming operation and if additional profits can be realized.

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