VALUE OF MAP SHARING BETWEEN MULTIPLE VEHICLES IN THE SAME FIELD WHILE USING AUTOMATED SECTION CONTROL

by

JEFFREY D. BENNETT

B.S. Iowa State University, 2001
B.S. Iowa State University, 2009

A THESIS

Submitted in partial fulfillment of the requirements

for the degree

MASTER OF AGRIBUSINESS

Department of Agricultural Economics

College of Agriculture

KANSAS STATE UNIVERSITY

Manhattan, Kansas

2016

Approved by:

Major Professor
Terry Griffin

ABSTRACT

Large acreage farms and even moderate sized farms employing custom applicators and harvesters have multiple machines in the same field at the same time conducting the same field operation. As a method to control input costs and minimize application overlap, these machines have been equipped with automatic section control (ASC).

For nearly all these multiple-vehicle operations, over application is a concern especially for more irregularly shaped fields; however modern technology including automated guidance combined with automatic section control allow reduced doubling of input application including seeds, fertilizer, and spray. Automatic section control depends on coverage maps stored locally on each vehicle to determine whether or not to apply input products and up to now, there has not been a clear method to share these maps between vehicles in the same field. Without sharing coverage maps, an individual ASC planting unit only has location data where it has applied individually and no location data for where other planting units have applied seed in that same field. Automatic section control relies upon shared coverage maps to be continually updated between each planting unit and utilizes existing machine telematics infrastructure for map data sharing. Telematics utilizes a cloud computing platform and cellular connectivity which in rural areas is known to have limited service levels.

Planting operations were simulated for two 16-row planters, each using two John Deere GreenStar3 2630 monitors, simulated GPS location data stream, electronic rate control units, and individual row unit clutches to have control at the finest granularity.

Each simulated planting unit is equipped with automatic section control and telematics gateways to share coverage map data from the first planting unit to JDLink cloud infrastructure then out to the second. This study evaluates the impact that field size and shape have on using multiple ASC planters and coverage map sharing, and estimates seed cost savings from reducing over application because coverage maps are shared between planting units. The impact of sharing coverage maps with both planting units using field boundaries with automatic section control and without using field boundaries were evaluated. Guidance line headings were determined using AgLeader SMS's mission planning feature to minimize the number of passes across each field based on the field boundary and implement width. Each field was run twice using parallel tracking, once each with and without coverage map sharing to observe the extent of over application.

The field level data were then taken to examine a fictious 3,000 acre farming operation where the field level data was used as a partial composition of the farm operation. An embedded Microsoft Excel macro was used to create 8,008 different composition scenarios to determine farm level savings. The average farm savings was $58,909 per year. Additionally, using the 8,008 scenarios, time value of money was examined to determine the the minimum area required annually for five years for this technology to pay back. The average was 133 acres each year for five years.

Equipment manufacturers and farmers have interest in these results. In general, equipment manufacturers desire to create a service-based product to be sold such that continual revenue path provides value added services after the precision agriculture hardware is sold. In this study, the existing telematics product offerings are tied to shared coverage maps to provide a value-add to an existing service. Farmers want to ensure this is a sound equipment investment with payback in a relatively short time period. As farm input costs continue to rise especially relative to crop prices, reducing over application will be critical to limit waste.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I: INTRODUCTION

Precision agriculture has evolved over the years from yield data collection to manual machine guidance, automatic machine guidance and electronic application rate control. Instead of enabling and disabling the planter's row units all at one time, it is possible to control each row unit individually. Automatic section control (ASC) has reduced seed waste by reducing the occurrence of double planting. At today's seed cost, this reduction of waste can lead to significant savings to a farmer's balance sheet.

The farm equipment industry is entering an era where bigger may not always be better. Larger equipment can take longer to set up and prepare to run in the field. Additionally, larger equipment can be difficult to transport between farm fields. In some cases, farmers turn to multiple machines operating in the same field to be more productive. However, with multiple machines running in the same farm field, some economic efficiency is lost due to ASC only understanding where the individual planter has been, not the others running in the same field.

Precision agriculture manufacturers are starting to offer connected machine solutions which enable sharing coverage map data between machines operating in the same field for automatic section control. This study determines the seed cost savings from two identical planters in the same field sharing coverage maps.

Seven different fields are used in an effort to correlate seed cost savings and differing field sahpes and sizes measured as perimeter to area ratios. Data on surplus areas were collected using real-time farm equipment simulators. These data were analyzed by determining how differing proportions of each field type impact the optimal decision for a rpresentative sized row crop farm. Using the identified cost savings, an annual amount of farmland area is calculated for breakeven returns in addition to positive three year and five-year payback periods for farms comprised of different proportions of the seven field types.

The remainder of this thesis is organized as follows. Chapter 2 presents background summary for many technologies used in precision agriculture. Literature review related to coverage map sharing is in Chapter 3. Economic methods are presented in Chapter 4 and data collection methods in Chapter 5. In Chapter 6 Results and Analysis. Lastly, Chapter 6 contains a discussion.

CHAPTER II: BACKGROUND

2.1 Introduction

Only until very recently have precision farming technologies advanced to enable shared information between farm vehicles in the same field in near real time. Deere & Company brought shared coverage maps through telematics to the market in Feburary 2016. This technology is so new, no known research has been conducted on in-field shared information; however, there has been ample research done in the three main subcomponents of in-field map sharing such as automatic section control systems, telematics data, and rural cellular connectivity. The following provides an overview of existing technologies.

2.2 Automatic Section Control System Decomposition

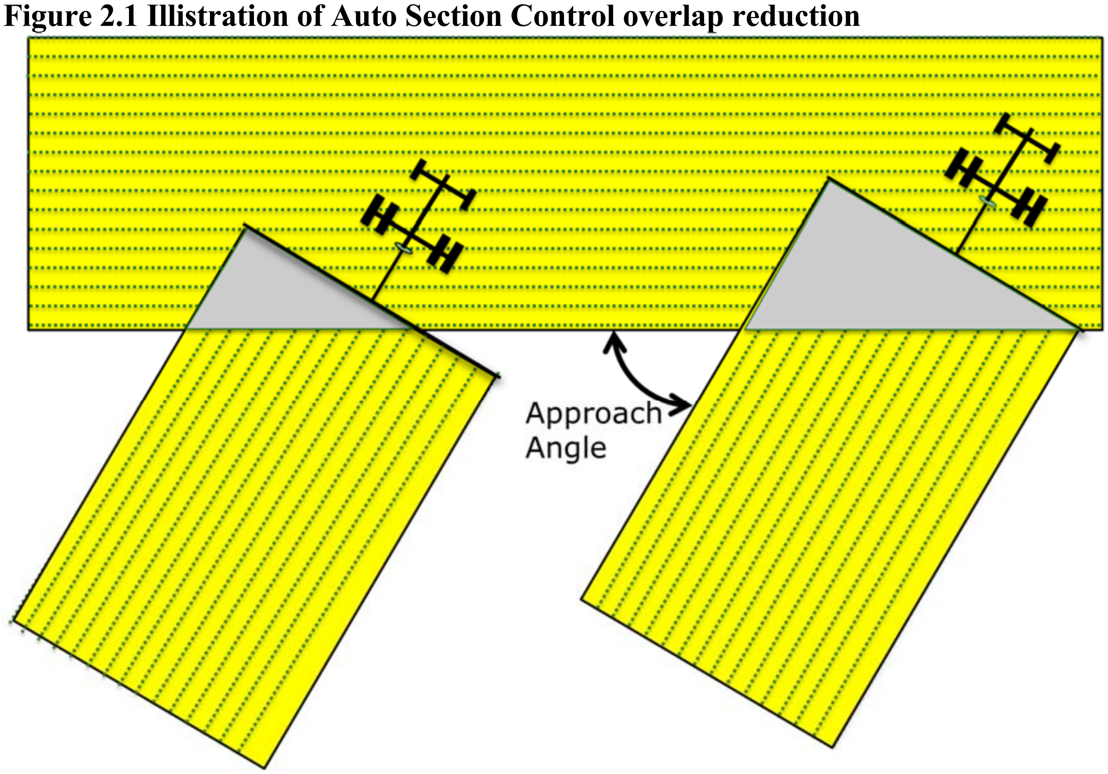
Modern farm machinery is equipped with embedded electronic control units. These electronic control units (ECU) control and monitor machinery functions such as steering in a vehicle guidance system or the product application rate for a planter or sprayer. The ECUs are connected together on a controller area network (CAN) to permit controllers to communicate to one another. The ECU's and the network the ECU's are attached to have allowed buttons, switches and dials to replace operator controls instead of levers and mechanical linkages. Automatic section control (ASC) can interface with ECU's, as well. ASC is a precision farming technology that combines Global Navigation Satellite System (GNSS, formerly known as global positioning system or GPS) data along with the ECU to determine if farm work is required in the specific geographic area. The primary goal for this technology is to reduce overlap in an effort to increase input efficiency and accuracy by automatically turning off the specific portions of the implement when application is not required.

The application rate for seeds or other products is determined one of three ways. The first way is to manually set in the rate controller resulting in a constant application rate across the field. The remaining two methods automatically set the application rate. The first automated way uses a prescription map where polygons within the field have been assigned rates and as the implement travels out of one polygon into another, the rate changes based on the rate assignment for that polygon. An out of field rate can be set for when the implement travels outside of the exterior field boundary. Also a fail-safe rate is set for prescription maps in case GNSS information is lost and the operator desires to continue application using the constant rate. The fail-safe rate is commonly referred to as the Missing GPS rate. The second automated way that a rate can be set without human intervention is by using sensors on the implement to determine plant health or soil conditions and apply appropriate rates of inputs based on on-the-go algorithms. These sensors translate the plant health reading into a target rate for application.

When a machine or implement is actively working in a field, location data is recorded to indicate where work has occurred. When this location only data is plotted, it is known as a coverage map. The ASC is a state machine, where based on different conditions a specific output is expected. For ASC, the conditions are whether or not work has been completed at this geographic location. Internally and continuously, ASC is asking the coverage map, "Have I done work here in the past?" When the state machine determines that it has done work in this location, it commands the farm implement's product application ECU to stop applying product otherwise it continues to apply. Although not required, existing field boundaries can be used with ASC. An exterior field boundary specifies the field's outside perimeter, which creates a geographic container for the field, and ASC only allows product to be applied inside that container. Working with opposite logic, interior field boundaries are used to ensure no product is applied inside the marked area. Interior boundaries are commonly used where the equipment operator can drive across inside a field landmark, but do not want to apply product such as a waterway (John Deere Ag Management Solutions, 2015). If using field boundaries, the ASC state machine simulatnesouly queries the coverage map and the field boundary to determine whether previously covered.

Automatic section control technologies result in finer control of product application instead of an “all on” or “all off” strategy across the implement’s entire width. Groups of planter row units or sprayer nozzles result in smaller, controllable sections which reduce overlapped application and wasted product represented in the gray triangles as shown in Figure 2.1. .

Figure 2.1 Illistration of Auto Section Control overlap reduction

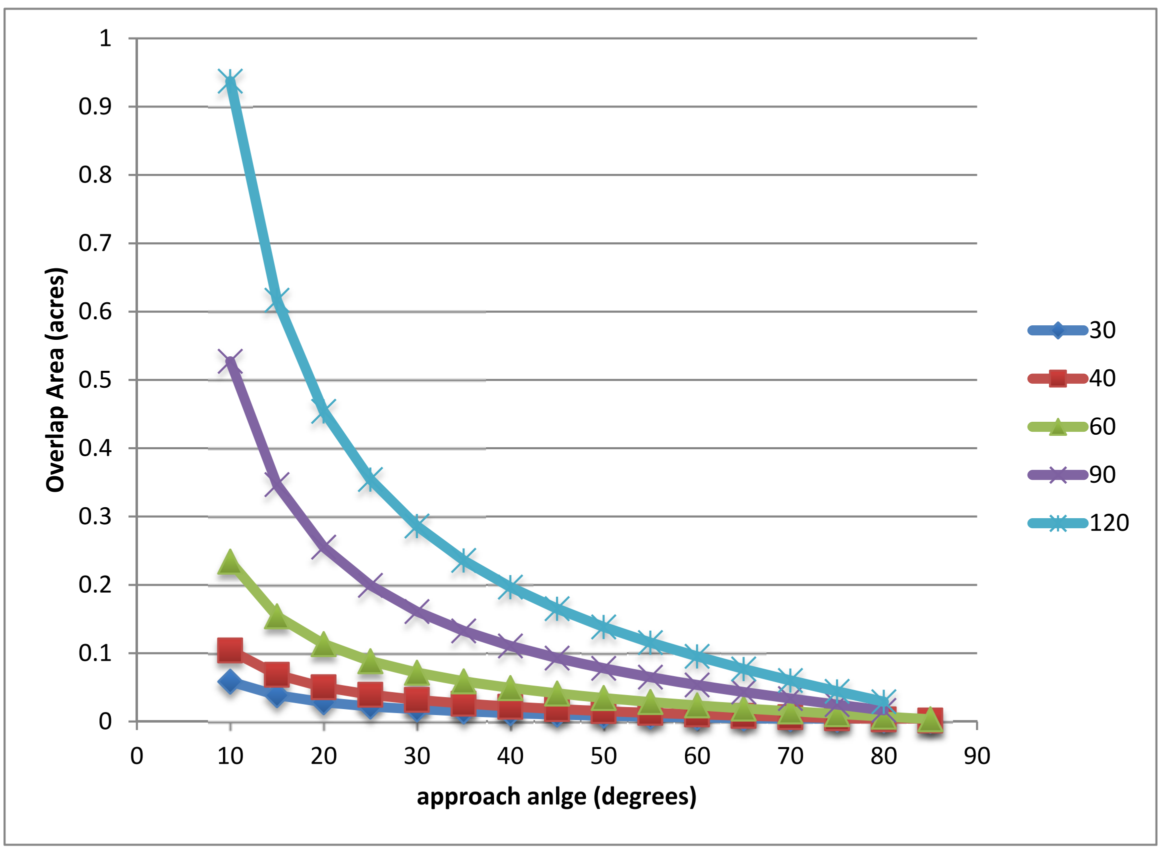


The overlapped area is defined in Figure 2.2 as a function of the implement width and the approach angle. The following equation has been unit adjusted for implement width in feet and area in acres. Figure 2.3 is a visulizaiton of Figure 2.2 where each line represents a different implement width in feet and the X axis is the Approach Angle. The resulting Y axis is area in acres.

Figure 2.2 Overlap area calculation equation.

$$area = \frac{(ImplementWidth)^2}{2(\tan(ApproachAngle))43560}$$

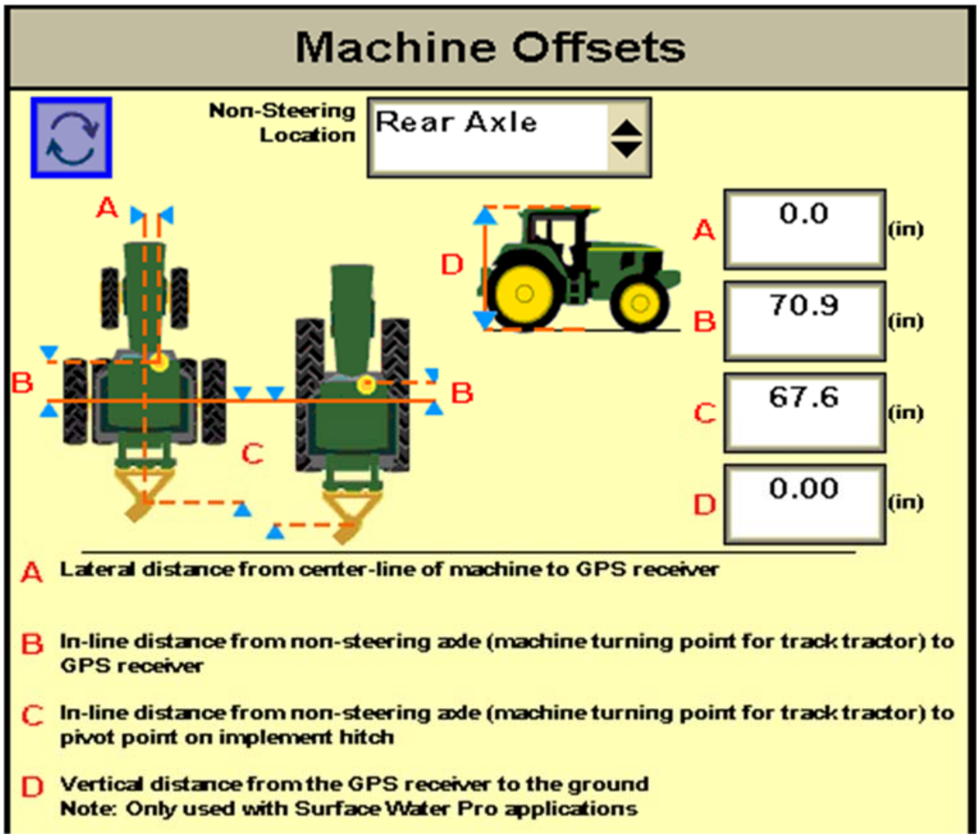
Figure 2.3 Overlap area saved by using ASC as a function of approach angle and implement width



ASC technologies are used throughout the growing season for Midwest farms. When installed on a row crop planter or seeder, this technology controls individual planter row units or groups of row units using a variety of different control systems. On a product application sprayer or fertilizer applicator, boom section valves breakdown the whole boom width into smaller, controllable sections for pre-plant or post emerge application. Lastly in the harvest season, while not commanding an ECU, the combine harvester's header attachment is broken down into smaller virtual sections to improve harvested area calculations as the crop is gathered when the combine is harvesting at less than a full header width (John Deere Ag Management Solutions, 2015).

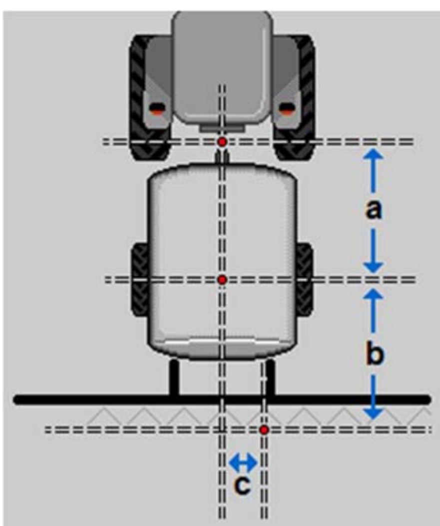
In its simplest configuration, implements with automatic section control capability share the information regarding location from the GNSS. Using a series of measurements and then machine/implement connection type, standardized by ISO-11783 Part 10 for tractors and implements, the implement's location can be calculated from the GNSS receiver's mounted location on the tractor so the implement's work point can be determined (International Organization for Standardization, 2015). It is important to ASC system accuracy that the machine and implement dimensions are entered into the system correctly. Figures 2.4 and 2.5 show examples to how offset dimensions are entered and saved.

Figure 2.4 Machine Offset Dimensions example



(John Deere Intelligent Solutions Group, 2016)

Figure 2.5: Implement Offset Dimensions example



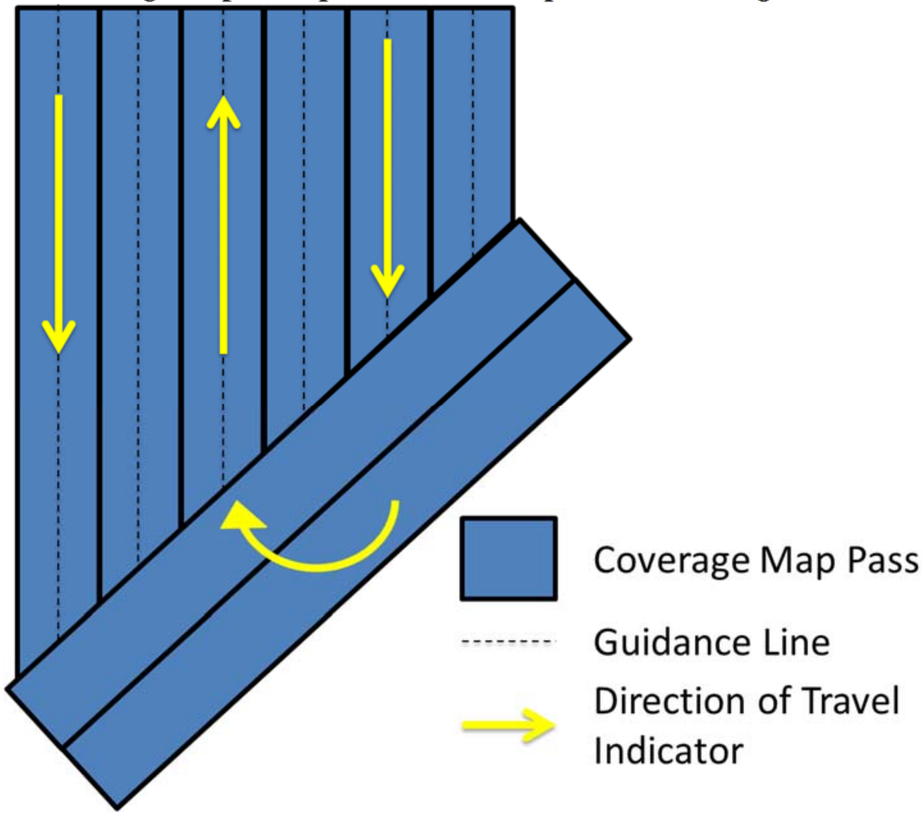
(Ag Leader Technology, 2016)

The GNSS heading is the radial direction of travel relative to geographic north, which is typically zero degrees. While in a turning motion, such as at an end row, a rigidly mounted implement such as a combine header, three point mounted planter or self-propelled sprayer boom will always have an identical GNSS heading as the machine while in turn where as a drawbar drawn planter will not have the same heading during the turn due to the pivot point at the drawbar pin. Selecting the correct implement connection type will ensure the implement's calculated location is characterized accurately while in a turning motion (John Deere Ag Management Solutions, 2015).

2.3 ASC Coverage Map and Why Sharing is Important

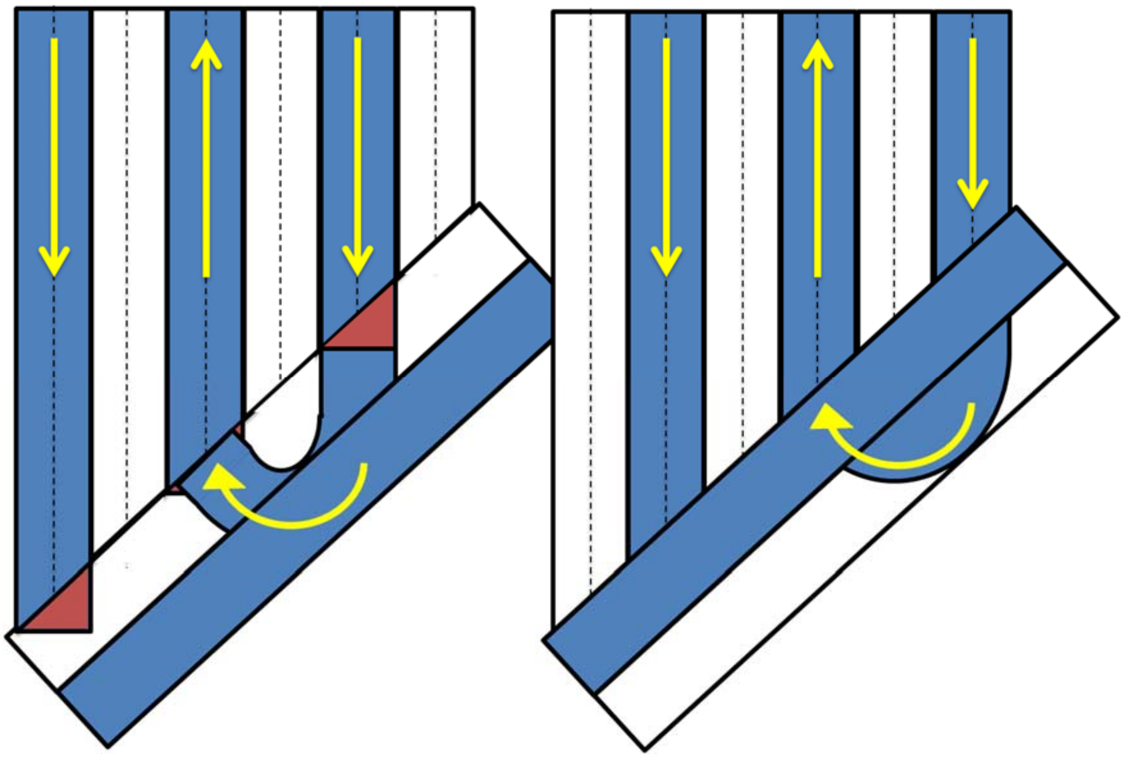
The ASC coverage map includes information regarding where work has been completed. It is a record of where product has been applied or seed has been planted. The coverage map is stored locally on the machine or implement associated with performing the work. When one ASC compatible implement is operating in a field, the resulting coverage map is similar to the one in Figure 2.6

Figure 2.6 Coverage map example for 1 ASC implement in a single field



There are challenges when two (or more) ASC capable farm implements are performing the same operation in the same field at the same time. The individual machines have information realtiave to where they have applied product, but without a way to share their individual coverage maps. The individual coverage maps will likely include areas of unintended product application similar to the hypothetical maps in Figure 2.7.

Figure 2.7 Example of two ASC implements operating in the same field, not sharing coverage maps

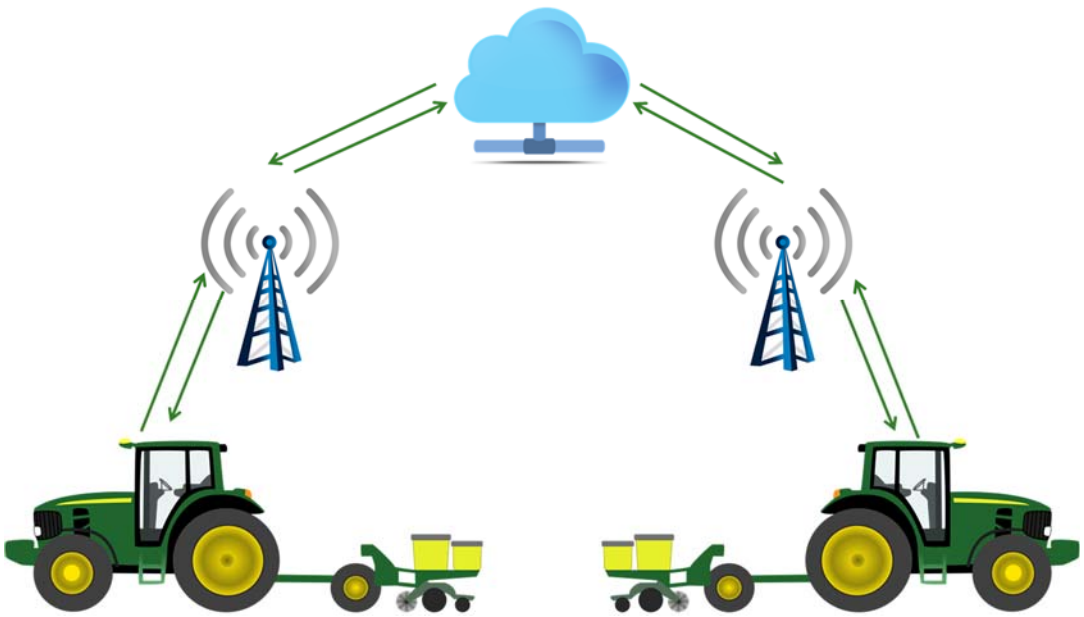


Deere and Company offers two different communication solutions to share the ASC coverage map between units in the same field. These are the Wi-Fi and cellular networks. A Wi-Fi network solution is a point to point communication network between planting units shown in Figure 2.8 and does not require cloud computing infrastructure.

Figure 2.8 Network architecture using WiFi to share data in field

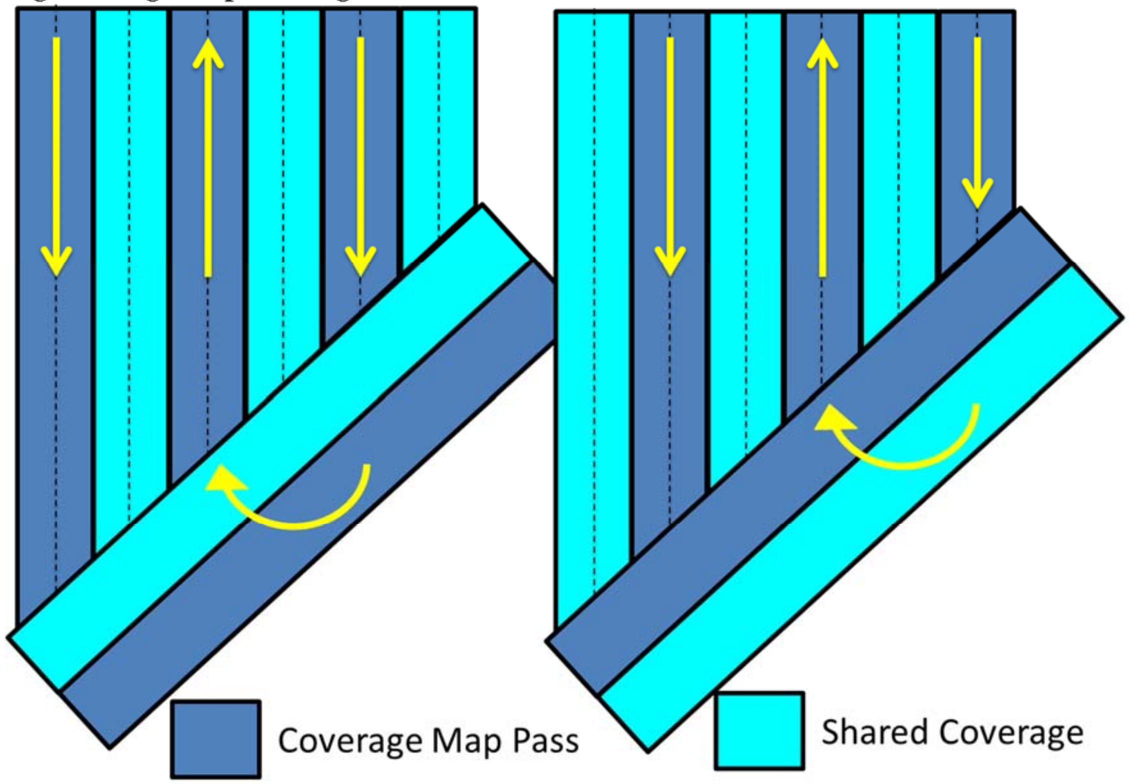
Within Wi-Fi coverage map data is shared between the units. For cellular connected farm vehicles equipped with a telematics gateway, coverage map sharing can use existing infrastructure (Figure 2.9) with no additional hardware required for purchase.

Figure 2.9 Network architecture using existing telematics infrastructure



When coverage map sharing is possible, the resulting coverage map is expected to be similar to Figure 2.10 where the dark blue represents the locally applied product and the cyan coverage is the work completed by the partner machine.

Figure 2.10 Coverage map examples from two different ASC implements in the same field using coverage map sharing



When using the cellular solution, planting units can come and go as needed because the coverage map is stored on the telematics server. The coverage map data is stored for 60 days. When using Wi-Fi, there is no telematics server equivalent and the point-to-point nature means data will only be shared if both planting units are concurrently connected. Vehicles which are not cellular equipped or for areas where cellular coverage is poor, a Wi-Fi network solution may be a viable option. Wi-Fi radios cost $3,699 and each planting unit requires one radio.

Topography plays a factor in cellular and Wi-Fi network signal reliability. It is possible that specific areas of fields that planting units could drop in and out of network coverage resulting in a delay in the coverage map being sent to or received by the partner planting unit. The ASC coverage map data builds a holding queue locally on the planting unit until a network connection can be obtained and the coverage map is sent or received. This delayed communication could result in the planting units transmitting or receiving coverage map data after an area has been planted.

Given a review of the technology, a literature search was conducted and is presented in the following chapter. Specific literature for coverage map was not found. However, literature was reviewed for the individual technology components to coverage map sharing.

CHAPTER III: LITERATURE REVIEW

3.1 ASC Economics for Row Crop Planters

Precision agriculture companies have marketed automatic section control (ASC) as a tool to reduce input overlap, therefore reducing input costs. The ASC savings have commonly been understated due to studies focusing exclusively on a single farm task, such as spraying. Over time, additional efficiencies have been identified when ASC technology is combined with passive (light bar) or active (vehicle integrated steering controllers) automated steering technology. Shockley et al. (2012) set out to study the impact on sprayers separate from planters. Additionally, he inspected the role of field shape along with an economic analysis including rate of return and payback period (Shockley, Dillon, Stombaugh, & Shearer, 2012).

Shockley et al. (2012) evaluated a ~80-foot (24-meter) sprayer equipped with ten equal width nozzle control sections and a 16-row ~40-foot (12 meters) planter with each row independently controlled. He selected four fields that reflected the size and shape common in Kentucky agricultural production. Field 1 and Field 2 were square in shape and were 99 acres (40 hectares) and 10 acres (4 hectares), respectively. Field 3 and Field 4 were irregularly shaped at 7.5 acres (3 hectares) 247 acres (100 hectares), respectively. A desktop computer tool (Field Coverage Analysis Tool, FieldCAT) simulated coverage within each of these fields, using parallel guidance lines and documenting overlap within each field (Shockley, Dillon, Stombaugh, & Shearer, 2012). Four scenarios were studied including 1) both the planter and sprayer together with machine guidance, 2) sprayer only with guidance, 3) planter only with guidance, and 4) planter and sprayer together without machine guidance. Their goal was to understand the profitability of precision agriculture technology including machine guidance and automatic section control. All the scenarios were profitable relative to the *status quo*, if the tractor was already equipped with machine guidance, planting was a better investment due to lower costs of technology. There were also indications that field shape plays a role in the determining ASC savings. Smaller, irregular fields resulted in greater increases in average net returns, greater returns on investment and shorter payback period (Shockley, Dillon, Stombaugh, & Shearer, 2012). Smith et al. (2013) built upon the foundation that Shockley et al. (2012) established, expanding the analysis from four fields to 553 real fields from farms in Colorado, Kansas, and Nebraska totaling 49,095 acres across thirteen different USDA crop reporting districts. Aside from the number of fields under the Smith et al. (2013) study, the key difference was that only economic impact of ASC while performing a spraying operation was considered. Given the number of different farm fields under consideration, the importance of field size and shape was confirmed to be important to payback period. In northwest Kansas fields, the investment in ASC payback period was less than a year. Also observed as field sizes increased, the net benefits of ASC decreased because the field area to headland area ratio decreases. Automatic section control payback period is even shorter when the same acres are sprayed during the same growing season. Additional applications on the same field gives the opportunity to spread system costs over more application acres. If a 1,000 acre farm is sprayed three per year, the opportunity for reduced system costs per acre due to more application area to cover is possible.

As demonstrated in previous ASC studies (Smith et al., 2013; Runge et al., 2014), payback period is highly dependent on field size and shape. The larger the field, the less impact ASC has on profitability. This indicates that the potential profitability of ASC is directly related to the number of on/off cycles commanded by the ASC application (Runge, Fulton, Griffin, Virk, & Brooke, 2014).

3.2 Telematics Data in Agriculture

Telematics and telemetric data is broadly described as data measured remotely. The adoption of telematics has sharply increased in the last 3 years in the agricultural industry. In their 2015 Precision Agricultural Services Dealership Survey results, Erickson and Widmar (2015) report that 20% of respondents are using telematics to transfer data for their precision agriculture business up from 15% and 7% in 2013 and 2011, respectively. This technology shares a quick adoption rate with machine guidance (Erickson & Widmar, 2015). What is interesting is that there is very little research and literature on how telematics data is being used by the end user and others for primary and secondary uses of data in agriculture (Griffin, et al., 2016).

JDLink is Deere & Company's cloud system for telemetric data. Used in both construction and agricultural equipment, it allows machine owners to remotely monitor a single machine or fleets from a single computer or mobile device. JDLink data is transmitted using the machine's modular telematics gateway and displayed in a web based portal. Types of data transmitted by machines include machine usage statistics (fuel consumption, utilization, idle time and more), machine health information (diagnostic trouble codes), and machine location information for location services. If properly configured, electronic alerts can be sent to take action such as notifying a dealer technician of a diagnostic trouble code or alerting law enforcement authorities that a machine has been moved outside the expected work area.

John Deere's GreenStar 3 2630 is an in-cab touch screen computer device which provides an operator interface for precision agriculture capabilities including machine guidance and agronomic data recording. Additional functions include mapping, prescription rate control and automated section control (John Deere Ag Management Solutions, 2015). The capabilities of the GreenStar 3 2630 can benefit from a JDLink connected machine. Remote Display Access (RDA) is a specialized virtual network connection which allows remote viewing of the display. A RDA session is initiated through an internet browser and the session must be permitted by the machine operator to prevent the remote person from making unsafe changes to the display. Once the session is started, the remote viewer has the same view as the machine operator, making troubleshooting far easier than having the operator describe the settings and readings on the display. Wireless Data Transfer (WDT) uses the machine's telematics gateway to move agronomic data and guidance lines to the user's MyJohnDeere.com account for post processing. Using WDT technology, field context data, field boundaries, guidance lines and field prescriptions can be pushed to the 2630 display for in-field use. A JDLink Connect subscription costs $600 for the first machine; and up to ten machines costs an additional $400 per machine (Sloan Implement, 2016). Coverage map sharing using the MTG builds an additional value proposition in Deere's telematics product offering.

Schemper Harvesting, a custom harvesting business located in Holdrege, Nebraska, recently completed an operation efficiency study using JDLink data and machine operation statistics across a fleet of seven combine harvesters of all identical models (Schemper, 2014). If an investment is made in JDLink, it is important to mold the data into business decisions such as training for proper machine operation and investments into support equipment. Using the telematics data, the study was able to report differences in how machines were operated through statistics such as fuel usage, machine hours, engine performance and activity. Schemper (2014) was able to identify which specific machine in the fleet was the most productive and the one with the highest fuel efficiency. The study demonstrated that machine operator experience was related to fuel usage rate. It was recognized that lesser experienced combine operators were not idling down during wait times in the field while completeing harvest.

3.3 Relationship of Rural Internet Connectivity to Precision Agriculture

Precision agriculture practices are generating large amounts of data. It has been estimated that as-applied planting data generates 5.5 megabytes (MB) per acre, and yield data collected by a combine harvester is estimated at 4.3 MB per acre (Shearer, 2014). Based on these rates, a 160 acre field would generated 1.5 gigabytes in a single growing season.

Transmitting precision agriculture data wirelessly through cellular networks has been identified as a solution to remove barriers from the early days of yield monitoring. These devices only had enough internal memory to log field summary data and not any GNSS location data. Manufacturers turned to portable, external media types such as memory cards to collect and store the data. Farmers would then be required to physically remove the data cards from the yield monitors and transport them from the field to the farm office computer, leaving the data susceptible to loss during the process (Whitacre, Mark, & Griffin, 2014). As internal flash memory became more affordable, external media was not required for recording geo-spatial data, but transporting the memory card was still required in the absence of wireless technology.

An improved solution for eliminating the possibilitiy of physical loss required wireless technology. Some precision agriculture technology providers offered wireless solutions such that data was transferred to other connected devices such as a smartphone or cellular equipped tablet computer via a small, local Wi-Fi or Bluetooth network. Then the connected device uploads the data to a cloud service when suitable internet connection was obtained. This type of solution improved data transferr from the field to the office computer but did not alleviate poor cellular internet connectivity or allow for passive data transfer. As precision farming technologies advanced, it drove the need for enhanced communication between the farm office to the tractor or between tractors in the same field. Reliable cellular connectivity helped to enable this communication.

Internet connectivity have been improving across the globe for utilization in education, culture, entertainment, financial services and many others. Throughout the world, 40% of the population (2.9 billion people) have internet access. Additionally, three-quarters of the 6.9 billion mobile internet subscriptions were in developing countries (Broadband Commission for Digital Development, 2014). This likely indicates that these developing areas skipped copper wire telephone networks and adopted wireless technology. By 2019 it is estaimted that as many as 5.6 billion smartphones will be connected worldwide.

Internet connections are traditionally measured in bits and file sizes are measured in bytes. There are eight bits in one byte. Between 2010 and 2015, broadband speed internet in the United States was defined as 4 Mbps (megabits per second) download speed and 1 Mbps upload. Internationally, broadband internet is defined as 256 kilobits per second, up or down (Broadband Commission for Digital Development, 2014). In January 2015, the Federal Communications Commissioners (FCC) redefined the definition of broadband internet to 25 Mbps down and 3 Mbps up. According to the Commission's January 2015 release *"(the 2010 standard) was inadequate for evaluating whether advanced broadband* *is being deployed to all Americans in a timely way"* (Federal Communications Commission, 2015a).

This large gap between download and upload transfer rates continues to cause problems in precision agriculture for those depending upon cellular technologies to transfer data (Whitacre, Mark, & Griffin, 2014). The relative difference between download and upload speeds are opposite farm-level needs given the size of the files generated by the tractor, sprayer, or combine harvester. All the data generated in the field must be transferred at the slower upload speed to the cloud. Data pushed from the farm office such as field boundaries, guidance lines, or prescription files would be downloaded from the office computer due to the direction the data is being pushed. These data generated at the office are realatively small file sizes and are downloaded to the farm equipment at the relatively higher download speeds.

In February 2015, the Federal Communications Commission passed regulations to "Protect the Open Internet" and to ensure America's broadband networks remain "fast, fair, and open". The FCC attempted to do this in 2010 for wired broadband service providers, but was challenged in court that they did not have the authority to enforce such rules (Federal Communications Commission, 2015b). The FCC ultimately lost and the court cited that because internet service providers were classified as Information Services, the FCC could not regulate (Robertson, 2014). As part of the 2015 rules, the FCC reclassified broadband networks to utility status, similar to America's landline telephone network. Additionally the 2015 open internet rules apply for wired broadband and mobile broadband providers.

As part of the FCC's 2015 Open Internet rules, three common practices have been banned. Those practices are:

1. No Blocking Content. In precision agriculture terms, mobile internet providers can not legally block "non-harmful devices" from connecting to their network and block services
2. No Throttling. An Internet service provider cannot purposefully degrade Internet traffic based on content.
3. No Paid Prioritization. A precision ag service provider, such as John Deere, cannot pay a mobile Internet provider, such as AT&T to make sure their telematics data internet traffic is given favor over common internet traffic. In popular press, this is known as internet fast lanes.

Without these protections (especially the first 2), precision agriculture companies could have been held hostage to internet providers in order for their product to work without interference from the mobile internet provider (Federal Communications Commission, 2015b).

An exhaustive literature review found no prior research evaluating the economics of automated section control specific to shared coverage maps between two planters. This study is meant to be considered a foundation regarding map sharing economics for future research.

CHAPTER IV: ECONOMIC METHODS

In previous auto section control (ASC) studies, a marginal analysis was conducted to estimate the savings in seed costs per acre and yield loss per acre due to over-planting (Shockley, Dillon, Stombaugh, & Shearer, 2012) (Smith, Dhuyvetter, Kastens, Kastens, & Smith, 2013) . Methods and economic theory similar to Shockley and Smith will be applied to the scenario where two ASC compatible planters equipped with map sharing coverage operate in the same field.

Partial budgeting techniques were applied to hypothetical farms comprised of differing proportions of seven fields. This was done to determine the cost savings from overlap reduction when coverage maps were shared between planting units using ASC. Coverage map sharing using cellular connectivity costs $1,495 per planting unit and requires the farmer to have an active JDLink subscription for an additional $1,000 per year per farm.

4.1 Economic Returns of Coverage Map Sharing

The economic analysis will be reported as savings or cost per acre across hypothical farm operations using a partial budgeting tool. Net returns on investment will be considered by dividing the new net earnings (savings) by the investment cost. Payback period is the length of time required to pay back the investment in coverage map sharing with an assumed interest rate and a no salvage value (100% depreciation after the payback period). In addition to calculating the number of breakeven acres required of each farm scenario, time value of money will be considered to determine if the purchase produces a positive net present value for both three year and five year investment schedule at a seven percent interest rate.

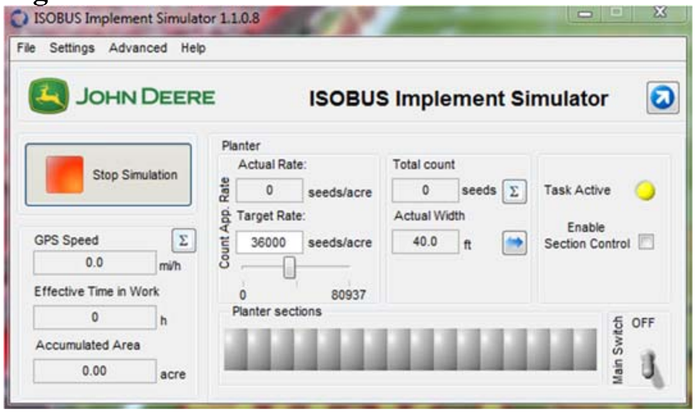
It should be reiterated that while this study is specifically focused on exclusively planting, coverage map sharing has tangible benefits throughout multiple farming tasks performed thourghout the growing season including reducing the overlapped areas for nutrient application and spraying, and reducing double counted area when not harvesting a full width for harvesting . Given the focus on only planting operatons, this analysis should be considered conservative.

CHAPTER V: DATA COLLECTION METHODS

The benefits of automated section control (ASC) are partially lost when two or more planters are operating as a team in the same field because without coverage map sharing, each individual planter unit only has information relative to where that specific planter has been. This results in ASC only turning on/off sections based on the locally stored coverage map for the specific planter unit.

Specialized simulators were used to generate data sutiable for analysis. A simulator setup consisted of a John Deere GreenStar3 2630 display used as the ASC capable planter monitor. Planter functions including seed rate electronic controllers and planter row clutches were simulated using specialized desktop computer software. Each simulator setup used a Vector CANCase which is a device to bridge the real Controller Area Network (CAN) used by the GreenStar3 2630 display and the simulated CAN from the computer based simulators. Each block in the Planter Sections area in Figure 5.1 represents an individual row clutch. A 16-row, 30-inch row spacing planter configuration was used in this study, identical to Shockley (Shockley, Dillon, Stombaugh, & Shearer, 2012), which made each planter pass 40 feet wide. Two identical simulator systems were used concurrently to simulate two planting units.

Figure 5.1 ISOBUS Planter Simulator Screenshot



A GNSS simulator provided by Deere and Company was used to simulate global positioning location data and vehicle movement. Field were loaded into the simulator to define the area of interest where simulated GNSS data is needed. Different driving patterns were selectable including driving exterior field boundary, parallel tracking given a heading, and a built in automated machine guidance simulator for the GS3 2630 to parallel track on guidance lines. In either boundary mode or parallel tracking mode, the GNSS simulator instructed the GS3 2630 where the planting unit should travel. In the case of automated machine guidance mode, the GS3 2630 instructed the simulator what line be should followed.

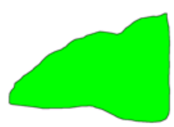
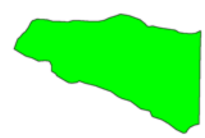
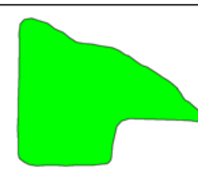
The planter simulator and the GNSS simulator information were bridged together and communicated to the GS3 2630 by creating a virtual CAN bus in the desktop computer. An engineering wiring harness was created for the GS3 2630 that included the auxiliary CAN bus high and low, constant power, switched power and ground. The Vector CANCase was used as the interface between the simulator computer's virtual CAN bus and the GS3 2630's physical CAN connection, creating a simplified controller area network which is similar to what would be found on tractor and planter. The GNSS receiver and GS3 2630 are connected to the tractor's auxiliary CAN bus inside the tractor's operator station and the planter connected to the Implement Bus Breakaway Connector (IBBC) located at the tractor's drawbar. The IBBC is the electrical connection between the tractor and the planter

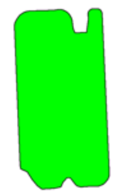
The physical systems used for this study also included modular telematics gateways (MTG), a cellular enabled vehicle electronic controller connecting the systems for data sharing using JDLink, Deere and Company's cloud service. In a real-world production environment, MTGs are connected to a farm vehicle's CAN bus and auxiliary CAN bus to enable telematics data sharing to JDLink. Agronomic data collected in the field can also be wirelessly transmitted to a customer's JDLink account from the GS3 2630, through the MTG to JDLink. In this study MTGs were used as the communication gateway for sharing coverage maps. When using the MTG as a communication gateway for sharing coverage maps, data is sent from Planting Unit 1 to JDLink servers then out to Planting Unit 2 and vise versa.

Similar to the methods of Shockley et al. (2012), seven farm fields with varying shapes and sizes were selected for this study. Aerial field images were obtained from Google Maps and georeferenced using SMS Basic (Ag Leader Technology, 2015). Once georeferenced in SMS, field boundaries were drawn using boundary-drawing tools. Guidance lines were then generated in SMS using the path-planning feature. Path planning determines the guidance line's set point and heading to minimize the number of passes over the field to complete the task. The inputs to path planning include number of headland passes, implement width, and the desired direction of travel. Once the context data, field boundaries and guidance lines were created in SMS, the data was exported to the GS3 2630 displays by a creating display setup file. The same setup file was imported to each display collecting data. The setup file was also imported to the GNSS simulator for field location and GNSS simulation within the field.

Figure 5.2 provides the geometric shape and a summary of the fields selected for this study. The farm fields were selected randomly based on their varying areas and shape. To evaluate technology over a range of field geometries, fields ranging from regular rectangular shapes with relatively consistent pass lengths to irregularly shaped fields with varying pass lengths. East Field contains 96 guidance passes and the smallest permiter to area ratio. East Field's area is 220 acres. Northwest contains 14 guidance passes and the highest permiter to area ratio is 6.101E-03. Northwest's area is 12.6 acres. From this point forward in this document, all permiter to area ratios will be presented without the "*E-03*" for improved readability.

Figure 5.2 Characteristics for fields under consideration

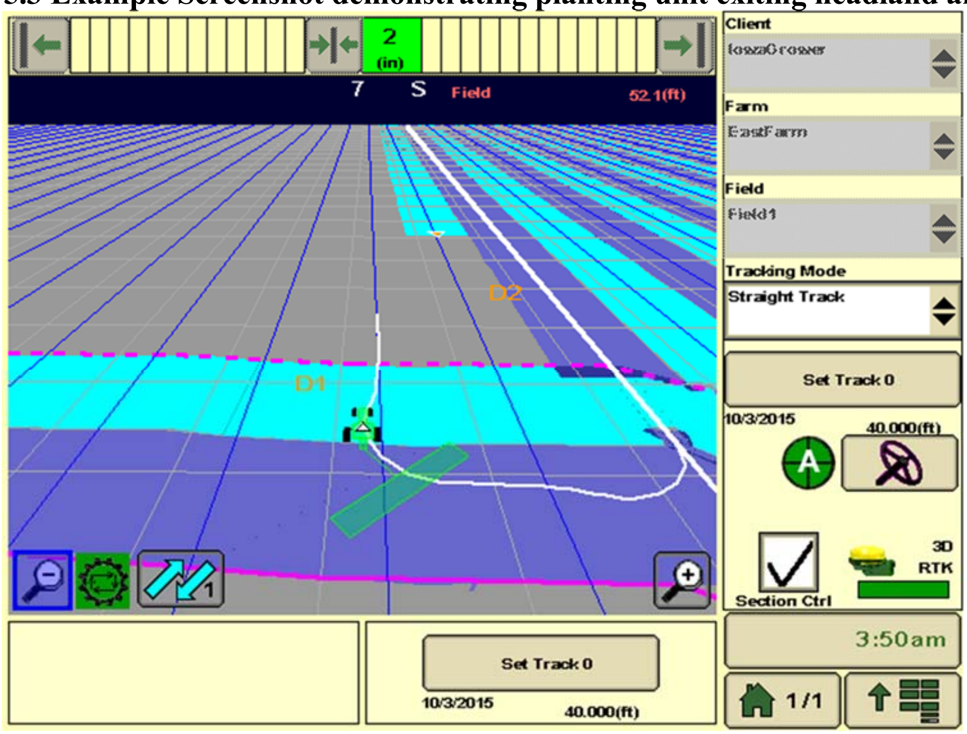
 **Name**: Mid-South **Perimeter**: 3807 feet **Area**: 13.4 acres **Perimeter to Area ratio**: 5.296 **Longest guidance line**: 973 feet **Guidance pass total**: 18	 **Name**: Mid-North **Perimeter**: 3337 feet **Area**: 15.7 acres **Perimeter to Area ratio**: 5.134 **Longest guidance line**: 1183 feet **Guidance pass total**: 17
 **Name**: Northwest **Perimeter**: 3441 feet **Area**: 12.6 acres **Perimeter to Area ratio**: 6.101	 **Name**: South **Perimeter**: 4504 feet **Area**: 23.1 acres **Perimeter to Area ratio**: 4.289 **Longest guidance line**: 1196 feet

Longest guidance line: 1048 feet **Guidance pass total**: 14	**Guidance pass total**: 26
 **Name**: Neb-West **Perimeter**: 6166 feet **Area**: 44.7 acres **Perimeter to Area ratio**: 3.102 **Longest guidance line**: 2137 feet **Guidance pass total**: 33	 **Name**: Neb-East **Perimeter**: 8280 feet **Area**: 77.3 acres **Perimeter to Area ratio**: 2.404 **Longest guidance Line**: 2524 feet **Guidance pass total**: 31
 **Name**: East Field **Perimeter**: 12360 feet **Area**: 220 acres **Perimeter to Area ratio**: 1.289 **Longest guidance line**: 2500 feet **Guidance pass total**: 96	

The data collection for each field shape will include testing with and without external boundaries. Each field variation will be completed with and without coverage map sharing to quantify the number of times ASC intersects with local coverage and shared coverage. Double planted areas are considered wasted seed

When collecting data, the mission plan was to complete two headland passes and then parallel track on the pre-loaded guidance lines. Planting Unit 1 always planted the outside headland pass. Planting Unit 2 always planted the inside headland pass as shown in Figure 5.3. After headland passes were completed, Planting Unit 1 planted the odd guidance pass numbers and Planting Unit 2 planted the even guidance pass numbers. The primary area of interest is when the interior field passes intersect with the exterior headland passes.

Figure 5.3 Example Screenshot demonstrating planting unit exiting headland area

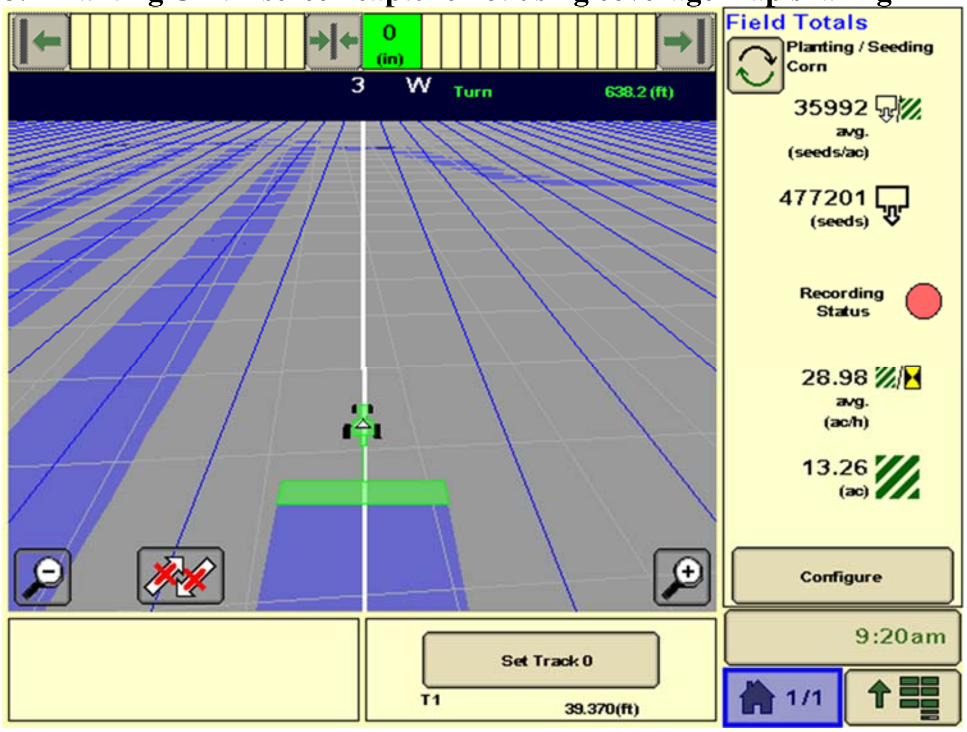


(John Deere Intelligent Solutions Group, 2016)

The simulator was assigned parameters consistent with corn planted at 36,000 seeds per acre at eight miles per hour. The seed brand and seed variety data are logged as a data attribute to each data point, Planting Unit 1 simulated planting brand B1 and variety V1 and Planting Unit 2 simulated planting brand B2 and variety V2.

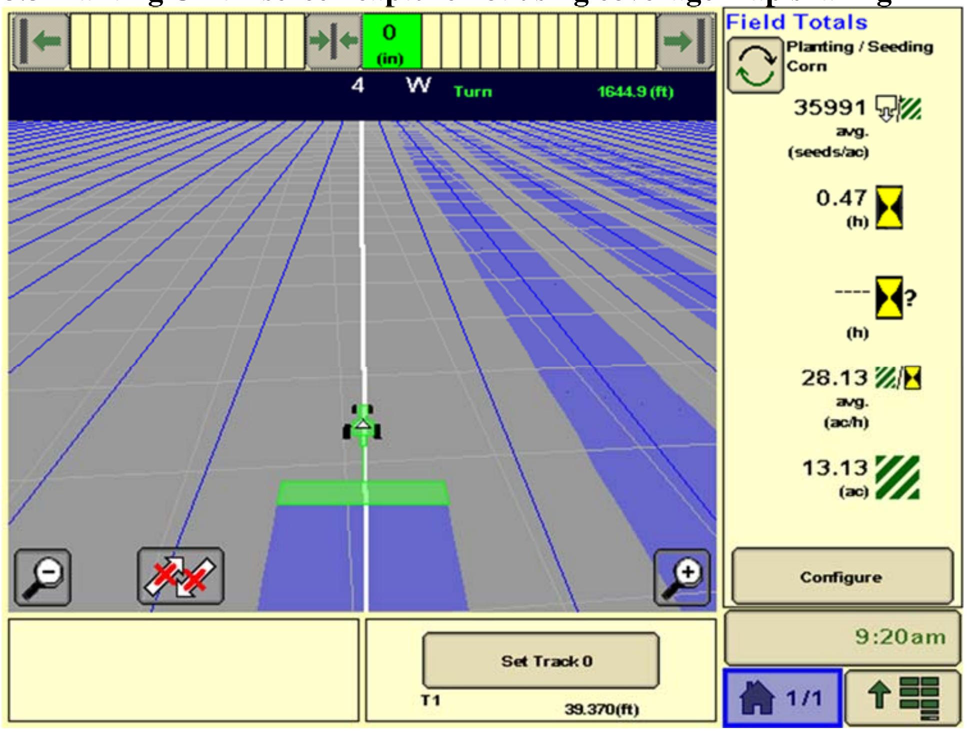
To quantify the benefit of using coverage map sharing, each field had a simulated planting operation completed where two ASC planting units were operating in the same field at the same time, but were not using coverage map sharing. Each planting unit collects planted area information individually as shown by the blue coverage, but the cyan color from the partner planting unit cannot be seen in the screen captures from Planting Unit 1 (Figure 5.4) and Planting Unit 2 (Figure 5.5).

Figure 5.4 Planting Unit 1 screen capture not using coverage map sharing



(John Deere Intelligent Solutions Group, 2016)

Figure 5.5 Planting Unit 2 screen capture not using coverage map sharing

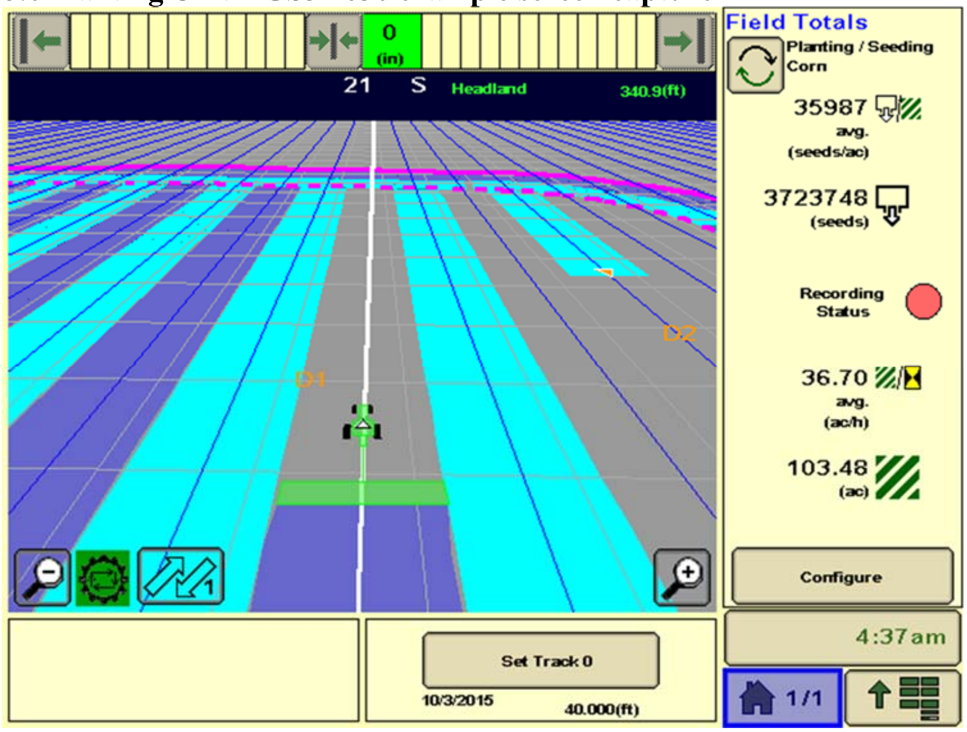


(John Deere Intelligent Solutions Group, 2016)

From the example screen captures in Figure 5.4 and Figure 5.5, in the same field However, Planting Unit 1 does not have information where Planting Unit 2 has planted and vise versa. This lack of information results in the overapplication of seed because the only information ASC contains on each planting unit has to use is the locally stored coverage map.

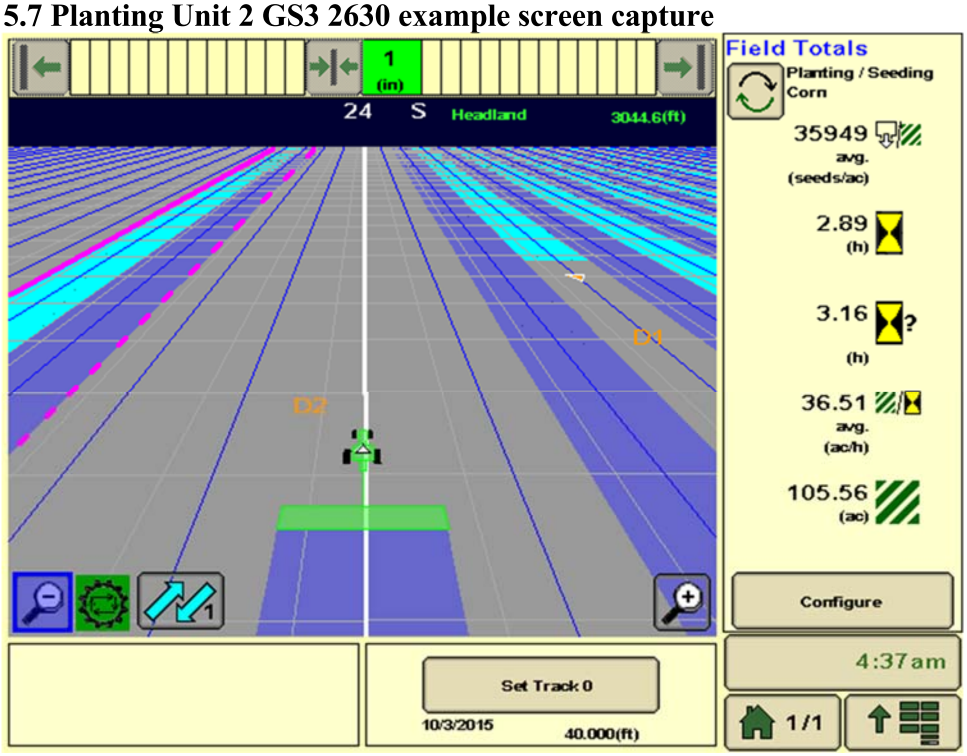
As a result of Coverage Map Sharing, the ASC for Planting Unit 1 has map data of where Planting Unit 2 has planted seed and vice versa. Screen captures from the GS3 2630 monitors while generaling and collecting data and using Coverage Map Sharing are presented in Figures 5.6 and 5.7 for Planting Unit 1 and Planting Unit 2, respectively. It should be noted that each planting unit collects planted area individually as shown by the blue coverage but receives information regarding the partner unit shown by the cyan area.

Figure 5.6 Planting Unit 1 GS3 2630 example screen capture



(John Deere Intelligent Solutions Group, 2016)

Figure 5.7 Planting Unit 2 GS3 2630 example screen capture



(John Deere Intelligent Solutions Group, 2016)

In each of the coverage maps above, the blue coverage is the result of the locally drawn coverage from the planting unit. The cyan colored coverage is a result of the shared coverage from the partner planting unit operating in the same field. Now that the data has been generated it is time analyize.

CHAPTER VI: ANALYSIS AND RESULTS

Automated guidance systems gain their efficiencies in the middle of fields as opposed to the gains from ASC that are on the ends of the field where machinery are turned around. In square and rectangle shaped fields, ASC has limited impact relative to irregularly shaped fields where it has the greatest impact. Field perimeter to field area ratio (p/a) is a field shape irregularity metric that allows numerical comparison instead of comparing fields based only on acreage. Field size, perimeter, and p/a reatio were computed for field boundary (Table 6.1) and coverage boundary (Table 6.2).

For both cases when ASC utilizes field boundary or coverage boundary, the relative randing of fields by p/a ratio remain constant. When the ASC utilizes field boundary, East Field results in the lowest p/a ratio at 1.289 due to its high area of 220.08 acres and 12,360 feet perimeter, i.e a regularly shaped field. The highest p/a ratio is in NorthWest, 6.172. Its area is 12.8 acres and 3,441.2 feet perimeter indicating a highly irregularly shaped field. When the ASC utilized coverage boundary, East Field had p/a ratio of 1.30 while NorthWest had 6.17.

Table 6.1 Field Perimeter, Area, and Perimeter to Area ratio using Field Boundary

	Field Permiter(feet)	Area (acres)	Permiter to Area ratio (ft/ft^2)
East Field	12360.0	220.1	1.29E-03
MidNorth	3337.7	14.5	5.30E-03
MidSouth	3807.4	17.0	5.13E-03
NorthWest	3441.2	12.9	6.10E-03
South	4504.5	24.1	4.29E-03
NebEast	8280.1	79.1	2.40E-03
NebWest	6166.5	45.6	3.10E-03

Table 6.2 Field Perimeter, Area, and Permeter to Area ratio using Coverage Boundary

	Field Permiter(feet)	Area (acres)	Permiter to Area ratio (ft/ft^2)
East Field	12360.0	218.5	1.30E-03
MidNorth	3337.7	14.0	5.45E-03
MidSouth	3807.4	16.3	5.37E-03
NorthWest	3441.2	12.8	6.17E-03
South	4504.5	23.5	4.40E-03
NebEast	8280.1	77.9	2.44E-03
NebWest	6166.5	45.1	3.14E-03

The field shapes were specifically selected for this study to observe the relationship between field shape and size to the amount of double-planted area. Surplus area is defined as the difference between two planting units working together in the same field with and without coverage map sharing (Figure 6.1) and Figure 6.2 is a sample calculation for East Field.. Full results from the data runs with respect to surplus area are presented in Table 6.3 while using a field boundary and Table 6.4 using a coverage driven boundary.

Figure 6.1 Surplus area calculation equiation

$$PercentDifference = \frac{\left|\left(PlantedWithMapSharing - PlantedWithoutMapSharing\right)\right|}{PlantedWithMapSharing} \times 100$$

Figure 6.2 Surplus area sample calculation for East Field

$$8.1\% = \frac{\left|\left(220.08 - 237.98\right)\right|}{220.08} \times 100$$

Table 6.3 Using Field Bounday, Area Comparison With and Without Coverage Map Sharing

	Planted area with map sharing (acres)	Planted area without map sharing (acres)	Surplus Area (acres)	Overlap area by percentage
East Field	220.08	237.98	17.9	8.1%
MidNorth	14.468	16.747	2.279	15.8%
MidSouth	17.024	20.244	3.22	18.9%
NorthWest	12.949	15.654	2.705	20.9%
South	24.11	28	3.89	16.1%
NebEast	79.06	84.07	5.01	6.3%
NebWest	45.63	51.45	5.82	12.8%

Table 6.4 Using Coverage Boundary, Area Comparison With and Without Coverage Map Sharing

	Planted area with map sharing (acres)	Planted area without map sharing (acres)	Surplus Area (acres)	Overlap area by percentage
East Field	218.49	237.98	19.49	8.9%
MidNorth	14.047	16.747	2.7	19.2%
MidSouth	16.273	20.244	3.971	24.4%
NorthWest	12.8	15.654	2.854	22.3%
South	23.5	28	4.5	19.1%
NebEast	77.91	84.07	6.16	7.9%
NebWest	45.05	51.45	6.4	14.2%

The results indicate that differencein area between using a pre-loaded field boundary and the planting unit drivers creating the boundary by planting the field headlands range from 0.7% to 4.41% (Table 6.5). East field resulted in the smallest percent difference between using the field boundary and the coverage boundary. Mid-South resulted in the highest error between field boundary and coverage boundary, 4.41%. It is possible that the observed error is related to the simulation error when collecting data. In all data collection runs, the coverage boundary use case resulted in a lower surplus area.

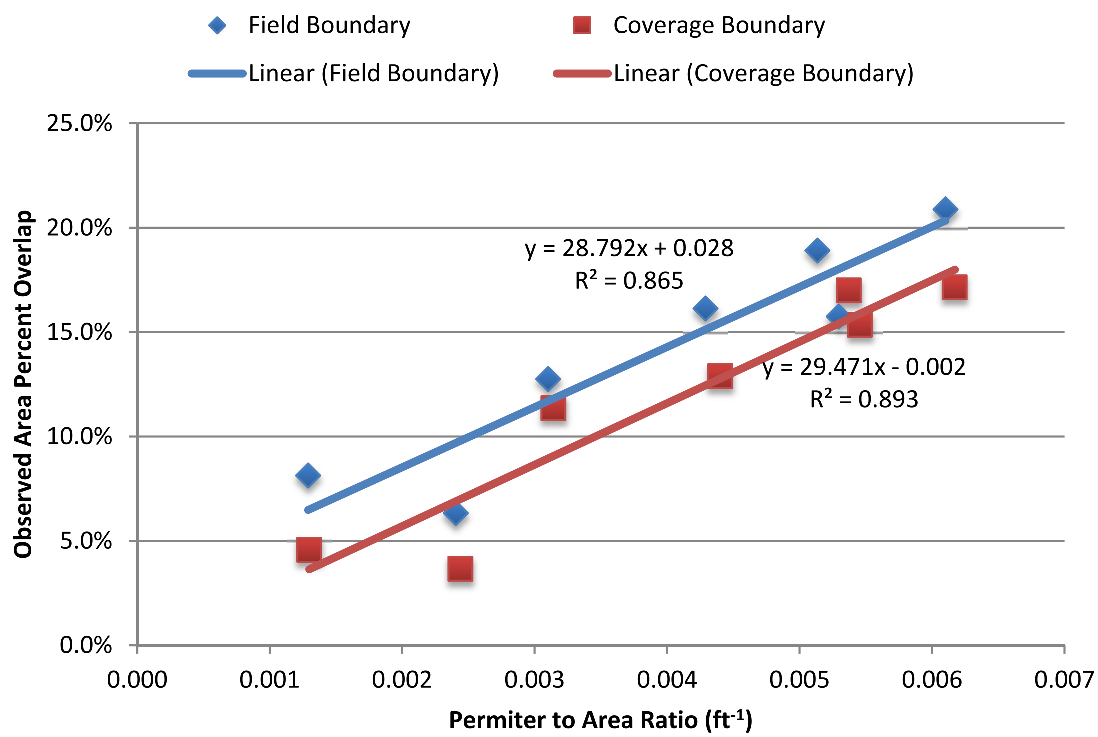
Table 6.5 Comparison of Field Boundary to Coverage Boundary

	Planted area with Field Boundary	Planted area with Coverage Boundary	Difference between Field and Coverage Boundary	Area Difference by percentage
East Field	220.08	218.49	1.59	0.72%
MidNorth	14.468	14.047	0.421	2.91%
MidSouth	17.024	16.273	0.751	4.41%
NorthWest	12.949	12.8	0.149	1.15%
South	24.11	23.5	0.61	2.53%
NebEast	79.06	77.91	1.15	1.45%
NebWest	45.63	45.05	0.58	1.27%

Field boundaries pre-loaded for planting have an advantage for the planter operator as it clearly defines the intended area to be planted. This is especially beneficial when the operator is not familiar with the field's surroundings. The downside is if the field's farming area changes, increase or decrease, due to field boundaries not easily edited in the tractor cab. It would be less time consuming to redrive the field boundary, matching the new farmable area, rather than edit on the desktop computer in the farm office. If the field area decreases then there is a chance of ASC applying product or seed in an area unintentionally. If the field area increases then ASC will prevent application in the new area. The observed error between the field boundary use case and the coverage boundary use case decreases as field sizes increase.

A linear relationship between p/a ratio and surplus area was observed. As field shapes become more irregular, i.e. p/a ratio increases, larger surplus areas were expected when ASC and coverage map sharing was not utilized (Figure 6.3). The values on the Y-axis come from Tables 6.3 and 6.4, Overlap Area By Percentage. Based on the estimated coefficients form an ordinary least squares (OLS) estimation, a regression line was calculated for both field boundary and coverage boundary (Figure 6.3). A substantial portion of the variability in the data were accounted for in this binary relationship. The rsquared values for field boundaries and coverage boundaries were 0.865 and 0.893, respectively. These r-quared values indicate that the estimated line explains nearly 90% of the variability in the data and can be loosely interpreted as a close fit between the observed data and the estimated regression line.

Figure 6.3 Relationship between Perimeter to Area Ratio and % Overlap Area



The number of planted acres required for the cellular coverage map sharing using the previously determined cost savings per acre to breakeven was evaluted. The number of acres annually required for each field such that a positive payback is realized in one year are presented in Table 6.4. Northwest using a field boundary results in the fewest acres to use the service for one year payback at 137.5. Northwest also has the highest p/a ratio of any of the seven fields evaluated. For the scenario of coveragbe boundary, NebEast had the greatest area requiment of 782 acres to achieve a positive payback in the first year of operation.These results demonstrate that if an entire farming operation is comprised up of fields having identical and constant p/a ratios.

Table 6.6 Area required for 1 year system payback

Field Boundary	Permiter to Area ratio (ft/ft^2)	Savings per acre (cost savings)	Required Acres for 1 year payback
East Field	1.289E-03	$ 11.30	353.0
MidNorth	5.296E-03	$ 21.89	182.3
MidSouth	5.134E-03	$ 26.28	151.8
NorthWest	6.101E-03	$ 29.03	137.5
South	4.289E-03	$ 22.42	178.0
NebEast	2.404E-03	$ 8.81	453.1
NebWest	3.102E-03	$ 17.72	225.1
Coverage Boundary	Permiter to Area ratio (ft/ft^2)	Savings per acre (cost savings)	Required Acres for 1 year payback
East Field	1.299E-03	$ 6.35	628.0
MidNorth	5.455E-03	$ 21.34	187.0
MidSouth	5.371E-03	$ 23.63	168.9
NorthWest	6.172E-03	$ 23.83	167.4
South	4.400E-03	$ 17.92	222.7
NebEast	2.440E-03	$ 5.10	782.2
NebWest	3.142E-03	$ 15.79	252.6

As an alternative to considering that each farming operation consists of fields with identical p/a ratios, a series of hypothetical 3,000 acre farms comprised of differing combinations of the seven fields were considered These proporstions were iterated using ten percent granularity that resulted in 8,008 different scenarios. Using the 8,008 farm composition scenarios, annual savings and net present value were calculated, using an assumed a constant 36 ksds per acre and $3.86 per 1,000 seeds (Plastina, 2016). An excerpt of these comibnations are presented in Table 6.5.

Table 6.7 Scenario Examples Of Porportions of the 7 Fields for a 3,000 Acre Farm

	East Field	MidNorth	MidSouth	NorthWest	South	NebEast	NebWest	
	$11.30	$21.89	$26.28	$29.03	$22.42	$8.81	$17.72	
FarmOp3932	10%	10%	10%	10%	10%	50%	0%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 2.24	$ 4.40	$ -	$ 15.50
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 6,726.10	$ 13,208.76	$ -	$ 46,485.75
FarmOp3933	10%	10%	10%	10%	20%	0%	40%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 4.48	$ -	$ 7.09	$ 20.42
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 13,452.20	$ -	$ 21,268.83	$ 61,271.92
FarmOp3934	10%	10%	10%	10%	20%	10%	30%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 4.48	$ 0.88	$ 5.32	$ 19.53
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 13,452.20	$ 2,641.75	$ 15,951.62	$ 58,596.47
FarmOp3935	10%	10%	10%	10%	20%	20%	20%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 4.48	$ 1.76	$ 3.54	$ 18.64
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 13,452.20	$ 5,283.50	$ 10,634.41	$ 55,921.01
FarmOp3936	10%	10%	10%	10%	20%	30%	10%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 4.48	$ 2.64	$ 1.77	$ 17.75
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 13,452.20	$ 7,925.25	$ 5,317.21	$ 53,245.56
FarmOp3937	10%	10%	10%	10%	20%	40%	0%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 4.48	$ 3.52	$ -	$ 16.86
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 13,452.20	$ 10,567.01	$ -	$ 50,570.10
FarmOp3938	10%	10%	10%	10%	30%	0%	30%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 6.73	$ -	$ 5.32	$ 20.89
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 20,178.31	$ -	$ 15,951.62	$ 62,680.82
FarmOp3939	10%	10%	10%	10%	30%	10%	20%	
Savings per acre	$ 1.13	$ 2.19	$ 2.63	$ 2.90	$ 6.73	$ 0.88	$ 3.54	$ 20.00
Farm Savings	$ 3,390.65	$ 6,566.70	$ 7,885.07	$ 8,708.47	$ 20,178.31	$ 2,641.75	$ 10,634.41	$ 60,005.36

A summary of the calculations are presented in Table 6.6. It was identified that the average cost savings for whole farm operation was $58,909 and maximum savings of $87,085 and minimum savings of $26,418 resulting in a range of $58,909 for the cellular option.

Table 6.8 Estimated annual whole farm cost savings for scenarios

3000	acres	
Min	$	26,418
Max	$	87,085
Diff	$	60,667
Total Savings for Farm Op		
Mean	$	58,909

	Min	**Max**	**count**
1	$26,418	$32,484	23
2	$32,484	$38,551	144
3	$38,551	$44,618	452
4	$44,618	$50,684	982
5	$50,684	$56,751	1585
6	$56,751	$62,818	1940
7	$62,818	$68,885	1673
8	$68,885	$74,951	899
9	$74,951	$81,018	274
10	$81,018	$87,085	35

In addition to the estimated seed cost savings for farms composed of fields of similar shapes, net present value (NPV) was calculated using seven percent interest and a five year cash flow. Each of the 8,008 scenarios resulted in a positive NPV relative to not using coverage map sharing. Considering a NPV of zero is a good investment, the Goal Seek tool in Microsoft Excel was used to calculate the number of acres for each farm composition scenario that resulted in a zero NPV for cellular communication. These results were broken down into ten ranges (Table 6.7). The ranges are equally spaced between the minimum value and maximum value. By examining the Accumulating percentage in Table 6.9, 91.12% of the scenarios required 111 acres per year for 5 years to result in a net zero NPV.

Table 6.9 Required acres annually for 5 years for NPV to result in zero using cellular

Area(acres)	Cellular		Min	Max	Occurences	Population Distribution	Accumulating%
Min	58	1	58	71	834	10%	10.42%
Max	191	2	71	85	3057	38%	48.59%
Diff	133	3	85	98	2325	29%	77.63%
		4	98	111	1080	13%	91.12%
		5	111	124	443	6%	96.65%
		6	124	138	171	2%	98.79%
		7	138	151	63	1%	99.58%
		8	151	164	24	0.3%	99.88%
		9	164	178	8	0.1%	99.98%
		10	178	191	2	0.02%	100.00%

Compared to typical sized Midwestern farms, these results demonstrate that Coverage Map Sharing requires a relatively small usage annually for five years for two planting units working together to result in a good investment.

CHAPTER VII: DISCUSSION

Unfortunately throughout the United States, there are areas with poor cellular coverage. Cellular connectivity can be difficult, specifically in rural areas, due to the high investment costs for cellular infrastructure and fewer users compared to an urban or suburban setting. As an alternative networking method to cellular, high-powered Wi-Fi radios are a communication option between planting units. Using Wi-Fi instead of cellular removes a failure point the farmer has little control over. A follow up study should include cellular data signal reliability to determine the financial impact on losing the cellular data signal for a prolonged period of time. This signal loss would result in coverage map data not being delivered in a timely manner affecting ASC performance. The farmer could use this financial impact data to determine whether or not it is a wise investment to change communication methods for coverage map sharing from cellular to high power Wi-Fi or at least consider if Wi-Fi is a viable redundant backup option.

Open Internet regulations implemented by the FCC in 2015 play an important role in telematics and specifically coverage map sharing as the farmer unlocks new economic potential. These regulations prevent the cellular carriers from withholding the farmer's coverage map until a payment is received. Without these regulations, cellular providers could try to request payment by the service providing company to ensure the data is not held up in Internet traffic, resulting possibly in a degraded customer experience until payment is received.

It should not be assumed that the entire seed cost savings from automated section control goes into the farmer's pocket. There could come a day where land owners could ask for premium rents due to good cellular connectivity which would transfer the economic advantages of coverage map sharing from farmer to land owner (Griffin, et al., 2016). If the farmer's equipment costs remain constant, technologies such as machine guidance, automatic section control and coverage map sharing unlock new economic potential resulting in the farmer's equipment costs being less expensive per acre and new opportunities to pay more for cash rent.

Any identified savings for a specific farm operation highly depends, not only on farm operation size and field shapes, but also on driving patterns and in-field obstacles. For this study and several previous ones, it was assumed there were no obstacles in the field to farm around and that all guidance lines are straight. Varying angle of approach into the headlands was done just by field shape, but infield obstacles would also influence approach angles too.

This study is a conservative estimate of the potential cost savings from coverage map sharing because it only takes into consideration seed costs while planting and using automated section control. Automated section control has other use cases while performing additional farm operations such as nutrient application and spraying. It has been previously demonstrated that from proper implement control along with good seed and product placement, increased yields were observed.

CHAPTER VIII: CONCLUSION

Automatic section control has been saving farmers money for nearly ten years by reducing overlap while applying product. This has been enabled by having finer control over the machine and implement and through machine guidance. If a farmer desires to be more productive, he/she should consider two mid-sized planters instead of one very large one. Larger planters have longer setup time and are more difficult to transport. Additionally, it should not be assumed the two planters are the same width. Field shape could make it possible where a smaller planter could be more efficient in specific field areas where a larger planter is more efficient in the middle. Given p/a ratios of many farmers' fields, two mid-sized planters or spryaers have higher field efficiency than one larger machiner and are able to cover more acres per hour. Custom applicators are likely to devote multiple machines to the same field at the same time and can benefit from shared coverage map technology.

Seven different fields had simulated planting operations performed with two planting units in the field at the same time. Each field was run twice, once without coverage map sharing between the planting units and once with coverage map sharing enabled with the goal of calculating the amount double planted area in each field. With seed costs, the seed savings per acre was determined for each field.

As with any farm investment, it is important that there are economic advantages to making the purchase. The study demonstrated there are tangible economic benefits to investing with annual acre requirement, which would be attained by farmers for a five year payback. The seed savings per acre is dependent on the field size, perimeter and the shape irregularity.

WORKS CITED

Ag Leader Technology. (2015, 12 1). Spatial Management System application. *SMS Basic v15.2*. Ames, Iowa, United States: Ag Leader Technology.

Ag Leader Technology. (2016, January 11). Application Controller. *ISOBUS Application Controller v1.8*. Ames, Iowa, USA: Ag Leader Technology.

Broadband Commission for Digital Development. (2014, September 21). *The State of Broadband 2014: Broadband for All.* Retrieved October 1, 2015, from Broadband Commission for Sustainable Development: http://broadbandcommission.org/Documents/reports/bb-annualreport2014.pdf

Erickson, B., & Widmar, D. A. (2015). *2015 Precision Agricultural Services Dealership Survey Results.* Purdue University, Department of Agricultural Economics / Department of Agronomy. West Lafayette: Croplife Magazine.

Federal Communications Commission. (2015a, January 29). *Federal Communications Commission.* Retrieved September 12, 2015, from 2015 Broadband Progress Report: https://www.fcc.gov/reports/2015-broadband-progress-report

Federal Communications Commission. (2015b, Feburary 26). *Federal Communications Commission.* Retrieved September 16, 2015, from Open Internet: https://www.fcc.gov/openinternet

Griffin, T. W., Mark, T. B., Ferrell, S., Janzen, T., Ibendahl, G., Shanoyan, A., . . . Maurer, J. L. (2016). Big Data Considerations for Rural Property Professionals. *Journal of the American Society of Farm Managers and Rural Appraisers*, TBD.

International Organization for Standardization. (2015). *Tractors and machinery for agriculture and forestry - Serial control and communications data network - Task controller and management information system data interchange* (2nd Edition ed.). Geneva, Vernier, Switzerland: ISO Copywrite Office.

John Deere Ag Management Solutions. (2015). *Operator's Manual GreenStar3 2630 Display.* Moline, Illinois, United States: Deere & Company.

John Deere Intelligent Solutions Group. (2016, 1 11). GreenStar3 2630. *v3.32.1224*. Urbandale, Iowa, USA: Deere & Company.

Robertson, A. (2014, 01 14). *Federal court strikes down FCC net neutrality rules*. Retrieved 12 05, 2015, from The Verge: http://www.theverge.com/2014/1/14/5307650/federal-court-strikes-down-net-neutrality-rules

Runge, M., Fulton, J., Griffin, T., Virk, S., & Brooke, A. (2014, October 1). *Alabama Cooperative Extension System.* Retrieved September 8, 2015, from Precision Agricultural - Section Control Technology: http://www.aces.edu/pubs/docs/A/ANR-2217/ANR-2217.pdf

Schemper, J. (2014, 5 9). *Efficiency of combine usage: a study of combine data comparing operators and combines to maximize efficiency.* Retrieved 11 1, 2015, from K-State Research Exchange: http://hdl.handle.net/2097/17738

Shearer, S. (2014, June 29). *The Ag Info Conference 2014.* Retrieved September 24, 2015, from Big Data: The Future of Precision Agriculture : http://infoag.org/abstract_papers/papers/paper_233.pdf

Shockley, J., Dillon, C. R., Stombaugh, T., & Shearer, S. (2012). Whole Farm Analysis of Automatic Section Control For Agricultural Machinery. *Precision Agriculture*, 411-420.

Sloan Implement. (2016, January 1). *Sloan Implement AMS Newsletter.* Retrieved January 9, 2016, from Sloan Implement: http://www.sloans.com/wp-content/uploads/2014/12/Dec-2014-newsletter.pdf

Smith, C. M., Dhuyvetter, K. C., Kastens, T. L., Kastens, D. L., & Smith, L. M. (2013). Economics of Precision Agricultural Technologies Across the Great Plains. *2013 Journal of the ASFMRA*, 185-206.

Whitacre, B. E., Mark, T. B., & Griffin, T. W. (2014, July 1). *Choices: The Magazine of Food, Farm, and Resources Issues.* Retrieved September 19, 2015, from How Connected Are Our Farms?: http://purl.umn.edu/188271

APPENDIX A: EMBEDDED VBA EXCEL MACRO CODE

A.1 Scenario Builder Macro

```
Sub ScenarioBuilder()
r = 1
For B = 0 To 10
For C = 0 To 10
For D = 0 To 10
For E = 0 To 10
For F = 0 To 10
For G = 0 To 10

If (B / 10) + (C / 10) + (D / 10) + (E / 10) + (F / 10) + (G / 10) = 1
Then
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 1) = "Scenario" & r
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 2).Activate
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 2) = B
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 3) = C
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 4) = D
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 5) = E
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 6) = F
    ThisWorkbook.Worksheets("Scenario").Cells(r + 1, 7) = G
    r = r + 1
End If

Next G
Next F
Next E
Next D
Next C
Next B

End Sub
```

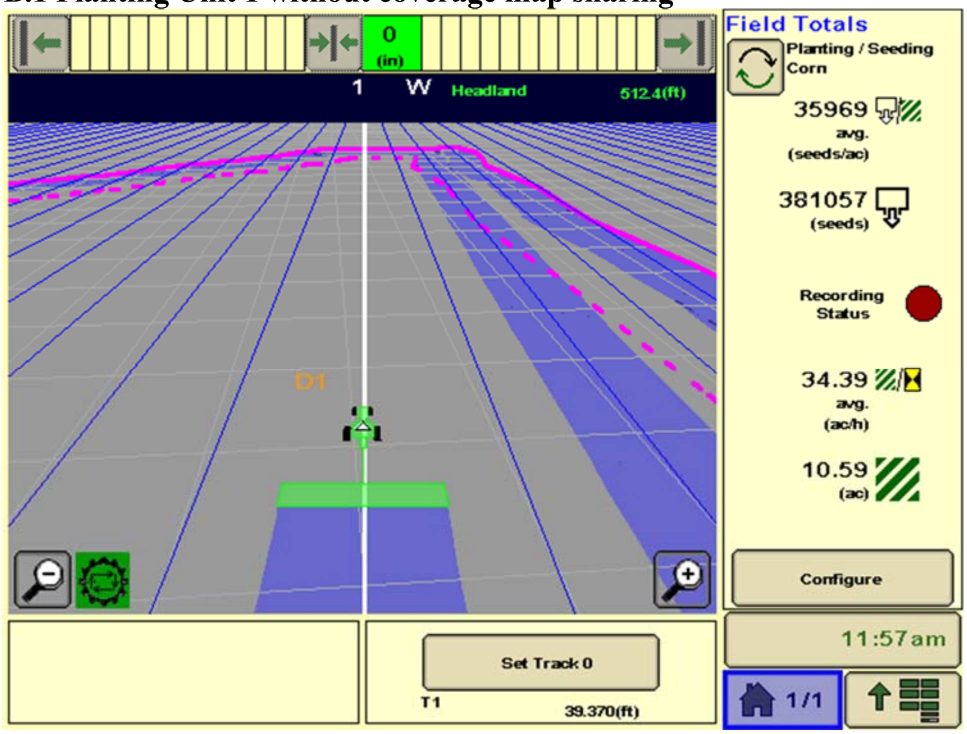
A.2 GoalSeek Macro

```
Sub GoalSeek()

For R = 3 To 8010

ThisWorkbook.Worksheets("NPV_Breakeven").Cells(R, 30).Activate
ThisWorkbook.Worksheets("NPV_Breakeven").Cells(R, 43).GoalSeek Goal:=0, _
ChangingCell:=ThisWorkbook.Worksheets("NPV_Breakeven").Cells(R, 30)

Next R

End Sub
```

APPENDIX B: ADDITIONAL GS3 2630 SCREEN CAPTURE PAIRS

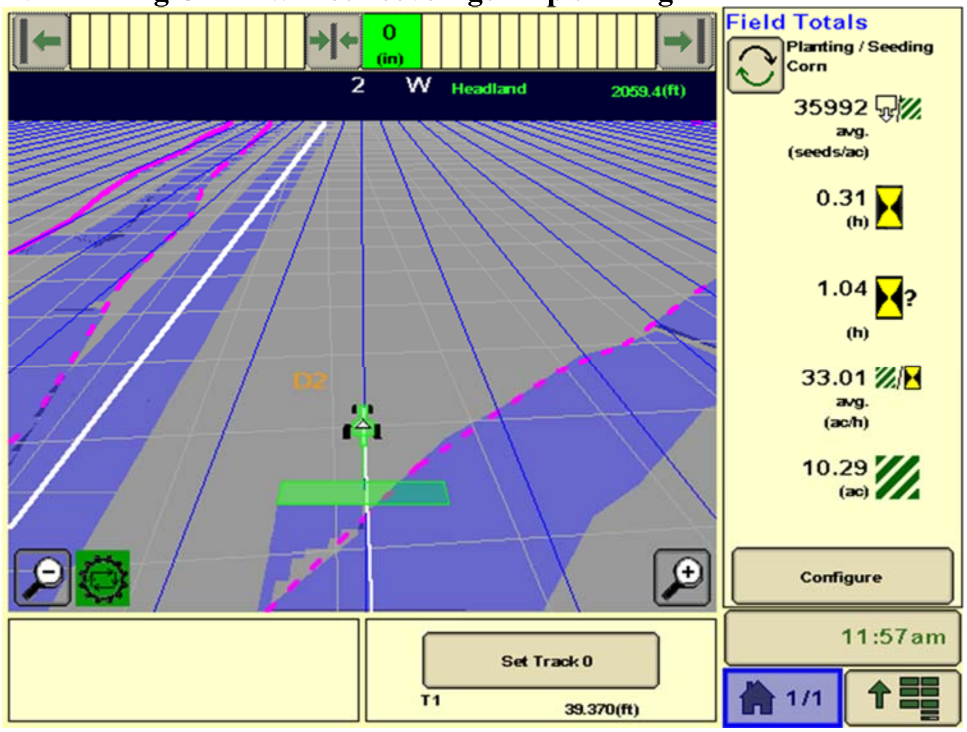
Figure B.1 and Figure B.2 were captured within seconds of each other while collecting data on the GS3 2630 displays. This pair is an example without Coverage Map Sharing.

Figure B.1 Planting Unit 1 without coverage map sharing



(John Deere Intelligent Solutions Group, 2016)

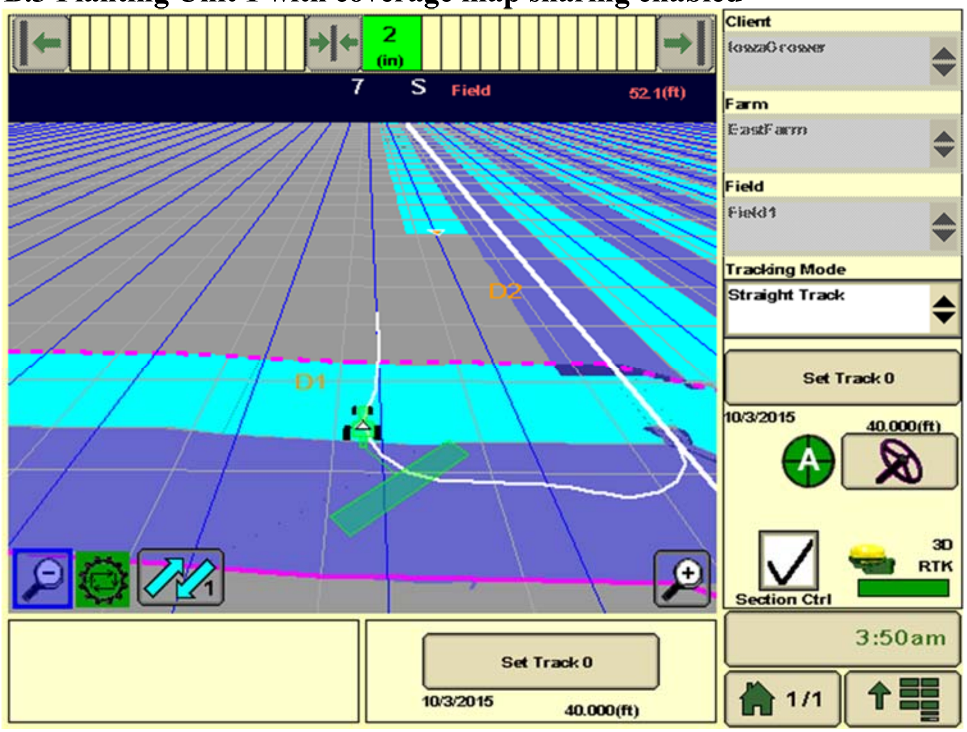
Figure B.2 Planting Unit 2 without coverage map sharing



(John Deere Intelligent Solutions Group, 2016)

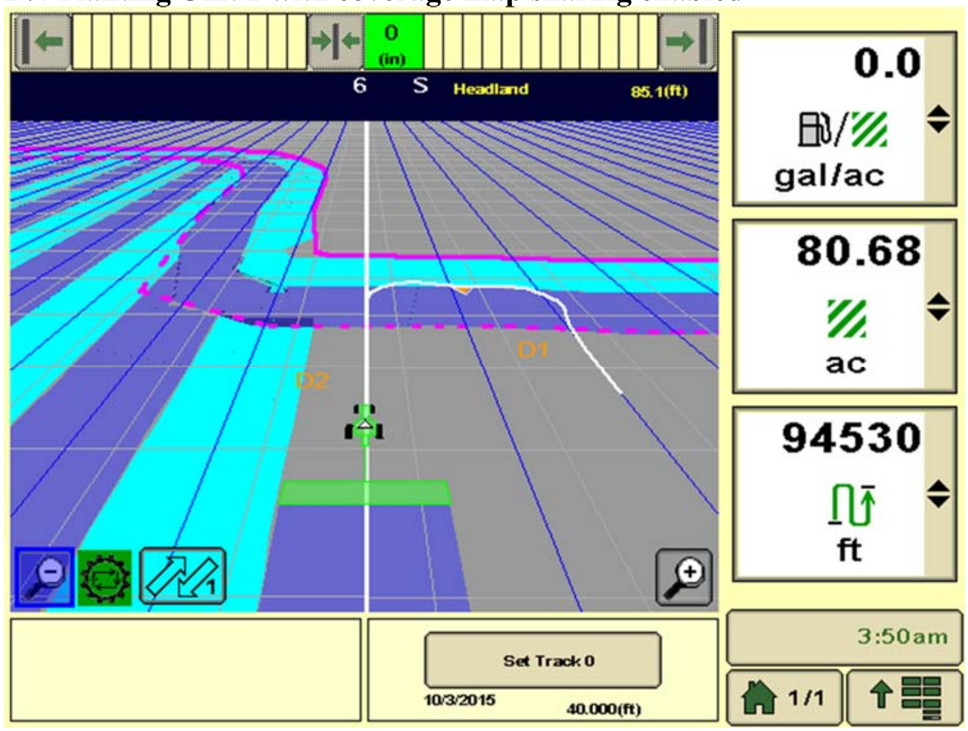
Figure B.3 and Figure B.4 are screen captures from the GS3 2630 displays while collecing data. In these screen captures, coverage map sharing was enabled.

Figure B.3 Planting Unit 1 with coverage map sharing enabled



(John Deere Intelligent Solutions Group, 2016)

Figure B.4 Planting Unit 2 with coverage map sharing enabled



(John Deere Intelligent Solutions Group, 2016)