Value of Internet Connectivity Uptime for Multiple Vehicles using Automated Section Control

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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. Without sharing coverage maps, an individual ASC planting unit only has location data where it has been 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 the machinery and utilizes existing machine telematics infrastructure. 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 tractor/planter combination is equipped with automatic section control and telematics

gateways to share coverage map data from the first tractor to JDLink cloud infrastructure then out to the second tractor. This study evaluates the impact that field size and shape have on using multiple planters ASC and coverage map sharing, and estimate the cost of experiencing cellular connectivity outages over a range of expected uptimes. 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.

Data were analyzed to assess the willingness-to-pay for the coverage map sharing feature using cellular connectivity. Additionally, data were analyzed to evaluate the possible effect that a degraded cellular connectivity may have on the automatic section control and whether or not this would lead a farmer to purchase a communication solution which did not have a dependency on a cellular network and a near guaranteed connection for farmers.

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.

Keywords: precision agriculture, automated swatch control, automated guidance, broadband, connectivity, wireless, data transfer

INTRODUCTION

Precision agriculture has evolved over the years from simple yield data collection to manual machine guidance, automatic machine guidance and electronic application rate control. With electronic rate control and guidance has come automatic section control where electronics and in-cab computers have made the planting far more technical. Instead of enabling and disabling the planter's row units 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 manufactures are starting to offer connected machine solutions which enable sharing coverage map data between machines operating in the same field, but do the efficiencies gained by understanding where other machines have completed work? 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 perimeter to area ratios for each field. Using the identified cost savings, an annual amount of area is calculated for positive three year and five-year payback periods.

BACKGROUND

Only until very recently have precision farming technologies advanced to enable shared information between farm vehicles in the same field in near real time. 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 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.

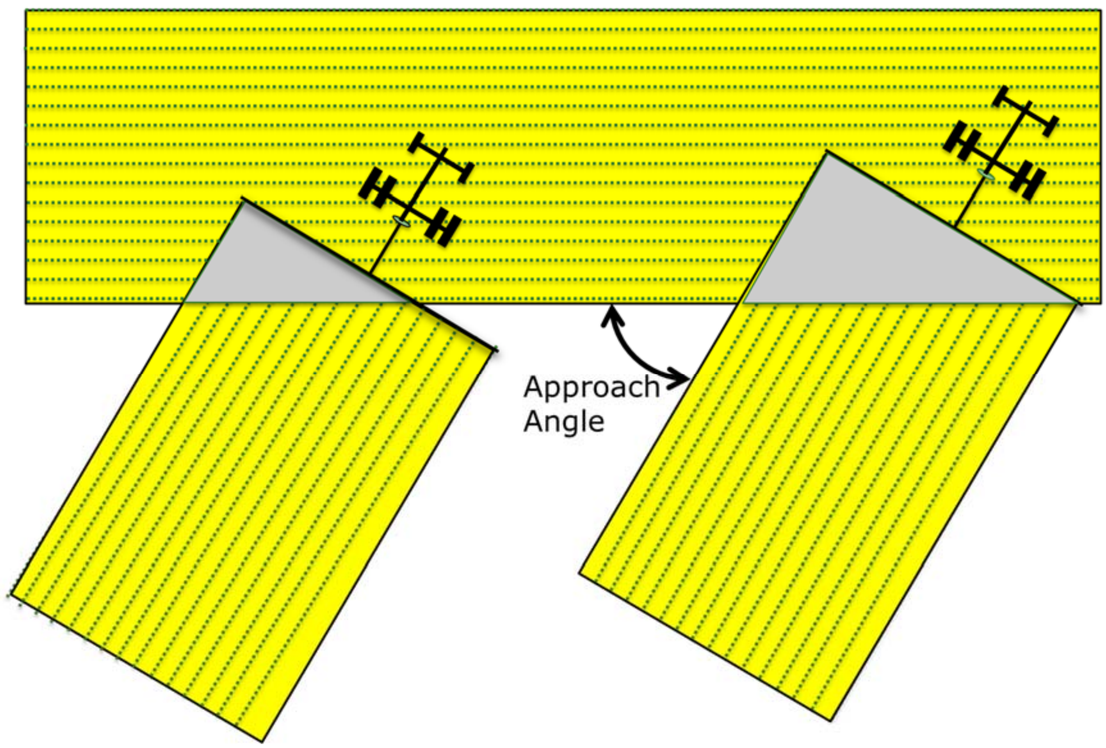
Automatic Section Control System Decomposition

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 controller area 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 can interface with ECU's, as well. ASC is a precision farming technology that combines Global Navigation Satellite System (GNSS) 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. There are two automatic methods the application rate can be set. The first way is 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 polygon's rate assignment. 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 final way a rate can be set automatically 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. ASC is a state machine, internally and continuously 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 or seed otherwise it continues to apply. Although not required, 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 queries for previous coverage on the coverage map and the field boundary simultaneously.

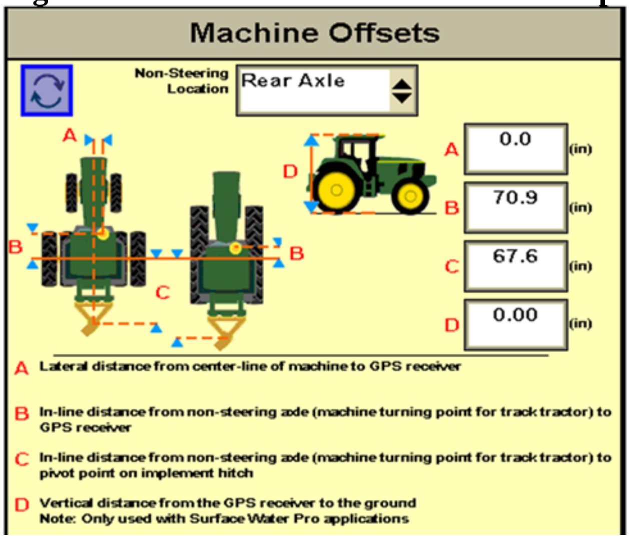
Automatic section control technologies result in finer control of product application instead of an "all on" or "all off" strategy across the implement's entire width. Groups of planter row units or sprayer nozzles result in smaller, controllable sections which reduce overlapped application and wasted product as shown in Figure 2.X and represented in the gray triangles. Control on a per row or per nozzle basis is available on the market today.



The area of the ACS technologies are used throughout a Midwest farming season. 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. 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).

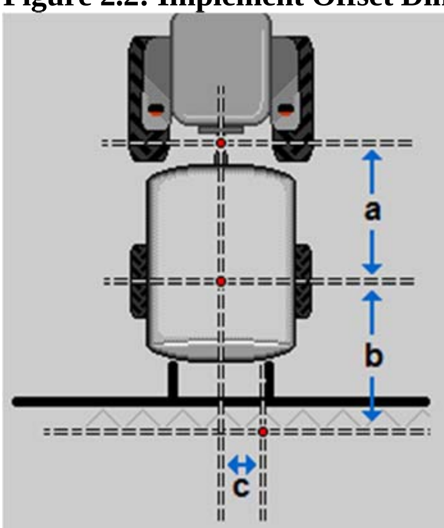
In its simplest configuration, automatic section control implements share the use of the machine's GNSS receiver location information. Using a series of measurements and then machine/implement connection type, standardized by ISO-11783 Part 10 for tractors and implements, the implement's location can 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 2.1 and 2.2 show examples to how offset dimensions are entered and saved.

Figure 2.1 Machine Offset Dimensions example



(John Deere Intelligent Solutions Group 2016)

Figure 2.2: Implement Offset Dimensions example

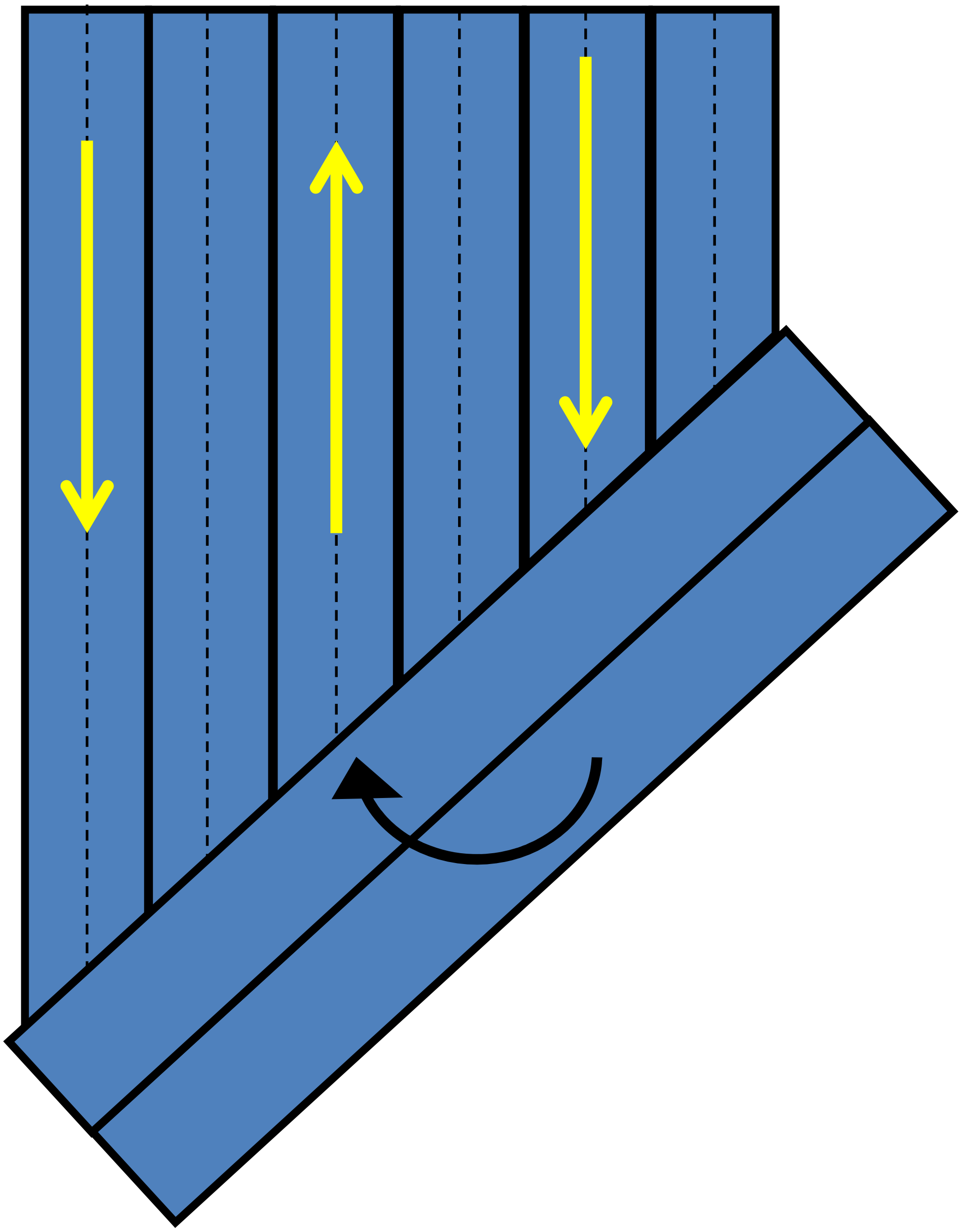


(Ag Leader Technology 2016)

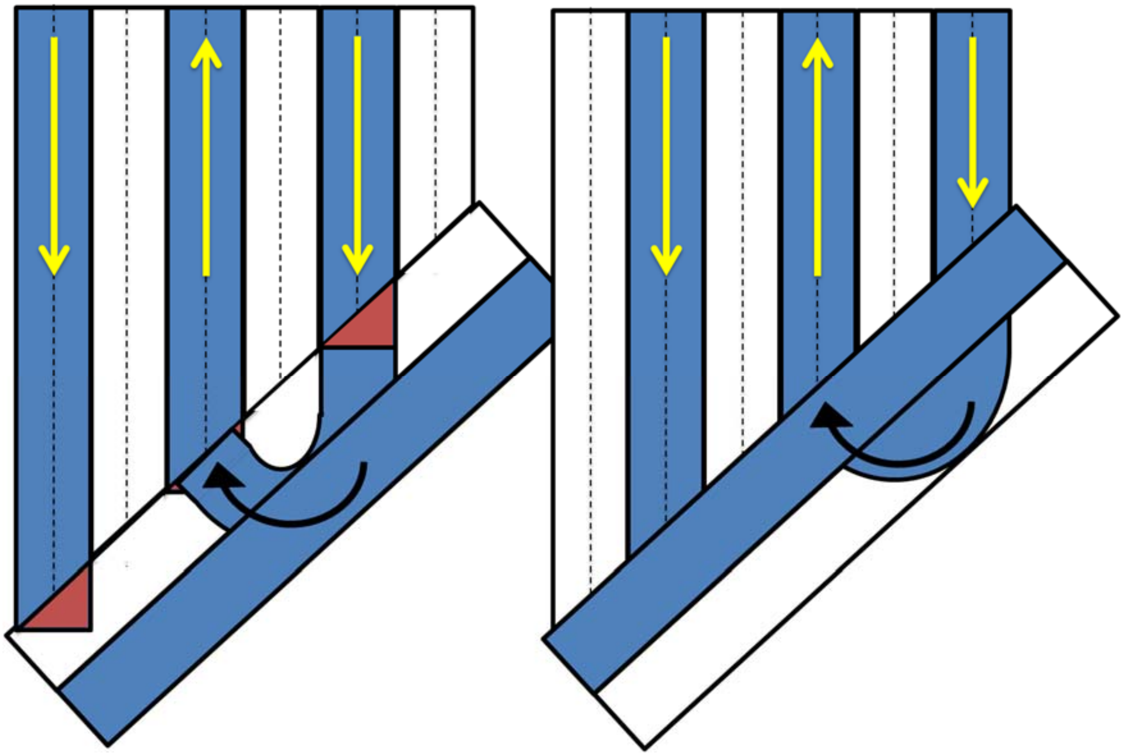
The GNSS heading is the radial direction of travel relative to geographic north, which is typically zero degrees. While in a turning motion, such as at an end row, a rigidly mounted implement such as a combine header, three point mounted planter or self-propelled sprayer boom will always have an identical GNSS heading as the machine while in turn where as a drawbar drawn planter will not have the same heading in 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).

ASC Coverage Map and Why Sharing is Important

ASC's coverage map records where work has been completed. It is a record of where product has been applied and seed has been planted. The coverage map is stored locally on the machine or implement which is performing the work. When one ASC compatible is operating in a field, it results in a coverage map similar to the one in Figure 2.X.

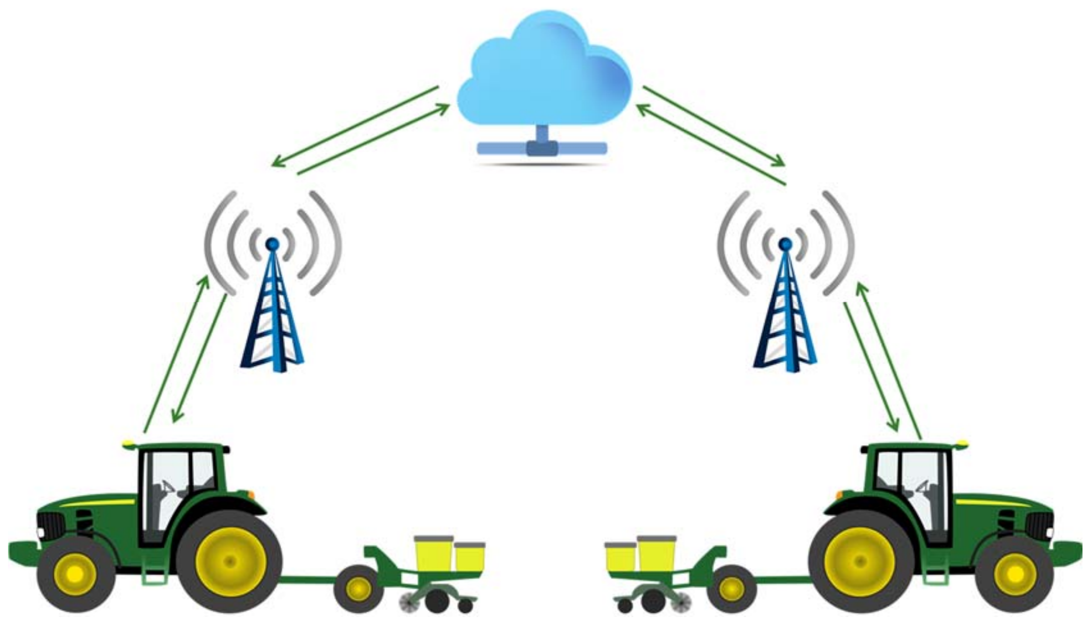


There are challenges when there are two (or more) automatic section control (ASC) capable farm implements performing the same farming operation in the same field at the same time. The individual machines and implements know where they have applied product or seed, but without a way to share their individual coverage maps, they will look similar to Figure 2.X where there is product application in unintended areas.

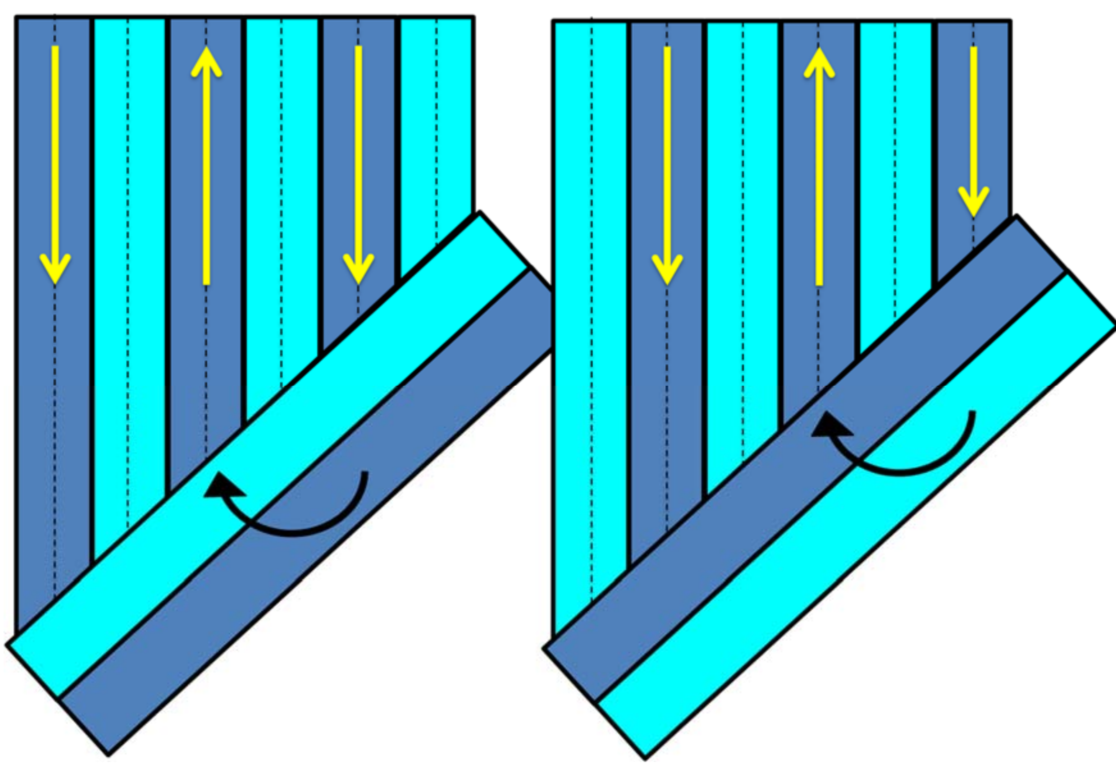


Deere and Company offers two different communication solutions to share the ASC coverage map between units in the same field. A Wi-Fi network solution is a point to point communication network between planting units shown in Firgure 2.X and does not require cloud computing infrastructure.

Coverage map data is shared between the units, but there is no cloud server in the middle retaining the data for sixty days. For cellular connected farm vehicles equipped with a telematics gateway, coverage map sharing can use this existing infrastructure displayed in Figure 2.X.



The resulting coverage map when sharing is possible results in a coverage map similar to Figure 2.X where the dark blue represents the locally applied product and the cyan coverage is a result of the work completed by the planting partner.



When using the cellular solution, planting units can come and go as needed because the coverage map is stored on the telematics server; Wi-Fi works differently. There is no telematics server equivalent and the point-to-point nature of Wi-Fi means data will only be shared if both planting units are in network. Vehicles which are not cellular equipped or for areas where cellular coverage is poor, a Wi-Fi network solution may be a better option. The Wi-Fi radios have a higher reliability but that does come at a cost. Each radio costs $3699 and one radio per planting unit is required.

Topography plays a factor in cellular and Wi-Fi network signal reliability. It is possible that specific areas of farm 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 second 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 on a delay. This could result in the planting units transmitting or receiving the coverage map data late after an area is planted.

LITERATURE REVIEW

Precision agriculture companies have marketed automatic section control 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 a simple economic analysis including a rate of return and payback period (Shockley, et al. 2012).

As part of Shockley et al. (2012), a ~80-feet (24-meter) sprayer width was used equipped with ten equal width nozzle control sections. The planter was modeled as ~40-feet (12 meters) wide, each of the 16 rows independently controlled. Four fields were selected, reflecting field size and shape common in Kentucky agricultural production, Field 1, 99 acres (40 hectares) and Field 2, 10 acres (4 hectares) square in shape. Field 3, 7.5 acres (3 hectares) and Field 4, 247 acres (100 hectares) were considered irregularly shaped. 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, et al. 2012). Four scenarios were studied, both the planter and sprayer together with machine guidance, sprayer only with guidance, planter only with guidance, and lastly planter and sprayer together without machine guidance.

The study's goal was to understand the profitability of precision agriculture technology including machine guidance and automatic section control. All the scenarios were profitable, 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 automatic section control savings. Smaller, irregular fields resulted in greater increases in average net returns, greater returns on investment and smaller payback period (Shockley, et al. 2012).

Smith et al. (2013) builds upon the foundation that Shockley et al. (2012) established, expanding the model from four fields to 553 real fields from farms in Colorado, Kansas, and Nebraska totaling 49,095 acres across thirteen different USDA reporting districts. Aside from the number of fields under the Smith et al. (2013) study, a key difference is that it only considered economic impact of ASC while performing a spraying operation.

Due to the amount of different farm fields under consideration, field size and shape continued to prove important in the payback. In northwest Kansas fields, the investment in automatic section control payback period was less than a year. Also observed, as the field size increases, the net benefits of automatic section control decreases because the field area to headland area ratio decreases. Automatic section control pays back multiple times across the same acres if a spray application is accomplished multiple times in the same growing season. This gives the opportunity to spread system costs over more application acres. If a farm is 1,000 acres and sprayed three times, the opportunity for reduced system costs per acre due to more application area to cover.

As demonstrated in previous auto section control studies including Smith et al. (2013) and Runge et al, (2014), payback is highly dependent on field size and field shape. These studies also indicated that the field size is important as well. The larger the field, the less impact that auto section control affects feature 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, et al. 2014).

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 quick adoption rate compares closely to machine guidance (Erickson and 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 in agriculture.

JDLink is Deere & Company's cloud system for telemetric data. Used in both construction and agricultural equipment, it allows machine owners to 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). It 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. Wireless Data Transfer (WDT) uses the machine's MTG to move agronomic data and guidance lines to the user's MyJohnDeere.com account for off board data processing. Additionally, 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; 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 usages, machine hours, engine performance and activity. The study was able to identify which specific machine in the fleet is the most productive and the one with the highest fuel efficiency rate. Lastly, the study demonstrated machine operation experience through fuel usage rate. It was recognized lesser experienced combine operators were not idling down during harvest wait times.

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 SRAM memory cards and compact flash memory cards to collect and store the data. Farmers would then be required to 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 and Griffin 2014). As internal flash memory has become more affordable, external media is not required for recording data, but still required for transporting in the absence of wireless technology.

An improved solution for removing the physical loss possibility requires wireless technology. Some precision agriculture technology providers have released wireless solutions where data is 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 provider when suitable internet connection is obtained. This type of solution does help with the transferring of data from the field to the office computer but does not fix the problem with regards to reduced levels of cellular internet and does not allow for the passive transfer of data. As precision farming technologies advance, it will drive the communication between the farm office to the tractor or between tractors in the same field. Reliable cellular connections help to enable this communication.

Internet connectivity has grown at large rates across the world to be used for many reasons including education, culture, entertainment, financial services and many others. Throughout the world, 40% of the population (2.9 billion people) have internet access. Additionally, there was 6.9 billion mobile internet subscriptions with three-quarters in developing areas of the world (Broadband Commission for Digital Development 2014). What this likely indicates is that these areas of the world skipped the copper wire telephone networks and adopted wireless technology. It is estimated that by 2019, there could be as many as 5.6 billion smartphones worldwide.

Internet connections are traditionally measured in bits and file sizes are measured in bytes. There are eight bits in one byte. Since 2010, to be defined as broadband speed internet in the United

States, a 4 Mbps (megabits per second) download speed and 1 Mbps upload speed. 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 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 2015b).

This large gap between download and upload transfer rates continues to cause problems in precision agriculture for depending on cellular technologies to transfer data (Whitacre, Mark and Griffin 2014). The high download speed and low upload speed are the opposite to what a farmer would need in the tractor, sprayer, or combine cab. All data generated will be transferred at the slower speed because the data must be uploaded from the cab 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.

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.

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

METHODS

In previous auto section control studies, a marginal analysis was done to estimate the savings in seed costs per acre and yield loss reductions per acre due to over-planting (Shockley, et al. 2012) (Smith, et al. 2013) . Similar methods and economic theory will be applied for scenario when two ASC compatible planters operate in the same field and with map sharing coverage between planting units.

Partial budgeting techniques were used to determine whether or not each field studied, independently, leads to a cost savings from the overlap reduction from sharing coverage maps between planting units using automatic section control. Coverage map sharing costs $1,495 per planting unit and requires the farmer to have an active JDLink subscription for an additional $1,000 per year. Because this service has both an upfront fee and an ongoing annual costs, the savings from seed must be greater than the annual fee and the difference between the cost savings and the annual fee is applied towards the upfront $2,990 product cost. Alternatively, the WiFi radios cost $3,699 per planting unit but do not require an ongoing JDLink subscription.

Economic Returns of Coverage Map Sharing

The economic analysis will be reported as savings or cost per acre across an assumed farm operation size using a partial budgeting tool. Net return 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 cost (100% depreciation after the payback period).

It should be reiterated that while this study is specifically focused on exclusively planting, auto section control and therefore coverage map sharing, too, has tangible benefits throughout multiple farming tasks performed during a single growing season including nutrient application, spraying by reducing the overlapped areas, and harvesting by reducing double counted area when not harvesting a full width. This analysis should be considered conservative.

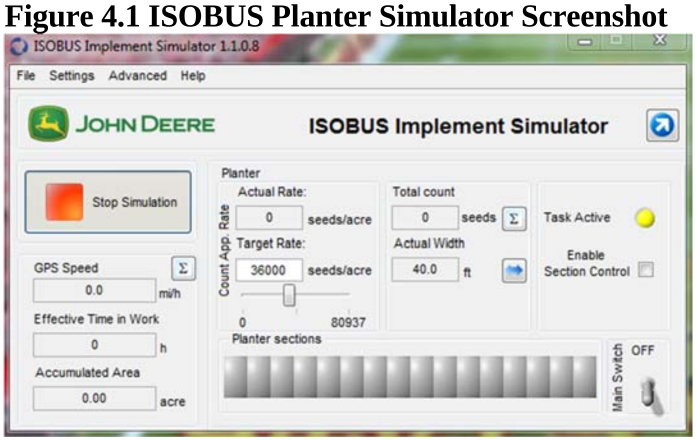
DATA AND ANALYSIS

Data Collection

The benefits of ASC are partially lost when two planters are operating as a team in the same field because without coverage map sharing, each individual planter only knows where it has been. This will result in automated section control only turning on/off sections based on the locally stored coverage map.

Two identical systems were used to simulate a planting operation. Each system consisted of a John Deere GreenStar3 2630 display used as the auto section control capable planter monitor. Planter functions including seed rate electronic controllers and planter row clutches were simulated using specialized desktop computer software. Each block in the Planter Sections area in Figure 4.1 represents an individual row clutch. A 16 row, 30-inch row spacing planter configuration was used in this study, identical to Shockley (Shockley, et al. 2012), which made each planter pass 40 feet.

Figure 4.1 ISOBUS Planter Simulator Screenshot



A GNSS computer simulator provided by Deere and Company was used to simulate global positioning location data and vehicle movement. Field boundaries were loaded to the simulator for it to understand the area of interest. Different driving patterns were selectable including driving exterior field boundary, parallel tracking given a heading, and a built in AutoTrac simulator for the GS3 2630 to parallel track on guidance lines. In boundary mode or parallel tracking mode, the GNSS simulator instructed the GS3 2630 where it should travel. In the case of AutoTrac mode, the GS3 2630 instructed the simulator what line it should follow.

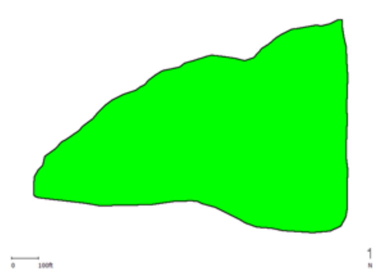
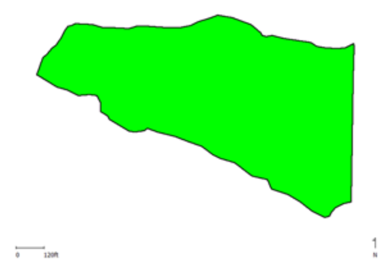
The planter simulator and the GNSS simulator information were bridged together and communicated to the GS3 2630 by creating a virtual CAN bus in the desktop computer. An engineering wiring harness was created for the GS3 2630 that included the auxiliary CAN bus high and low, constant power, switched power and ground. A 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 CAN network which is similar to what would be found on tractor and planter where the GNSS receiver and GS3 2630 would be connected to the tractor's auxiliary CAN bus inside the tractor's operator station and the planter connected to the Implement Bus Breakaway Connector located at the tractor's drawbar.

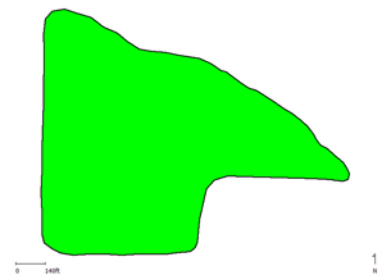
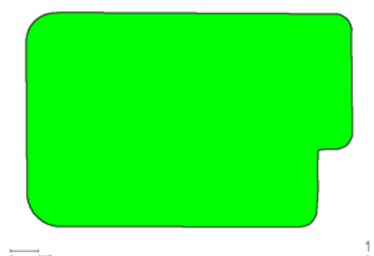
The physical systems used for this study also included modular telematics gateways (MTG), a cellular enabled vehicle electronic controller connecting the systems for data sharing using JDLink, Deere and Company's cloud service. In a real life environment, MTGs are connected to a farm vehicle's vehicle 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. Direct link communication from Planting Unit 1 to Planting Unit 2 when using MTGs as the communication gateway for coverage map sharing.

Similar to the methods of Shockley et al. (2012), four farm fields with varying shapes were considered for this study. Three of the four farm fields were single field farms; and the remaining farm field consisted of a collection of smaller, highly irregularly shaped fields. The farm fields were selected based on their varying areas and shape. It was desired to have regular shaped fields with long row lengths and also irregularly shaped fields with varying pass lengths.

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 its 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 4.2 Characteristics for fields under consideration

	
Area: 13.4 acres Perimeter to Area ratio: 5.296E-03 Longest guidance line: 973 feet Guidance pass total: 18	Area: 15.7 acres Perimeter to Area ratio: 5.134E-03 Longest guidance line: 1183 feet Guidance pass total: 17

 Area: 12.6 acres Perimeter to Area ratio: 6.101E-03 Longest guidance line: 1048 feet Guidance pass total: 14	 Area: 23.1 acres Perimeter to Area ratio: 4.289E-03 Longest guidance line: 1196 feet Guidance pass total: 26
 Area: 44.7 acres Perimeter to Area ratio: 3.102E-03 Longest guidance line: 44 feet Guidance pass total: 33	 Area: 77.3 acres Perimeter to Area ratio: 2.404E-03 Longest guidance Line: 76 feet Guidance pass total: 31
 Area: 220 Acres Perimeter to Area ratio: 1.289E-03 Longest guidance line: 2500 feet Guidance pass total: 96	

The variations to these field shapes will include testing with and without external boundaries. Each field variation will be executed with and without coverage map sharing to quantify the number of times auto section control intercepts with local coverage and shared coverage. Double planted areas will be considered wasted seed and an assumed reduced yield will be considered as well in these overlapped areas.

When collecting data, the mission plan was to execute two headland passes and then parallel track on the loaded guidance lines. Planting unit 1 always planted the outside headland pass; Planting unit 2 always planted the inside headland pass. After headland passes were completed, Planting unit 1 planted the odd guidance track numbers and Planting unit 2 planted the even track numbers. The simulated crop planted was corn and planting rates were held constant at 36,000 seeds per acre at eight miles per hour for each field planted. The GS3 2630's field documentation feature was setup to better identify the data once imported to SMS for post processing. Because seed brand and seed variety data is logged as a data attribute to each data point, Planting Unit 1 simulated planting B1 and V1 representing brand and variety and Planting Unit 2 simulated planting B2 and V2 representing brand and variety.

Analysis

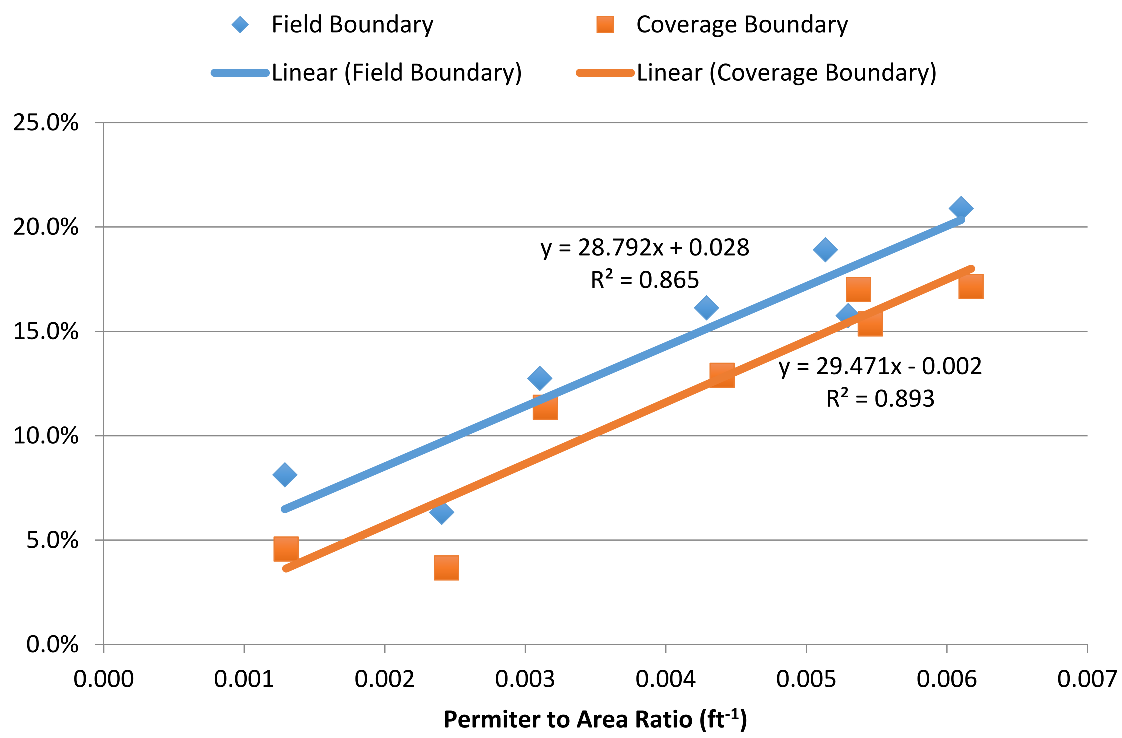
Automated guidance systems gain their efficiencies in the middle of fields where automatic section control gains are on the ends of the field and in turns. In square and rectangle shaped fields ASC has limited impact relative to irregularly shaped fields, where it has a big impact. Field perimeter to field area ratio (p/a) is a field shape irregularity metric that allows an easily computed comparison instead of just comparing fields based only on acreage size. Refer to Table 4.1 for the field perimeter, size and p/a ratio. East Field results in the lowest p/a ratio, 1.289E-03, due to its high area of 220.08 acres and 12,360 feet perimeter indicating a regularly shaped field. The highest p/a ratio is in NorthWest, 6.172E-03. Its area is 12.8 acres and 3,441.2 feet perimeter indicating a highly irregularly shaped field.

Table 4.1 Field Perimeter, Area, and Perimeter to Area ratio

	Field Permiter(feet)	Area (acres)	Permiter to Area ratio (ft/ft^2)
East Field	12360	220.08	1.289E-03
MidNorth	3337.7	14.47	5.296E-03
MidSouth	3807.4	17.02	5.134E-03
NorthWest	3441.2	12.95	6.101E-03
South	4504.5	24.11	4.289E-03
NebEast	8280.1	79.06	2.404E-03
NebWest	6166.5	45.63	3.102E-03
	Coverage Boundary		
	Field Permiter(feet)	Area (acres)	Permiter to Area ratio (ft/ft^2)
East Field	12360	218.49	1.299E-03
MidNorth	3337.7	14.05	5.455E-03
MidSouth	3807.4	16.27	5.371E-03
NorthWest	3441.2	12.8	6.172E-03
South	4504.5	23.5	4.400E-03
NebEast	8280.1	77.91	2.440E-03
NebWest	6166.5	45.05	3.142E-03

The field shapes chosen in this study were specifically selected to attempt to observe any correlation between field shape and size to the amount of double-planted area. For field boundaries and coverage boundaries, r-squared values of 0.865 and 0.893 in Figure 4.3 were found indicating a strong positive correlation between perimeter to area ratio (p/a) and the overplanted area indicating coverage map sharing has a positive impact when multiple planting units operate in the same field. As p/a ratio increases, it is expected there would be an increased percentage of overlapped area if ASC and coverage map sharing is not used. This also indicates greater benefit from using this technology.

Figure 4.3 Using Perimeter to Area Ration to Predict % Overlap Area



A summary of the results from the data runs executed are presented in Table 4.2. Surplus area is defined as the difference between two planting units working together in the same field with and without coverage map sharing. The results in the table below indicate the area difference between using a pre-loaded field boundary and the planting unit drivers creating the boundary by simply planting the field headlands. East field resulted in the smallest percent difference between using the field boundary and the coveage boundary. All the error between the two use cases has the opportunity to spread error across more area. MidSouth resulted in the highest error between field boundary and coverage boundary, 4.41%. It is hypothizied that part of the observed error is related to the simulation error when collecting data. In all data collection runs, the coverage boundary use case results in a lower area.

Table 4.2 Comparison of Field Boundary to Coverage Boundary

	Planted area with map sharing (acres)	Planted area without map sharing (acres)	Surplus Area (acres)	Overlap area by percentage	Percent difference between Field Boundary and Coverage Boundary, shared coverage
East Field-Field Boundary	220.1	238.0	17.9	8.1%	
East Field-Coverage Bdy	218.49	237.98	19.5	8.9%	0.72%
MidNorth-Field Boundary	14.5	16.7	2.3	15.8%	
MidNorth-Coverage Bdy	14.047	16.747	2.7	19.2%	2.91%
MidSouth-Field Boundary	17.0	20.2	3.2	18.9%	
MidSouth-Coverage Bdy	16.273	20.244	4.0	24.4%	4.41%
NorthWest-Field Boundary	12.9	15.7	2.7	20.9%	
NorthWest-Coverage Bdy	12.8	15.654	2.9	22.3%	1.15%
South-Field Boundary	24.1	28.0	3.9	16.1%	
South-Coverage Bdy	23.5	28	4.5	19.1%	2.53%
NebEast-Field Boundary	79.1	84.1	5.0	6.3%	
NebEast-Coverage Bdy	77.91	84.07	6.2	7.9%	1.45%
NebWest-Field Boundary	45.6	51.5	5.8	12.8%	
NebWest-Coverage Bdy	45.05	51.45	6.4	14.2%	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 benefitial when the operator is not familiar with the field's surroundings. The downside is if the the field's farming area changes, increase or decrease, field boundaries are not easily edited in the tractor cab and likely quicker just to redrive rather than edit on the desktop computer in the farm office. If the field area decreases then there is a chance of automatic section control applying product or seed in an area unintentionally. If the field area increases then automatic section control will prevent application in the new area. The observed error between the field boundary use case and the coverage boundary use case in the data collected does decrease as the field size increases. Table 4.3 provides a summary of payback periods. As stand alone profit centers, only five of the fourteen fields produced a positive payback period. East Field when using a field boundary has a payback period of 1.2 years and East Field when using a coverage boundary pays back in 4 years. Three others, NebWest with field boundary, Neb West with coverage boundary, and NebEast with field boundary have payback periods of 15, 27, and 32 years. It is not wise to make an investment with a payback that long of period. With the East Field use cases with the only realistic payback periods, it suggests there is a necessary minimum farm size in order to use this technology and provide economic benefit. If these individual fields are considered an entire farming operation where the product cost is spread out across the entire operation, payback is in the first year of using coverage map sharing.

Table 4.3: Extra Seed Costs, Seed Savings, and Payback Period

Field Boundary	Surplus Area	Seed costs per acre @ 36k sds/ac	Extra Seed Cost	Savings per acre (cost savings)	Payback Period (years)
East Field	17.9	138.96	$ 2,487.38	$ 11.30	1.2
MidNorth	2.279	138.96	$ 316.69	$ 21.89	--
MidSouth	3.22	138.96	$ 447.45	$ 26.28	--
NorthWest	2.705	138.96	$ 375.89	$ 29.03	--
South	3.89	138.96	$ 540.55	$ 22.42	--
NebEast	5.01	138.96	$ 696.19	$ 8.81	32
NebWest	5.82	138.96	$ 808.75	$ 17.72	15
Coverage Boundary	**Surplus Area**	**Seed costs per acre @ 36k sds/ac**	**Extra Seed Cost**	**Savings per acre (cost savings)**	**Payback Period (years)**
East Field	9.99	138.96	$ 1,388.21	$ 6.35	4
MidNorth	2.157	138.96	$ 299.74	$ 21.34	--
MidSouth	2.767	138.96	$ 384.50	$ 23.63	--
NorthWest	2.195	138.96	$ 305.02	$ 23.83	--
South	3.03	138.96	$ 421.05	$ 17.92	--
NebEast	2.86	138.96	$ 397.43	$ 5.10	--
NebWest	5.12	138.96	$ 711.48	$ 15.79	27

A scenario was run to determine the number of planted acres required for a three-year and five year payback for the cellular communication and Wi-Fi radio methods of coverage map sharing using the previously determined cost savings per acre. In Table 4.4 above, the number of required acres annually are displayed for each field in order to have a positive payback in three years or five years for both communication solutions. Northwest using a field boundary results in the three year and five year pay back in the fewest amount of acres run. Northwest has the highest p/a ratio. NebEast requires the greatest area, 391 acres, to achieve a positive payback in three years.

Table 4.4 Area required for 3 year and 5-year payback periods

Field Boundary	Permiter to Area ratio (ft/ft^2)	Savings per acre (cost savings)	Area required per year for positive payback in 3 years with MTG (acres)	Area required per year for positive payback in 5 years with MTG (acres)	Area required per year for positive payback in 3 years with MCR Radios (acres)	Area required per year for positive payback in 5 years with MCR Radios (acres)
East Field	1.289E-03	$11.30	176.7	141.4	306.37	183.82
MidNorth	5.296E-03	$21.89	91.2	73.0	158.19	94.92
MidSouth	5.134E-03	$26.28	76.0	60.8	131.74	79.05
NorthWest	6.101E-03	$29.03	68.8	55.0	119.29	71.57
South	4.289E-03	$22.42	89.1	71.3	154.44	92.67
NebEast	2.404E-03	$8.81	226.7	181.5	393.22	235.93
NebWest	3.102E-03	$17.72	112.7	90.2	195.37	117.22

Coverage Boundary	Permiter to Area ratio (ft/ft^2)	Savings per acre (cost savings)	Area required per year for positive payback in 3 years with MTG (acres)	Area required per year for positive payback in 5 years with MTG (acres)	Area required per year for positive payback in 3 years with MCR Radios (acres)	Area required per year for positive payback in 5 years with MCR Radios (acres)
East Field	1.30E-03	$6.35	314.3	251.5	544.99	326.99
MidNorth	5.45E-03	$21.34	93.6	74.9	162.28	97.37
MidSouth	5.37E-03	$23.63	84.5	67.6	146.55	87.93
NorthWest	6.17E-03	$23.83	83.8	67.1	145.31	87.19
South	4.40E-03	$17.92	111.4	89.2	193.26	115.96
NebEast	2.44E-03	$5.10	391.4	313.3	678.81	407.29
NebWest	3.14E-03	$15.79	126.4	101.2	219.25	131.55

This shows that there are early economic advantages in choosing the cellular method to share maps; however with this comes a continuous annual subscription cost to keep using the technology. The Wi-Fi radio network has a high start up cost, and it is shown in the required area for a positive payback in three or five years.

RESULTS AND 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.

Open Internet regulations implemented by the FCC in 2015 are 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 a degraded customer experience until payment is received.

It should not be assumed that the entire seed cost savings 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. An interesting follow-on study would include interior boundaries to drive through and around. Additionally it would include curved driving patterns.

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. ASC 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.

CONCLUSION

Automatic section control has been saving farmers money for nearly ten years now 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.

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 be 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 three-year or five year payback. The seed savings per acre is dependent on the field size, perimeter and the shape irregularity.

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