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Assessment of utilization and downtime of a commercial level multi-pass corn stover harvesting systems

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Assessment of utilization and downtime of a commercial level multi-pass corn stover harvesting systems

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DEDICATION

I would like to dedicate my thesis and graduate education to my beloved grandparents

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ABSTRACT

With commercial scale cellulosic ethanol in the formative stages of building large-scale feedstock supply chains there is a requirement for biomass harvesting equipment to be capable of increasing the densification of agricultural residue. The current technologies in use are large square balers, which were not specifically designed for the harvesting of agricultural residues such as corn stover. With the growing demand for corn stover harvesting, the equipment needs to be improved and refined to overcome the challenges that corn stover harvesting presents, while meeting and exceeding industry standards for custom harvesting. The harvest capacity of this equipment set is greatly decreased in corn stover biomass harvesting because of increases in maintenance and downtime caused by the harsh operating conditions.

The objective of this research was to discover correlations between harvesting equipment's downtime and productivity. Results of this work analyzed a comprehensive corn stover harvesting data set from an 8000-acre commercial corn stover harvest. The outcome of this research will benefit both the cellulosic processers, as well as the growers and custom harvesters of agricultural biomass

CHAPTER 1. GENERAL INTRODUCTION AND REVIEW OF LITERATURE

The ability to economically harvest and transport biomass is essential to the development and commercialization of cellulosic ethanol production. Production of this renewable fuel has the capacity to improve the energy independence of the United States by reducing the dependency of foreign imported oil. The United States Congress denotes the importance of cellulosic ethanol in the Energy Independence and Security Act of 2007. This policy mandates that cellulosic fuel production meet a volume capacity of 250 million gallons by 2011 and an increase to 16 billion gallons by 2022 (EISA, 2012).

In order to meet this production goal, processing plants will require large amounts of biomass feedstock. Corn stover is a readily available, viable cellulosic biomass feedstock found throughout the Midwestern United States. Two companies have realized the Midwest's feedstock potential and are developing a harvest, storage, and transportation process for cellulosic biofuel refineries. Construction has begun on two of the first cellulosic ethanol production facilities in the United States. One of the facilities will be built in northwest Iowa by POET. POET has been in the Midwest biofuel business since 1986, making them the largest corn ethanol manufacturer in the United States (POET, 2012). POET's proposed 20-million gallon per year cellulosic ethanol facility is intended to be online and operational in the fall of 2013, making it the largest commercial scale cellulosic ethanol plant in the world. (POET, 2012) This title will be short lived however as DuPont Cellulosic Ethanol brings its 25 million gallon per year ethanol plant online in 2014 (DuPont, 2011). DuPont's plant is currently under construction in Nevada, Iowa located adjacent to the Lincoln Way Energy corn grain ethanol plant. DuPont's production facility alone will require the delivery of over 400,000 tons of corn stover every year to operate at full capacity. In order to produce and supply the facility with such a large volume of feedstock, the agricultural equipment used in the harvest and transportation process needs to be enhanced and streamlined as much as possible.

Since the agricultural equipment used in this process is being repurposed from other agricultural industries, the equipment does not always perform to the manufacturer's original specifications. Not having baseline knowledge or expectations of this equipment has led to the need-driven research of production equipment operating in different crop conditions. Information on the efficiency and productivity of this harvesting equipment set is essential in understanding and developing realistic supply chain models, which in turn will drive data-based marketing decisions. Understanding the metrics outlined, such as efficiency and productivity, will provide accurate values used to make educated analytical decisions in economic models and harvesting estimations. A critical assessment and sensitivity analysis of the current production system will also lead to informed recommendations for process improvement. The knowledge and education provided as an outcome of this research will improve the supply chain efficiency of partial residue collection and provide additional economic opportunity to farmers and landowners in the Midwestern United States.

Objectives

The objectives for this research were as follows:

- Define the metrics necessary for categorizing equipment utilization.
- Quantify the productivity and downtime associated with commercial multi-pass stover harvesting equipment.
- Quantify the efficiencies associated with corn stover harvesting equipment.
- Analyze operational organization and performance using GIS software.
- Analyze the correlation between harvesting equipment's productivity and downtime.

Thesis Organization

This thesis contains a general introduction of the topic, a technical chapter, and an overall conclusion. The general introduction includes a statement of the primary purpose and objectives of the thesis along with a description of the thesis's organization, a statement from the authors defining his primary rolls in the research along with a synopsis of the literature review.

The first technical chapter, entitled "Determining the productivity and downtime associated with large square balers in a corn stover biomass harvest systems" will be submitted as a research article to the journal *Applied Engineering in Agriculture*. This article describes the process used to capture corn stover harvesting performance data from both machinery and operational organization. Topics include defining how different performance metrics used in conjunction with terminology describing durations of time and events related to productivity; quantifying the productivity and downtime associated with commercial multi-pass stover harvesting equipment; defining the metrics necessary for categorizing equipment utilization; analyzing operational organization and performance using GIS software; and quantifying efficiencies associated with corn stover harvesting equipment. The final topic in this chapter involves discovering a correlation between harvesting equipment's productivity and downtime. The general conclusion includes a summary of the efficiencies calculated in the technical chapter along with a recommendation of future work and research.

Authors' Role

The primary author, with the support and guidance of co-author Dr. Matthew Darr, composed the research articles submitted in this thesis. Dr. Matthew Darr also provided continuous support, encouragement and guidance during the writing and editing process. Unless otherwise indicated, all procedures were performed by the primary author.

Literature Review

As the demand for renewable fuels increases, the feedstock supply for the fuels needs to scale to meet the demand, while at the same time not taking cropland out of production. Dedicated energy crops such as miscanthus, energy cane, and switchgrass are all crops that produce a high volume of feedstock. However, these are new crops and will require land to be taken out of current crop production, such as corn and soybeans. With corn prices averaging $7.50 per bushel and soybeans averaging $14.00 per bushel (Agricultural Commodities, 2012) there is an economic disadvantage to the production of these dedicated energy crops. For this reason, an agricultural residue from a currently produced crop would be an ideal feedstock.

Corn is one of the most abundantly produced crops in the United States, which means that there is also an abundance of corn residue, or corn stover, left on the fields. Additionally, as corn yields continue to climb, the amount of corn stover is increasing dramatically as well (Xiong, et al, 2010). This increase in corn stover opens a door for cellulosic feedstocks to come from corn stover, especially in the Midwest where the corn production is at its highest level. Figure 1 shows a field in which corn stover is being harvested, in the form of large square bales. Even after the corn stover has been harvested, there is still enough material left on the field to prevent erosion during the winter, and provide organic matter to the soil.

Figure 1: Corn stover harvest in Central Iowa

This is the beginning of harvesting corn stover on an industrial scale, so it will bring new benefits, as well as new challenges to light. One of the benefits of harvesting corn stover is another tool for farmers to deal with residue management. Currently, farmers are making multiple tillage passes through the field to plow the stover under and incorporate it into the soil. However if some of the stover is removed through stover harvesting, there will be less material to plow under, therefore fewer tillage passes through the field will result. Fewer trips through the field are beneficial for economic and agronomic reasons. Economically, fewer trips through the field means the farmers will spend less money on fuel and labor for their fall tillage. On the other end of the spectrum, with more work to be done in the form of harvesting the corn stover, more local jobs will be available therefore stimulating the local economy.

Several new challenges will also be presented, as corn stover harvesting becomes an industrial practice. One such challenge is collecting the material with the least amount of soil contamination possible. In the hay industry, the bales are not as contaminated with soil due to the fact that there is still another layer of plant material between the material to be harvested in the windrow and the soil. With corn stover, however, the material is being collected directly from the ground, which brings soil into the bale, and causes processing and transportation problems (Schon, 2012). Another major challenge with corn stover harvesting, and the challenge that this thesis will address, is the challenge of managing harvest equipment so that its utilization achieves its full potential.

The American Society of Agricultural and Biological Engineers defines field efficiency as the ratio of effective field capacity to theoretical field capacity. Field efficiency accounts for a failure to use the theoretical working width of a machine, operator habits, turning time, and field characteristics (ASABE, 2005). Theoretical field capacity is based on the average operating speed and the actual field capacity, based on field size and harvest time. The theoretical field capacities are substantially greater than the effective field capacities. Field efficiency and capacity data are typically collected through time-motion studies; however, with the increasing popularity of precision agriculture technologies, the data collection process can be automated and in many instances is occurring without operator input. Spatial data obtained through GPS can be used to evaluate field efficiency of planting and harvesting operations (Viacheslav I, 2004).

Though machinery inputs are a significant portion of crop production expenses, machinery selection has long been a challenge for crop producers. Software and expert systems at various levels have been developed to aid machinery selection and evaluation. Research has been conducted to provide information to assist in machinery management decisions. However this research is often quite specific to an environment and difficult to generalize (Grisso, 2002). The ability of a machine to perform efficiently within an environment is an important criterion that affects machinery management decisions. This environmental factor represents repurposing a baler to harvest stover instead of grass.

With geographical information systems (GIS) data, various types of information imbedded in the records of geographic positions are logged during various field operations. Maps can be created, transforming sets of data into a map of machinery performance including cost of operation, capacity, and efficiency (Grisso, 2004). Using GIS maps, Webster was able quantify fuel consumption rate and crop conditions using both GPS location and combine engine parameters from the CAN Bus (Webster, 2011). The controller area network (CAN) provides the central communication link on virtually every sensor and ECU on modern agricultural machinery. In agriculture and bioenergy applications, parameters for machinery performance and management are widely used for equipment sizing and cost estimation. Direct measurement of CAN Bus metrics, including average operating speed, engine load, implement engagement, and fuel consumption, can help supply chain managers design equipment solutions that maximize field and transport efficiency while lowering equipment cost (Darr, 2012). Peyton instrumented standalone CyCAN loggers in a Biomass harvesting system and recorded specific messages from the tractors ECU and ISOBUS. His experiment resulted in the analysis of engine loading providing a direct assessment of the power requirements for specific tractor-implement pairs and was used to optimize tractor sizing for a specific application (Peyton, 2012). Figure 2 shows the CyCAN data loggers Peyton and Webster used in their research.

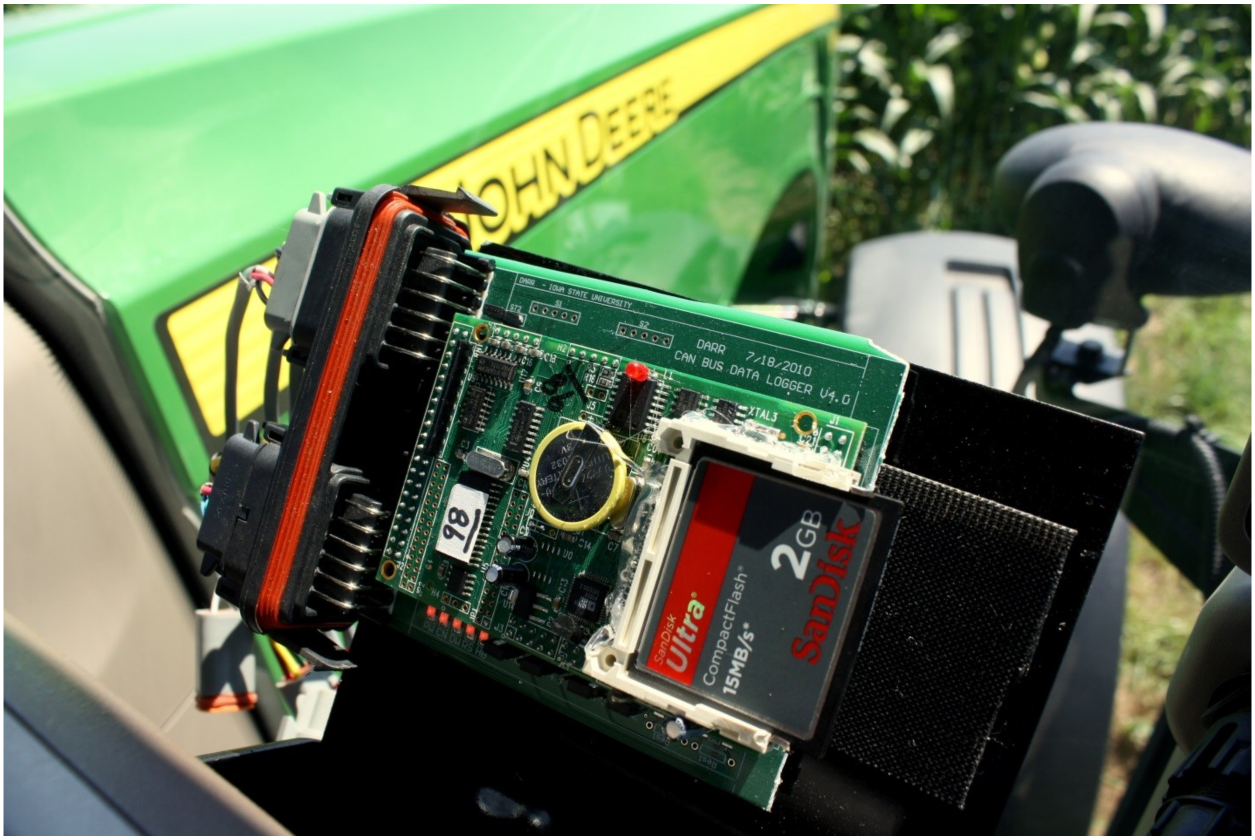

Figure 2: CyCAN Logger installed in a John Deere 8335R tractor connecting to the ISOBUS diagnostics port and providing direct access to all available CAN Bus information

Connected directly to the ISOBUS diagnostic port in the tractor cab, this device provides a direct access to all available CAN Bus information. The CyCAN data logger merges CAN data with GPS data to enable spatial analysis of machinery in a harvest system. The ability to accurately time and track equipment spatially eases and improves the data collection process. This information is further improved by harnessing the operational data streams available on controller area networks. Linking a position to operational data allows for more in-depth analysis than previously possible.

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CHAPTER 2. DETERMINING THE PRODUCTIVITY AND DOWNTIME ASSOCIATED WITH LARGE SQUARE BALERS IN A CORN STOVER BIOMASS HARVEST SYSTEM USING GIS SOFTWARE

A paper to be submitted to the Journal of the

Applied Engineering in Agriculture

Benjamin Covington, Matthew Darr

Abstract

Productivity is a metric used to evaluate the effectiveness of completing a task in a timely manner. Harvesting corn stover is unique in the sense that the equipment used in the collection process of stover is repurposed from another agricultural industry. The current technologies used in stover collection are adaptions from the hay industry. Although in the same Poaceae family, grass hays and corn stover have different characteristics and properties that react differently when collected and compressed in a square package known as a bale. With cellulosic ethanol being a new industry in central Iowa, machinery performance data in corn stover is in the formative stages of development. Research scale harvesting operations have been conducted in order to quantify the effectiveness of these repurposed hay equipment harvesting corn stover. The lack of data available on a harvesters performance in these conditions has led to a research assessment of an industrial scale stover harvest.

The performance metrics are comprised of both productivity and efficiency. To calculate these metrics, time and area must be quantified. The time a machine spends within the field boundaries is a direct reflection of productivity. Modern tractors are controlled by several microcontrollers that communicate on the Controller Area Network (CAN). The messages sent across the CAN Bus and are used to control the functions of the tractor include the, engine, transmission, implement Status and many others. Time and area are collected using electronic data logging devices that capture both GPS positions and CAN signals. CAN messages such as PTO

speed, Engine speed and GPS speed are recorded to provide the parameters needed for calculation of machine utilization terms.

Introduction

The ability to economically harvest and transport biomass is essential to the development and commercialization of cellulosic ethanol production. Production of this renewable fuel has the capacity to improve the energy independence of the United States by reducing the dependency on foreign oil. The United States Congress denotes the importance of cellulosic ethanol in the Energy Independence and Security Act of 2007. This document mandates that cellulosic fuel production meet a volume capacity of 250 million gallons by 2011 and an increase to 16 billion gallons by 2022 (EISA, 2012).

As DuPont Cellulosic Ethanol grows closer to its commercial scale plant coming online, it has begun the process of scaling up its stover harvest operation in central Iowa. The large square baler has become the preferred unit of the DuPont Cellulosic Ethanol harvest system because of its ability to produce a dense and easy to handle bale that can withstand handling to the plant (DuPont, 2011). Approximately 120 balers and tractors plus 170 shredders with power units and about 50-60 bale collectors will be required to service just one biorefinery. A large equipment set is needed to accomplish this harvest within a 35 day central Iowa harvest window. Having such as relatively short time frame, has led to research of how square balers perform in harvesting corn stover. The current phase of corn stove supply chain is in development and will require significant efficiency improvements of harvesting equipment to ensure profitability and sustainability.

In order to calculate these efficiencies, a production scale research harvest of approximately 8000 acres was designed to better understand the productive and downtime associated with biomass collection systems in a multi-pass corn stover harvest scenario. This research aims to compare the performance and efficiencies between two large square baler operating in a corn stover harvest environment. The 2011 stover harvest evaluated commercially available balers from two of the industry's foremost hay equipment manufacturers. In this experiment, approximately 1000 acres was designated to each balers to be harvested individually. Both tractors were instrumented with a CYCan logger that recorded GPS and CAN signals throughout the harvesting process.

A critical assessment and sensitivity analysis of the current production system will also lead to informed recommendations for process improvement. The knowledge and education provided as an outcome of this research should improve the supply chain efficiency of partial residue collection and provide additional economic opportunity to farmers and landowners in the Midwestern United States.

Research Objective

The research objective of this study was to establish a protocol, utilizing Geographical Information Systems (GIS) software, to determine the productivity and downtime of large square balers in a multi-pass corn stover biomass harvesting system. This case study entailed analyzing machinery performance parameters gleaned from both Global Position Satellite systems (GPS) and Controller Area Network (CAN)-based data accusation systems.

Materials

Machinery Parameter Data Collection

An embedded CAN and GPS data logging system, called a CyCAN Logger, was used to collect specific machinery parameters on commercially available agriculture equipment. The CyCAN logger is an external, Non-OEM, standalone recording device which captures as-applied data. This additional component does not require any user interface from the equipment's operator, allowing units to be deployed into a production environment (Peyton, 2012). The information collected from this device is received from an externally mounted GPS through an RS-232 serial cable, and from the vehicle Implement CAN bus. The major benefit of using this external recording device is that both the GPS and CAN data are recorded simultaneously, establishing a geographical reference point with machinery parameter data. Connection into the tractor's CAN bus provided information about the current status and operational state of both the tractor and implement (Webster, 2011). Specific machinery attributes collected include the vehicle position, as well as operational parameters from the powertrain, including engine speed, torque and load, PTO speed, and GPS-based vehicle speed (Table 1).

Table 1: Description and source of recorded parameters

Data	Source	CAN Parameters		
		PGN	Start Bit	Length (Bits)
Latitude	RS-232	-	-	-
Longitude	RS-232	-	-	-
GPS Speed	RS-232	-	-	-
Engine Load	CAN	61443	16	8
Engine Speed	CAN	61444	24	16
Engine Torque	CAN	61444	16	8
Hydraulic SCV Flow	CAN	65040	0	8
PTO Speed	CAN	65091	0	16

Data Collection with CyCAN Loggers

The CyCAN loggers are designed to operate and record data from the ignition switch power. The CyCAN logger begins recording when the tractor ignition is keyed “On”**.** The machine’s operating parameters were captured and recorded to the data logger at a rate of 1 hertz. This provides the appropriate timing and operational Status needed for a detailed performance analysis of both the agricultural equipment, as well as the limitations of the harvesting operation personnel. Every time the tractor is keyed “On”, the logger begins to record the selected GPS and CAN parameters, creating a new, time specific file with a one second sampling resolution. These files are recorded and numbered consecutively starting with the first second of recorded data, as logger file “1”, and ending when the tractor is keyed in the “Off” position. The last file is then saved to a compact storage disk before the keyed ignition power is disconnected, and the logger finishes recording. This data collection method and resolution was used to capture the duration of the time when the tractor was turned both “On” and “Off”.

Software Analysis and Filtering

Geographic Information System (GIS) software was used for direct spatial analysis of the collected machinery parameter data. Individualizing the specific machinery parameter and then associating it with a geographical location allowed for several parameters to be measured at one location. Each specific machine parameter was then defined and recorded as a new attribute within the GIS software. For example, attributes such as engine speed, torque and PTO data can all be found at each individual GPS location. All GIS examples presented in this paper were completed using the commercially available SMS Advanced GIS software package from Ag Leader Technology (Ames, Iowa**).** The GIS software provides a platform for the spatial querying and data filtering necessary for machinery performance analysis. Attributes in this software package can serve as both categorical and continuous variables, which are used to aid the classification of the operation (Peyton, 2012). An example of a categorical variable would be a binary output, such as a 1 or a 0, which defines an operational State as either being on or off. This study only required the use of continuous variables due to the large variation in machinery parameters. Dynamic variables such as engine speed, PTO speed and GPS based vehicle speed are labeled as such.

Case Study Data Set

Sixteen representative field data sets were selected to demonstrate the GIS-based machinery performance analysis presented in this paper. The fields were selected from a pool of over eighty harvested fields and contain variance in size, shape, and terrain. This was done to eliminate any spatial bias, and to prove the capabilities of the evaluation method. The fields selected for the detailed analysis in this paper ranged from 40 to 179 acres, with the average field size being 106 acres. The purpose of this case study was to analyze operational organization and equipment efficiencies of harvesting corn stover. In order to accomplish this, the harvestable acres were divided amongst two separately organized and managed crews. Each crew was not reliant on the other, having the availability and resources necessary to perform routine maintenance, operate, and repair the equipment independently of the other harvest crew. This independence ensures that all organizational data was based upon each crew’s personnel performance and/or characteristics. Of the fields selected, eight of them were harvested with an AGCO Massy Ferguson 2170 XD large square baler. The other eight fields were harvested with a Krone 1290 HDP BiGPack large square baler. Both balers used in this case study were chambered to the dimensions of three feet in height, by four feet in width, with an overall bale length of eight feet. Having two different manufacturer's balers in the study allowed for a comparison of machinery efficiency between two brands of equal capacity models. A total of 1,747 harvested acres were processed and analyzed using the automated process defined in this paper. All data was generated for this paper was collected during the fall 2011 corn stover harvest in central Iowa.

For this paper, the term "baler" refers to an implement that can only be operational when it is attached to a power unit, such as a tractor. Also when the term "baler" is used in this paper, it is assumed that the tractor in this scenario is turned on and running, unless otherwise stated. The term "tractor" is used to describe the baler's State of activeness and ability to perform operational tasks.

Safety Emphasis

This case study required the use of high horsepower, high capacity harvesting equipment to be repaired, adjusted and maintained periodically throughout the day, in order to operate at optimal performance. In order to ensure physical safety, strict safety policies were enforced following both manufacturers' safety procedures, along with the safety practices put in place by Iowa State University. All equipment operators had to complete a supervised training course prior to the start of the harvest season to ensure the safety and well-being of both the operators and the equipment. During the 2011 stover harvest all maintenance, repairs, and refueling of the tractors and harvest equipment was performed with the equipment properly parked and turned off with the ignition key in the operator's pocket, to ensure the safety of the operator. No safety violations or accidents were reported during this study. The safety emphasis is important in the evaluation of crew operational performance because it reiterates the fact that the service and maintenance of the equipment was performed when the tractor was off.

Methods

Starting and Ending Field Activities

In order to properly describe how to spatially analyze a machinery data set, a field was selected at random and processed step-by-step using the methods section of this paper. As a reference, the field chosen for further analysis was F92. From this field, tractor number 51 – a John Deere 8335R was selected. This tractor was used in conjunction with the Krone 3'x4' large square baler, providing the data necessary for the demonstration of quantifying the productivity and downtime associated with the machinery used in a commercial multi-pass stover harvest.

When a field is being spatially analyzed, the first step is to identify the duration that the tractor was within the boundaries of the harvestable field. In order to quantify when the baler was within the provided field boundaries, a query function was executed using SMS Advanced on all data points within the corresponding location, confirming the fact that the baler was, indeed, within the field boundaries. After this query was performed, the GIS software compiled all the selected data points and exported the summarized results in the form of a comma-separated values table. Compiling all the information available associated with that field allowed for a fast spatial recognition of locating the field entrance, which was used for converting the tractor and baler from the road/transportation environment to a field production setting. The spatial analysis performed on the field, in conjunction with a hybrid of both satellite imagery and road map, allowed for a visual conformation of the locations and the direction of travel where the tractor and baler entered and exited within the field. Figure 3 depicts an aerial image of a field entrance where a driveway allows access and passage of equipment from the roadway into the field.

Figure 3: Spatial image of field entrance for F92

Selecting the data points closest to, or directly above, the driveway, provides the most accurate date and time of the field entry and exit spatially possible. These critical data points are the beginning to a thorough analysis of duration that the tractor and baler spend within the field. Figure 4 displays a query performed using SMS Advanced, showing the maximum and minimum date and time that the tractor entered and exited the field boundary. This maximum and minimum time will be represented as the starting and ending times of field operation.

Query 1

Layer 1 - 8335R - 51 | 2011

Main Layer

Total area	0.00 ac
Length	0.00 ft
Count	2

Description	Average	Total	Minimum	Maximum
Date / Time	10/25/1911 6:23:24 AM		10/24/1911 5:58:26 PM	10/25/1911 6:48:21 PM

Figure 4: Queried results of the Min and Max Date and Time

Note in Figure 4, the data offset between the maximum and minimum. Here the harvest crew arrived to the field at 5:58 pm on October 24 and left the following day at 6:48 pm. Having the starting and ending times that the tractor and baler were in the field provides the necessary information needed for calculating the Total Duration the machinery set spent within the field. This number can be quantified by using the Total Duration equation.

Equation 1 Total Duration

$$Total\ Duration\ (minutes) = Ending\ Time\ -\ Starting\ Time$$

In this equation, the *Ending Time* and *Starting Time* were represented using the Maximum and Minimum times queried with SMS Advanced from the data set. In this data set, the baler was within the field boundaries for 1,490 minutes. It is necessary that this step be completed first so the productivity and downtime analysis can be performed accurately.

Active State

The next process used in determining the efficiency of biomass harvesting equipment is finding out the percentage of time that the tractor was keyed on with the engine running while in the field. This State of activity is classified as being Active. Tractor "On" is a term used to represent the duration of time that the tractor's engine was running within the operational range of normal engine speed. Analyzing the data set required a query on all data points throughout the entire field. Through this process, a count or summation of all data points within the field boundaries was compiled.

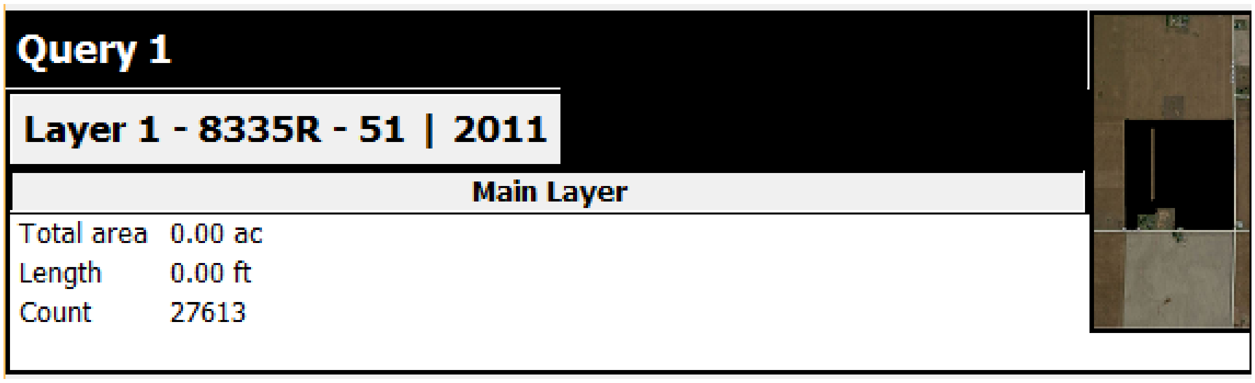


Figure 5: Entire Field Query for F92 resulting in the number of "On" seconds for the vehicle

Figure 5 displays the count for this particular field as being 27,613. Given the one second temporal resolution of the CyCAN logger, the total count represents the duration the tractor was keyed "on" within the boundaries of the field. Displayed in seconds, this data can be transformed into a workable number such as minutes. For this particular field the Tractor On Duration was 460 minutes. Tractor On Duration is a key component to understanding the first distinguishable level of equipment efficiency known as Effective Field Capacity. Defined by the American Society of Agriculture and Biological Engineers, Effective Field Capacity is a term that describes the actual rate of land or crop processed in a given time (ASABE, 2005). The second component that comprises Effective Field Capacity is knowing the size of the area of land being processed. In the case of F92, 79 acres is used to create an Effective Field Capacity. Using Equation 2 reveals an Effective Field Capacity for F92 as 10.3 acres per hour.

Equation 2: Effective Field Capacity

$$Effective\ Field\ Capacity\ \left({}^{ac}/_{hr}\right) = \left[\frac{Area}{Tractor\ \text{"On"}\ Duration\ (minutes)}\right] * \frac{60\ minutes}{hour}$$

Once the Tractor On Duration is quantified, the Percentage Active Time can be calculated, using Equation 3 Percentage Active Time.

Equation 3 Percentage Active Time

$$Percentage\ Active\ Time = \frac{Tractor\ \text{"On"}\ Duration\ (minutes)}{Total\ Duration\ (minutes)}$$

The resulting percentage can reveal how well the tractor was managed and utilized. For F92, the tractor was Active for approximately 31 percent of the time it was in the field. The calculated percentage is factored including the time the tractors spent in the field without an operator. This time will be quantified later in the chapter. This level of efficiency is a crucial step in determining how well the equipment was utilized by the operators and crews. This information is crucial for accurate supply chain modeling and optimization. Decisions for this data can be used to further evaluate the time management skill of the operators, along with the mechanical efficiencies of the harvest equipment.

Machine Status

Often times the Tractor On Duration is a false indicator that the tractor is being properly utilized for baling purposes. A tractor's Active utilization can be defined into three Status; Productive, Idle, and Transport. These Status concepts are classified to have productivity as the highest and most sought-after level of utilization. Productivity can only be possible if all three attributes are at the highest level of efficiency. Transportation of equipment from one part of the field to the next is a known factor, and a part of every harvesting operation. Though it is necessary, it is important that this Status be minimized and reduced if possible. Equipment in Idle Status is not ideal. The Idle time is a critical component in the assessment of operational organization. Idle time represents the time that could be spent productively operating in the field instead of consuming fuel and adding unnecessary hours to the tractor. Having the ability to capture different attributes simultaneously allows for a detailed analysis of the functions being performed by the tractor. Filtering and combining different parameters allows for a semi-automated analysis of the productivity and downtime of biomass harvesting equipment. A Status is defined as different levels of utilization and is categorized based upon performance attributes, such as PTO speed, engine speed, and ground speed. In order to properly define these States, the parameters of each attribute must be analyzed and defined before Tractor On Duration can be categorized into the three Status States.

PTO Engagement

Part of understanding the efficiencies of both the repurposed balers and crew organization can begin to be clarified from analyzing the Power Take Off (PTO) engagement. PTO is used to transfer rotary motion from the tractor to mechanically power an implement, in this case study a baler. Here the PTO is used to represent the stages when baler has become operational. Embedded within the tractor's CAN bus is a message corresponding with the PTO speed in revolutions per minute (rpm). Having a CAN-based message allows the data to be spatially filtered using GIS software from attributes such as PTO speed. Since the baler is an implement, it is only operational when the operator executes a command from the tractor, allowing the baler to become functional which allows the baler operation to be monitored and queried based off of the tractor's PTO speed. Using SMS Advanced spatial software, an analysis was performed on the Entire Field Query represented in Figure 5. This query allowed for all the data points to be transposed into a comma-separated value excel table. From this, table-specific attributes, like PTO speed, engine speed and GPS speed, could be selected for further processing. PTO speed was selected for a detailed analysis and a histogram was generated, displaying the distribution of PTO speeds, as seen in Figure 6. Although balers require a minimum PTO speed of 1000 rpm to operate in compliance with the manufacturer's specifications (AGCO, 2013), lower PTO speeds often occur as a result of higher torque loads on the tractor's engine, caused by heavier crop conditions. This variability in PTO speeds requires an analysis to be performed, with the understanding that not all operational PTO speeds occur at 1000 rpms and higher. With this in consideration, a histogram of PTO speeds was created to identify the speed ranges when the baler was and was not operational.

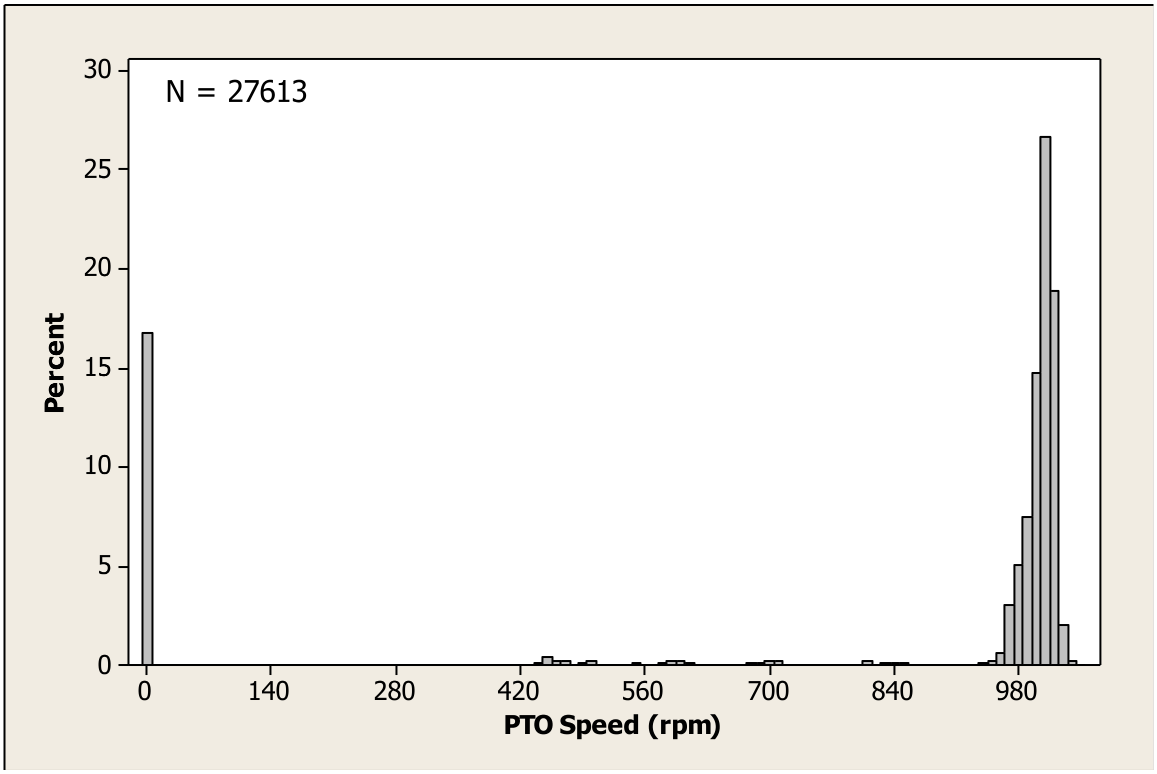


Figure 6: Histogram of PTO Speed for baler in F92

The data presented in Figure 6 is representative of the PTO speed data from Tractor On Duration. After seeing the spread in distributions, a filter was applied to the data, filtering for all speeds above 125 rpm to include all possible data points that the baler could possibly be operational. Due to the resolution of the PTO speed sensor used in modern agricultural equipment, 125 rpm was selected as a filtering threshold. A PTO speed of 125 rpms or less is classified as zero speed, or no rotation for this analysis. This filter consolidated the data to eliminate any data points where the PTO was not in rotation. After the filter was applied, a statistical summary was created, seen in Figure 7**.**

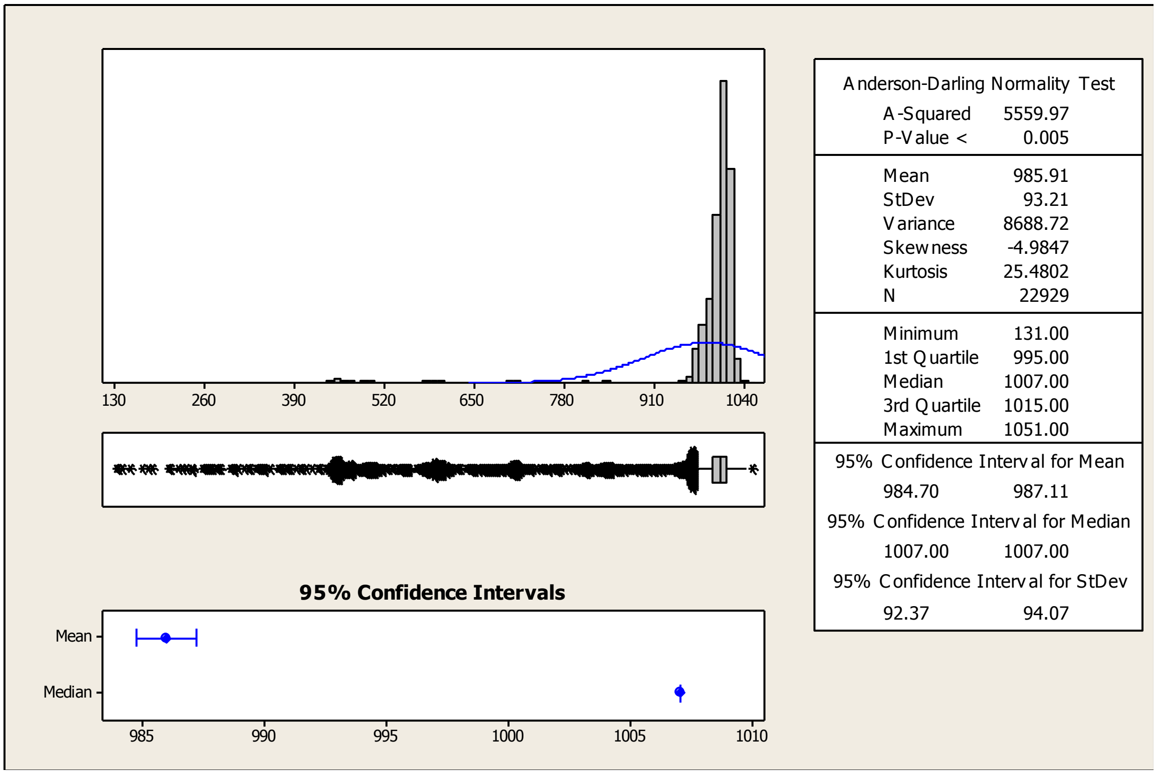


Figure 7: Summary for PTO Speeds for baler in F92, filtered for speeds greater than 125 rpm

The summary generated in Figure 7, revealed the mean value of the data set, along with identifying the standard deviation. The calculated mean from all the data was 985 rpms with at standard deviation of 93 rpms. Those values were used to create PTO speed threshold to be used for filtering and semi-auto processing. This analysis was performed by subtracting three standard deviations from the mean, and applying a statistically-sound PTO filter for all speeds above 706 rpms. In this analysis, a threshold level of 706 rpms was used to identify the difference between when a baler was in operation and when it was not in use. The data below 706 rpms, including the points previously filtered with a threshold of 125 rpms and below, would be used in classifying the baler as non-operational. Non-operational data points will be accounted for and analyzed later in this paper under a different set of criteria. The lower PTO speed points primarily occurred during the startup and shutdown lag of the baler. Once a statically appropriate minimum PTO speed is established, the results can be applied towards creating a PTO Speed legend in SMS Advanced spatial software. Here, this filter can be used to spatially identify the areas of the field where the baler was or was not operating with the specified parameters. SMS Advanced allows PTO Speed legend to be modified to filter the data into the two regions of baler utilization: operational vs. non-operational, the legend has green identified as PTO On and red as PTO Off. Once the filter has been applied, a spatial query can be performed, filtering the data by legend range. Seen in Figure 8, when selected the black region (previously green until selected) ranges in speed from 706 rpms to 1051 rpms, the red area on the map represent a data where the PTO speed is less than 706 rpms. This green region was selected, and then queried, revealing the count of the data set within the specified parameters of PTO speed to be 22,158 or approximately 80% of the Tractor On Duration. This method of using SMS Advanced to filter the data set, based upon legend, is a very fast and effective way of determining duration the PTO was on.

Query 1

Layer 1 - 8335R - 51 | 2011

Main Layer

Total area	0.00 ac
Length	0.00 ft
Count	22158

Description	Average	Total	Minimum	Maximum
PTO Speed (rpm)	1,002.1 rpm	22,205,305 rpm	706.00 rpm	1,051.0 rpm

Figure 8: Query of PTO speeds greater than 706 rpms

For this particular field, the duration that the PTO was on was 369 minutes. Once the PTO On Duration data is quantified, its counter, PTO Off Duration can also be quantified using the following equation:

Equation 4 PTO Off Duration

$$PTO\ \text{"Off"}\ Duration\ (minutes) = Tractor\ \text{"On"}\ Duration - PTO\ \text{"On"}\ Duration$$

For this particular field, the PTO was off for 91 minutes or 20% of the Tractor On Duration. This indicates the amount of time that the tractor was within the field boundary and had a running engine, but was not Actively baling. This duration could also be quantified by inverting the map on SMS

Advanced. The inverted map would require selecting the areas in red instead of green. Both methods will produce the same results.

Engine Speed

Engine speed is a key component in defining a machine's Status. Used in conjunction with PTO Engagement, engine speed quickly eliminates key "On" false positives and determines whether the engine was at an operating speed. To identify the proper speed threshold used in the baling process, an analysis must be performed in a similar fashion as the method used for identifying the PTO On Duration. With a machine's Status in the State of Productive being the highest and most sought-after State, the engine speed is filtered in such a way as to hone in on this particular area. This method uses the previously filtered data identified in the PTO On Duration as a starting point. An engine speed analysis will be performed on all points above 706 rpms to ensure a uniform distribution of engine speeds. A statistical summary was performed on the data points that met the criteria of having speeds 706 rpms or greater. Figure 9 displays the average engine speed of 2005 rpms. Once three standard deviations were subtracted from the mean, an engine speed threshold of 1838 rpms was created. In this analysis, a threshold level of 1838 rpms was used to identify the difference between when a PTO was operational and it was not properly used. If the engine is not under a load, then the baler was not functional, and is likely either in the Idle or Transport Status.

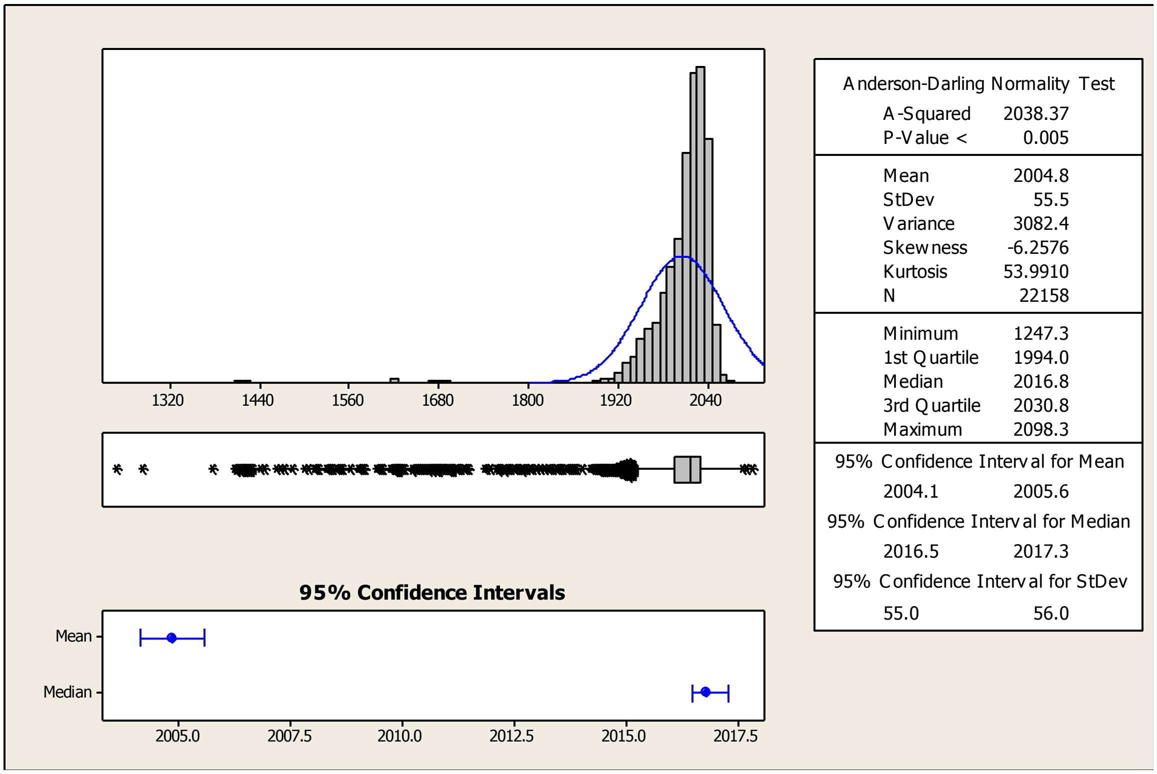


Figure 9: Engine Speed for baler in F92, filtered for greater than 706 PTO rpms

When the Engine speed data is reprocessed, (selecting only the engine data with engine speed greater than 1,838 rpms), a more uniform distribution is clearly defined as seen in Figure 10. This method of creating an engine speed threshold from a filtered data set will yield accurate results that can be replicated with a spatially queried over the entire Tractor On Duration data set. An example of the benefits of using the spatial method can be seen in comparing the final sample size in each processed data set. Notice the size of the sample in Figure 5, represented as the count as being 27,613 data points, the summation of the entire Tractor On Duration, while the sample size for PTO On Duration, seen in Figure 9 is 22,158 points. When the data is spatially analyzed and filtered for engine speed points above 1838 rpms as seen in Figure 11, it yielded 21,934. Compared to the yield of 21,877 points in Figure 10, the spatial analysis method had an additional 57 points. Compared over the Tractor On Duration, it is less than a 1% difference.

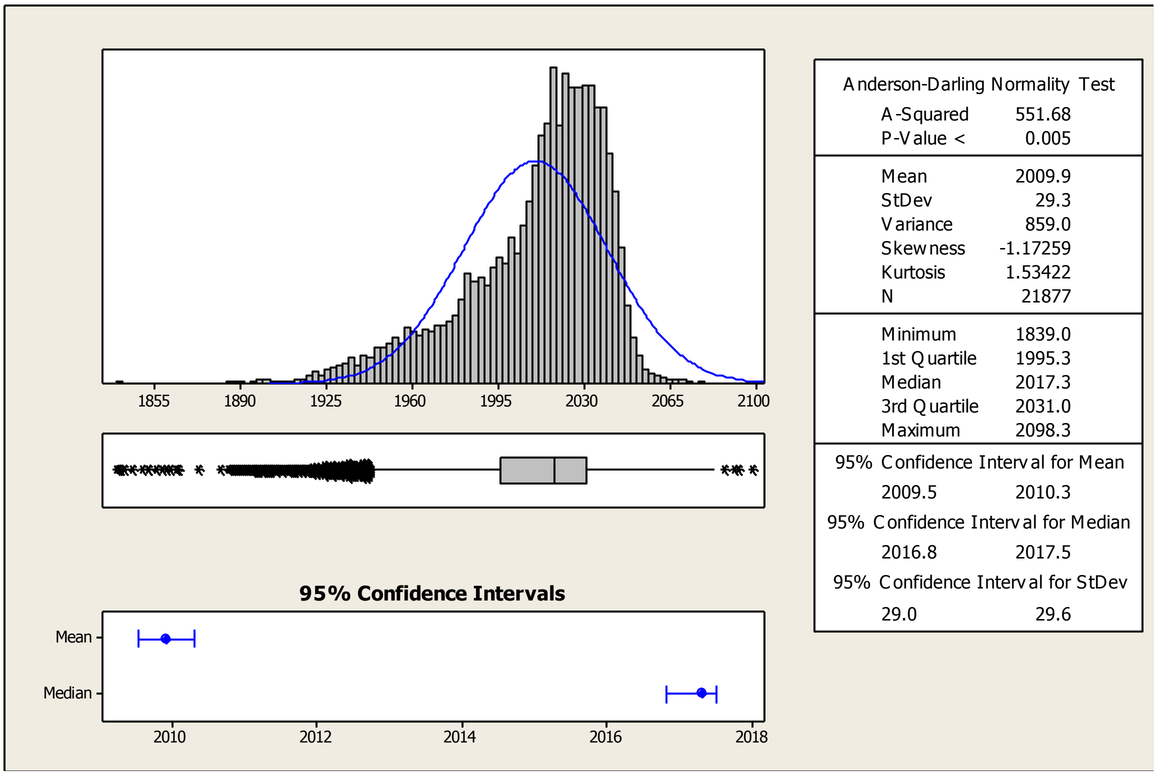


Figure 10: Summary of Engine Speed for baler in F92, filtered for speeds greater than 1838 rpms

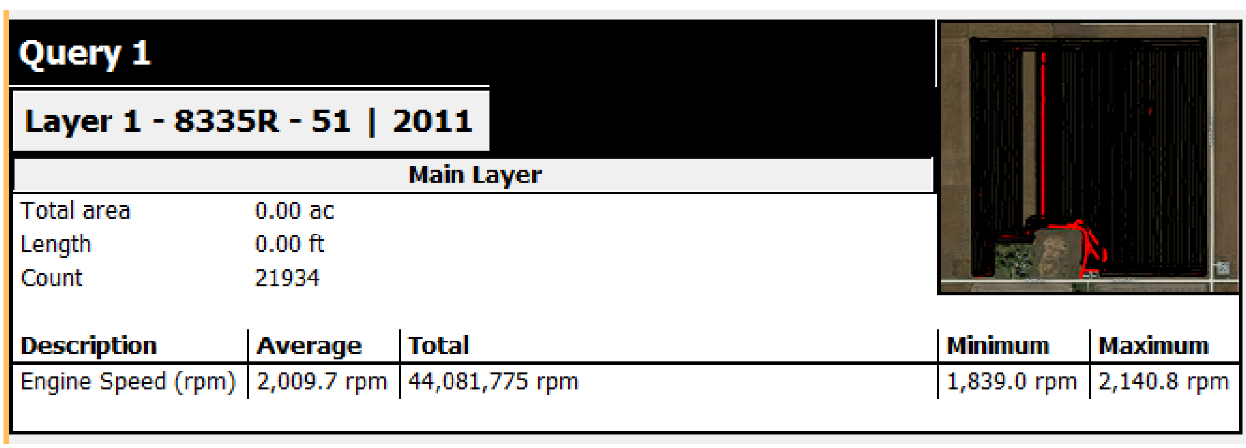


Figure 11: Queried Results for baler in F92, filtered for Engine Speeds greater than1838 rpms

During this analysis process, it is important to validate the results and determine if they meet practical levels. For example, compare the spatially analyzed PTO On Duration with the spatially analyzed engine speed. Based on the knowledge that PTO speed is dependent on engine speed due to mechanically coupling, both events should have a similar duration. This theory holds true in this example as the PTO On Duration has 22,158 points while engine speed is represented by 21,934 points, a difference of 224 points, or approximately 1% error. It is important to check the percentage of error to confirm that data is being processed accurately. If, for instance, a tractor had an engine speeds faster than 1,838 rpms with a PTO speed less 706 rpms, this would increase the percentage of error between the PTO and engine speeds. This event most likely would be caused by the tractor being in the Transport Status but this assumption cannot be verified until the machines field speed is added into the analysis.

GPS Speed

Once the PTO and engine parameters are defined, the final attribute of GPS field speed can be analyzed. A vehicle's Field Speed is defined by American Society of Agricultural and Biological Engineers (ASABE), in the Standard S495.1, as the rate of machine travel in a field during an uninterrupted period of functional activity (ASABE, 2005). When performing a GIS spatial query, there is not enough significant evidence to determine which data points are in an uninterrupted State of functional activity. It is with this uncertainty that GPS speed must be determined by averaging only the points within compliance of the other two attributes. Once a filtering threshold has been established for the tractor's PTO and engine speed, a histogram can visualize the distributions of tractor's ground speed in kilometers per hour (kph). Figure 12 shows the distribution of GPS speeds from the data in Figure 10. Note that these data points are being analyzed from a pre-filtered data set. It is important to preliminary process the GPS speed from this smaller, filtered data set, than with the spatial query method using the summation of Tractor On Duration data. By using the pre-filtered data set, the averages of speed will be uniform and more importantly represent only the times when the baler was operational. The GPS field speed is the final process in establishing the parameter necessary for categorizing tractor utilization into the three discrete Statuses. In order to do this, statistical information must first be calculated to justify informed decisions. Figure 12, calculates the mean of the filtered sample to be 10.2 kph. With the PTO and engine speed analyzed; the GPS speed will be evaluated in a similar fashion. In the agricultural hay and forage community, the term "slugging" is used to describe the process when too much material is passing through the machine. The hay industry uses this term when the baler's front mechanical pickup is not transferring the material from the ground into the compression chamber as efficiently, most likely due to excess in the vehicle's speed in heavy crop conditions. When "slugging" occurs, the tractor's operator must reduce speed and decrease the material throughput for the baler, until this issue is resolved. The reduction in material throughput hinders the capacity of the machine and affects overall productivity of the system. Knowing this issue, requires a vehicle's lower GPS threshold speed to be adjusted to accommodate these situations. This adjustment is made by setting the threshold speeds, using two standard deviations instead of the three as used previously for calculating the PTO and engine speeds.

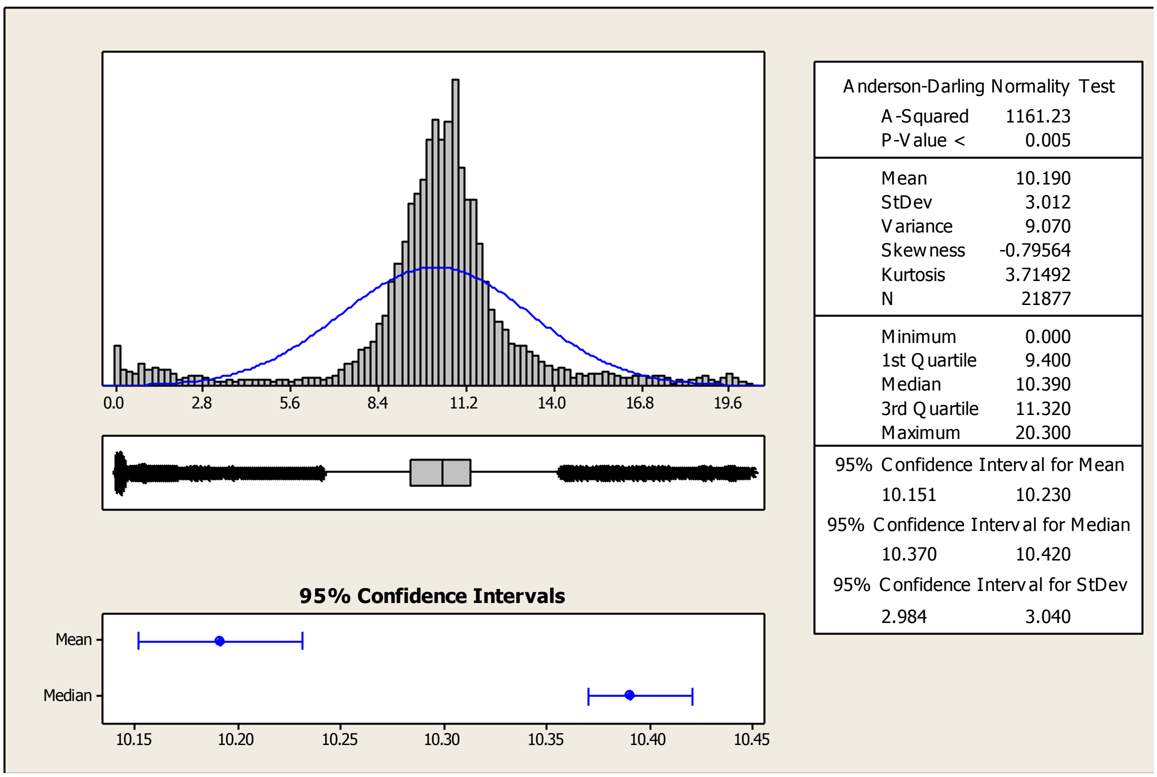


Figure 12: Summary of GPS Speed for baler in F92, filtered for speeds greater than 1838 rpms

Using the data in Figure 12, the GPS speed thresholds can be calculated, by subtracting two standard deviations from the mean, the lower speed is set at 4.2 kph. Unlike the mechanically limited attributes such as PTO speed and engine speed, an upper speed threshold must also be set. Adding two deviations to the mean sets the upper limit at 16.2 kph. When the speed thresholds are applied, the results reveal a sample size of 19,932 data points, with an average speed of 10.5 kph, as seen in the statistical summary of Figure 13.

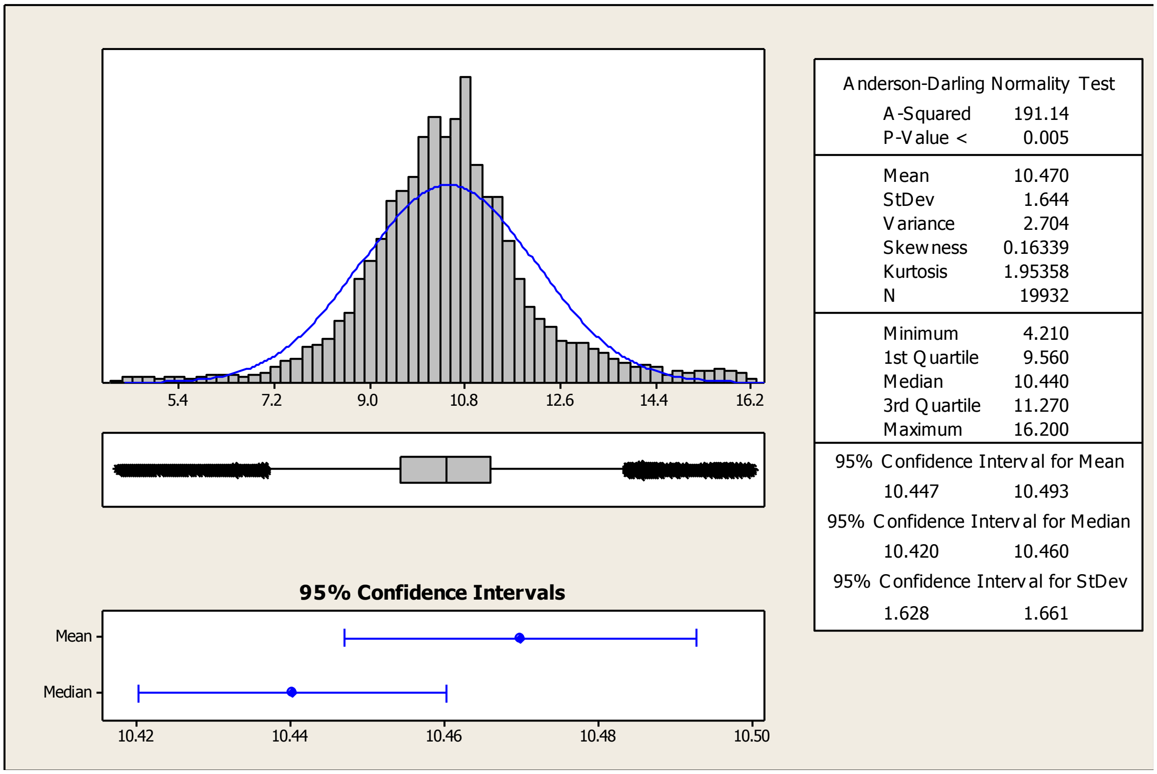
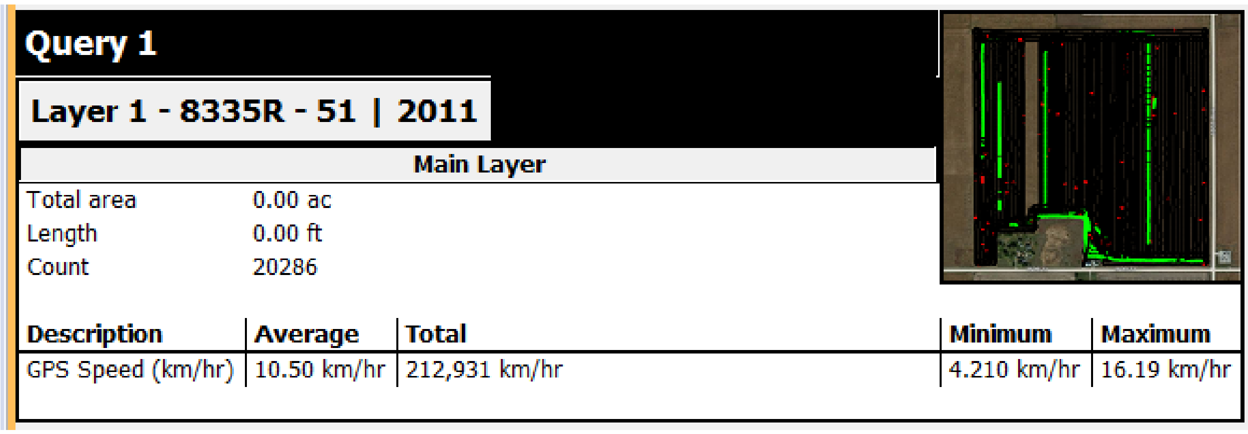


Figure 13: Summary of GPS Speed for baler in F92, filtered between 4.2 and 16.2 kph

However, it is equally important to understand the material throughput capacity of a baler. Understanding the mechanical limitations of an equipment set will help separate the machinery performance data from the non-productive personnel data. By removing the equipment operator from the equation, a human resource evaluation can be performed on personnel organization, and theoretical field capacity. In order to determine theoretical field capacity, the baler must be operating in the Production Status; not accounting for any non-productive time in the field, such as stopping events, breakdown, in-field transport and idle events (Peyton, 2012). Essentially what this represents is how long would it take to bale the field at a constant speed without any interruptions. In the case of F92 the Theoretical Field Capacity can be identified in the sample size (N) of Figure 13, represents the Theoretical Field Capacity of the baler as 19,932 data points which is equal to 5.5 hours.

The method of filtering is preferred because basing decisions on previous decisions makes this the most accurate method for identifying the events when the tractor was at peak utilization. If a GPS speed query was performed without considering the PTO and Engine speeds, a skewed result would occur as seen in SMS Advanced query of GPS speed found in Figure 14.



Query 1

Layer 1 - 8335R - 51 | 2011

Main Layer	
Total area	0.00 ac
Length	0.00 ft
Count	20286

Description	Average	Total	Minimum	Maximum
GPS Speed (km/hr)	10.50 km/hr	212,931 km/hr	4.210 km/hr	16.19 km/hr

Figure 14 Queried Results for baler in F92, filtered for GPS Speed, filtered between 4.2 and 16.2 kph

Figure 14 shows a count of 20,286 points when the pre-filtered method in Figure 13, had 19,932 points, a difference of 354 data points. The percentage of error for the difference using the spatially analyzed the Tractor On Duration data set was approximately 2%. Though a 2% error is acceptable, this error was calculated on a single field. Variability with equipment, field size and organization structure can lead to larger error and less accurate results. It is due to this variability that just one attribute cannot confidently be used to categorize machinery Status States. However, when combined, these three attributes can filter any data set very accurately.

Field Efficiency

Querying GIS data using three attributes proves to be an effective way of determining the Theoretical Field Capacity of a baler harvesting corn stover. With the biofuels industry in the formative stages, equipment utilization is a key component in developing economic models and helping management estimate their operating cost. Efficiency is a metric designed to be used in the estimation and selection process of biomass harvesting equipment. ASABE Standard S495.1, *Uniform Terminology for Agriculture Machinery Management*, defines field efficiency as the ratio between Effective Field Capacity and Theoretical Field Capacity. (ASABE, 2005) Using Equation 5, a percentage of tractor utilization can be determined.

Equation 5: Field Efficiency

$$Field\ Efficiency = \frac{Effective\ Field\ Capacity\ (ac/hr)}{Theoretical\ Field\ Capacity(ac/hr)}$$

During the 2011 corn stover research harvest, the Krone baler in F92 was in full operation 72 percent of the time. Field Efficiency can be used to evaluate productivity, as well as non-productivity. When making management decisions, it is equally important to identify the areas where the baler was not in the productivity Status. Once identified, these non-productivity areas can be evaluated and managed to increase machine performance and efficiency.

Dormant State

The Dormant State can be quantified by using Equation 6. In this equation, Tractor Off Duration is the time the tractor spent within the field boundaries with the tractor not under engine power. This duration can include the overnight time when the operators have gone home along with any mechanical breakdowns, refueling, servicing and scheduled maintenance.

Equation 6 Tractor Off Duration

$$Tractor\ \text{"Off"}\ Duration\ (minutes) = Total\ Duration - Tractor\ \text{"On"}\ Duration$$

The Tractor Off Duration was analyzed using a combination both GIS and Microsoft Excel software. After processing the Total Duration data, SMS Advanced compiled all the selected data points and exports the summarized results in the form of a comma-separated values table. Figure 15 shows an example of how having the data in a table are used in conjunction with spatial mapping. In Figure 15, the column labeled “Featured ID” represents the duration of each individual event in which the tractor was keyed on. As indicated in the change in consecutive numbering found in Figure 15, the tractor was turned off after 2,624 seconds and then keyed on again, changing back to the Active State, labeling the change in event with “1”.

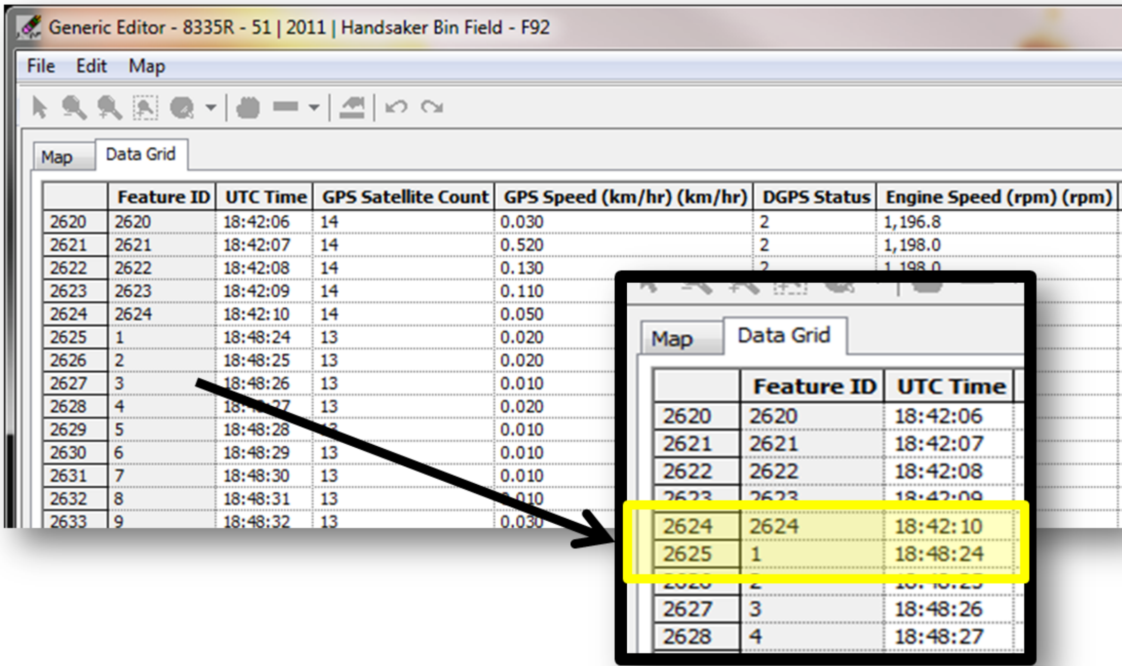


Figure 15: Feature ID and UTC Time Stamp Data Grid

The ability to distinguish between starting and stopping events allows for an accurate analysis of the durations of both Active and Dormant States. The Dormant State can be further analyzed on an event-by-event basis by subtracting the UTC Time from the start of the tractor on event from the ending of the previous on event, thus providing the duration between the tractor's starting and stopping events. The UTC Time stamp provided by the GPS receiver ensures an accurate method for measuring duration intervals, a more accurate method than recording starting and stopping events with a stopwatch.

Unlike the analysis performed using Equation 6, calculating a summation of Tractor Off Duration, the method using the Feature ID and the UTC Time stamp, actually quantifying each of the individual tractor on and off durations, as they switch back and forth between the Active and Dormant States. When all events are added together, they equal the number that would be queried using SMS Advanced. (Figure 5) The frequency and duration between Active and Dormant States can be calculated through an analysis of these results.

The ASABE Standard S495.1, *Uniform Terminology for Agricultural Machinery Management*, defines this unexpected change in duty Status from operational to non-operational, due to mechanical failure as a Breakdown (ASABE, 2005). Given the parameters and metrics collected data during the 2011 stover research harvest, there is not sufficient evidence within the collected CAN data to distinguish the difference between a stopping event due to mechanical failure, overnight time or operator attentiveness. The ASABE Standard S495.1 does not have a term for measuring the metrics of an unexpected change in duty Status from operational to non-operational due to an unknown cause, it is yet to be defined. It is for that reason that the term “Downtime” was created to fill the knowledge gap. Limited by the advancement in the CyCAN software used in the 2011 stover harvest, Downtime was used to refer to any duration between Active States.

Results

Spatially analyzing data to categorize tractor utilization proves to be an effective method to determine the productivity and downtime of large square balers in a multi-pass corn stover biomass harvesting systems. This method analyzed machinery performance parameters gleaned from both GPS and CAN-based data accusation systems to classify the different tractor “On” and “Off” events. Once the GIS data was separated as the tractor being “On” or “Off” a Machine State was created to organize the data as being either Active (On) or Dormant (Off). Once categorized in a State, the data was then filtered to identify how well the tractor was being utilized while in the State. The Dormant State classified all Tractor Off Duration’s as being Downtime, while the Tractor On Duration was classified as being in the Active State. Using collected CAN and GPS information, thresholds were established for PTO, engine, and GPS speeds, defining the parameters necessary for a tractor’s utmost level utilization. This highest level of utilization was categorized as having a Production Status.

Utilization Paradigm

Knowing the parameters required to obtain the Production Status led to the creation of the Utilization Paradigm known as UP, a decision tree that defines the categorizing tractor/baler utilization. UP is a decision support tool that uses a tree-like model of decisions and their possible outcomes. The GIS data is categorized into a Machine State and then filtered into levels of utilization know as Status. The UP diagram is comprised of four discrete Status, (1) Production, (2) Transport, (3) Idle and (4) Downtime representing durations of both the Active and Dormant States. UP separates Status's into individual columns, of specific parameters. Having the ability to distinguish between a Machine Statuses based on parameters, as seen in the bottom of Figure 16 provides a reference to the contributing areas of Machine efficiency.

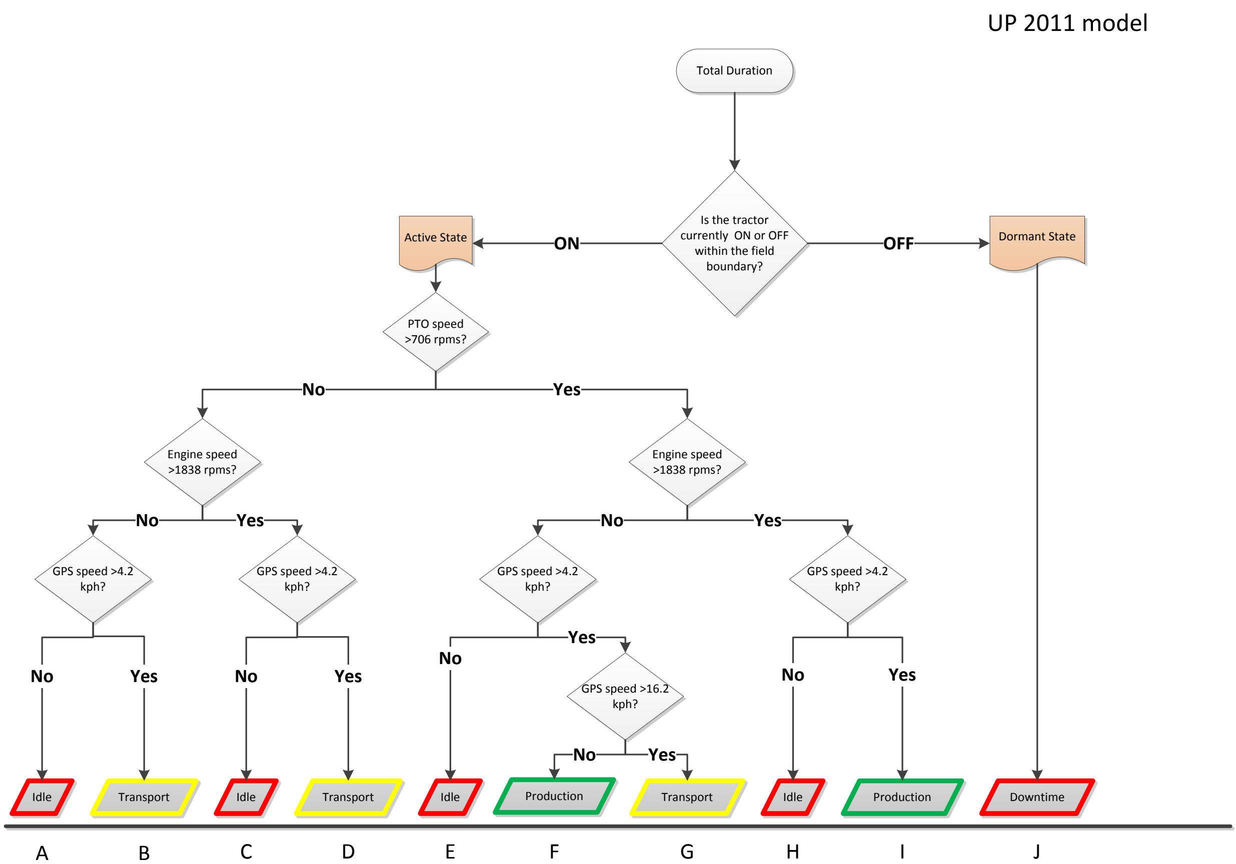


Figure 16: Utilization Paradigm Decision Tree specified for F92

The results of F92, categorized using the UP, are presented in Figure 16. The highest duration of tractor utilization is spent in the Dormant State represented in the column "J" as Downtime. Column "J" is a compilation of 89,400 seconds or 24.8 hours that the tractor was off within the field boundary. The next highest duration is found in column "I", Production. This sought after column reflects the time the tractor spent baling while in the field. This number reveals that column “I” contributed 20,779 second of Production to the harvest of corn stover. The Production duration for F92 can be quantified by combining columns “F” and “I”. The field F92, comprised of 79 acres took a total of 20,813 seconds or 5.8 hours to harvest, a ratio of 13.6 acres an hour.

Table 2 UP Output for F92

Experiment	Units	Idle-A	Transport-B	Idle-C	Transport-D	Idle-E	Production-F	Transport-G	Idle-H	Production-I	Downtime-J
F92	Seconds	4735	575	20	50	308	34	1	1111	20779	89400
	Percentage	4%	0%	0%	0%	0%	0%	0%	1%	18%	76%

An example of validating the theory behind UP can be quantified using Table 2.When the data is processed using the UP parameters, outputs such as Production-F, theoretically, should contain very few data points. Due to the mechanical nature of agricultural equipment, it is not anticipated that the tractor would be able to classify the majority of its Tractor On Duration as maintaining a PTO speed above 706 rpms with the engine speed less than 1838 rpms and with a ground speed greater than 4.2 kph and less than 16.2 kph. This assumption holds true in the case study of F92. After processing the Total Duration data through the UP, the count of data points in Sub-category Production-F was 34. This means that 34 seconds out of more than 6 hours of logged with the CyCAN was spent in this particular Status of Production. This confirms the assumption that duration of Production-F Status would have a low value, providing validation to the processed data.

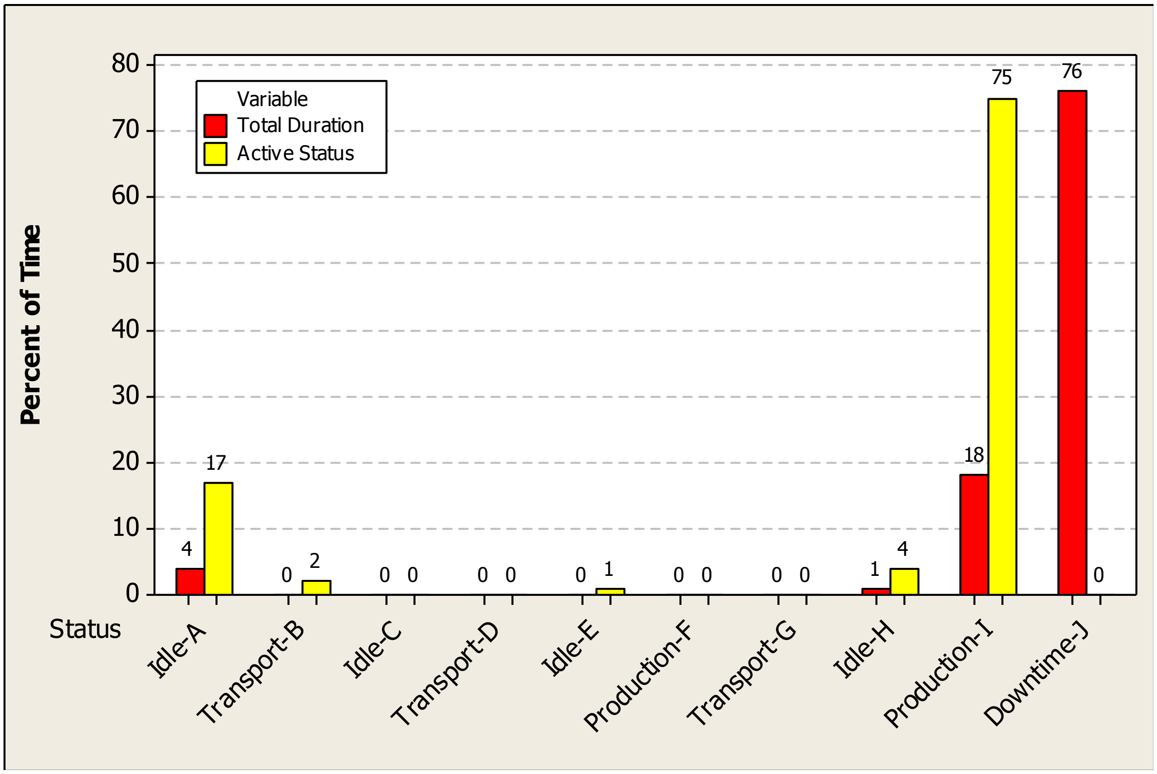


Figure 17: UP Distribution of Total and Active Percentages F92

A comparison of the percentage of time for each Status is made in Figure 17.The percentages reflect the duration the tractor was utilized for each Status. This bar graph represents the processed data for F92 with two conditions. The first condition is represented in red as a percentage of the Total Duration. Total Duration as listed previously in the chapter refers to the entire duration that the tractor was in the field. This time consist of both the Active and Dormant States. The second condition is viewed in yellow as the percentage of each Status in the Active State. The Active State only includes the times where the tractor was turned on. Using the information provided in Figure 17, a statement can be made that the tractor spent 76% of the time in the field with its engine off in the Downtime Status. Another statement is that the tractor spent 18% of its time in the Production Status validated in the percentage seen in column “I”. Evaluation of the percentages of the time the tractor in each Status identifies the reoccurrence of specific parameters. A further analysis is performed on these high occurring Statuses when the Downtime is removed from the data set. This data is identified in Figure 17 as the percentage of time in the Active State. When the Dormant State is not factored into the equation, the Production duration is increase to 75%. Decreasing the size of the data sets, leverages the usefulness of the proportion of Active data, and identifies how each Active Status contributes to the overall efficiency of the harvest system.

Batch Processing Parameters

Often times, management would like to know how well equipment and personnel are performing. From a managerial stand point, it is better if these assets are monitored on a daily or weekly basis, instead of seasonally. A daily performance review has some limitations. For instance, performing an evaluation on a daily basis would produce highly variable results. A baler might be more efficient one day over the next due to several reasons, including crop conditions, personnel attentiveness and environmental conditions. However, given the knowledge gathered from the 2011 stover harvest, a generic set of threshold can be established so a rapid analysis of productivity and downtime can be performed. A batch command function can be executed on GIS data using SMS Advanced given the following attribute parameters. The generic, non-baler specific, PTO speed threshold is 650 rpms, within the thresholds of both AGCO and Krone balers. In a similar fashion the generic Engine speed is set at 1700 rpms. Due to the high variability, the GPS speed is slightly more difficult to determine. However, the lower speed threshold is set at 2.0 kph and 17.0 kph. The lower threshold of 2.0 kph was established using the personal experience collected from three years of stover harvesting in central Iowa, confirming that speeds less that 2 kph are likely the result of "slugging", or the process of which too much material is passing through the machine. The upper limit of 17 kph is set higher than Krone threshold of 16.2 because it is better to error on the side of caution and overestimate for the upper limit, than to underestimate it.

Table 3: Evaluation between Generic and Statistic Filtering Parameters for F92

	Parameters	Idle-A	Transport-B	Idle-C	Transport-D	Idle-E	Production-F	Transport-G	Idle-H	Production-I	Downtime-J
	Statistical	4735	575	20	50	308	34	1	1111	20779	89400
	Generic	4690	563	33	72	277	45	0	957	20976	89400
Difference		-45	-12	13	22	-31	11	-1	-154	197	0
% of Active		-0.2%	0.0%	0.0%	0.1%	-0.1%	0.0%	0.0%	-0.6%	0.7%	0.0%

A comparison of the two methods used to identify filtering parameters was performed on F92. The results of this comparison can be seen in Table 3. In this table, the method using the statistical parameters, calculated specifically for F92, (PTO 706 rpms, Engine 1838 rpms, GPS speed 4.2 and16.2 kph) can be seen in the row labeled Statistical. The Generic parameter (PTO 650 rpms, Engine 1700 rpms, GPS speed 2 and17 kph) are listed one row below the Statistical. The difference between the statistical and generic parameters was calculated and results displayed on the bottom of the table. When the differences were compared across the table, the percentage of change was less than 1%. The percentage was calculated by taking the value of Difference in each column divided by summation of columns “A” –“I”. This meant that the Difference value would be represented as a percentage of the Active duration. Having the ability to use the generic parameters means a semi-automated process can now be performed on a daily basis, providing the feedback necessary to make economic and personnel data-based decisions.

Baler Comparison

The 2011 stover harvest was performed with commercially available balers from two of the industry’s foremost hay and forage equipment manufacturers. This research between large square baler aims to compare the performance and efficiencies operating in a corn stover harvest environment. Differences in design and operation of each baler suggest that the bales are different and should be evaluated separately (Peyton, 2012).The first baler evaluated was the AGCO Massey Ferguson 2170 XD platform. The second baler evaluated, was a Krone BiGPack 1290 HDP baler. Both balers were operated by different crew, with different levels of baling experience. In this experiment, approximately 1000 acres was designated to both balers to be harvested individually. The AGCO baler harvested 873 acres, across 8 fields, ranging in size from 40 to 157 acres, while the Krone baler harvested 910 acres across 8 fields ranging in size from 73 to 170 acres. The data from these fields was processed following the UP diagram using the generic parameters. The results of this evaluation can be seen in both tables 4 and 5.

Table 4: Results of UP, Acres harvested with AGCO baler

Experiment	Acres	Idle-A	Transport-B	Idle-C	Transport-D	Idle-E	Production-F	Transport-G	Idle-H	Production-I
1	157	39%	2%	0%	8%	0%	0%	0%	1%	49%
2	66	13%	3%	0%	1%	2%	0%	0%	2%	79%
3	154	46%	1%	2%	1%	1%	0%	0%	2%	48%
4	40	39%	1%	0%	2%	2%	1%	0%	1%	55%
5	96	43%	1%	0%	0%	0%	0%	0%	2%	52%
6	73	24%	1%	1%	29%	0%	0%	0%	2%	43%
7	96	35%	2%	0%	2%	0%	0%	0%	2%	59%
8	155	33%	0%	0%	1%	0%	0%	0%	2%	64%
Total	**837**	**34%**	**1%**	**0%**	**5%**	**1%**	**0%**	**0%**	**2%**	**56%**
Value		**128399**	**4802**	**1671**	**14884**	**2130**	**506**	**0**	**6464**	**185370**

Table 4 displays the distribution of Status events throughout the harvested fields. When a summation of each column is performed, the resulting value is represented as a proportion of the sample size. In the case of the AGCO baler represented in Table 4, the tractor spent 56% of its time in the Production Status. Using the UP diagram, the total Production Status for a season can be quantified by combining columns F and I. Once calculated, the value can be compared as the time spent to harvest a known area, using Equation 7.

Equation 7: Productivity

$$Productivity\ (ac/hr) = \frac{Total\ Area}{\frac{\sum Production\ Status * 1\ hour}{3600\ seconds}}$$

Through this method a baler's productivity represented on a acres per hour basis can be calculated. The AGCO baler is verified as having a harvesting capability of 16.2 acres per hour. In comparison the Krone baler was also processed in the same fashion as seen in Table 5.

Table 5: Results of UP, Acres harvested with Krone baler

Experiment	Acres	Idle-A	Transport-B	Idle-C	Transport-D	Idle-E	Production-F	Transport-G	Idle-H	Production-I
1	170	27%	3%	0%	1%	1%	0%	0%	5%	63%
2	101	4%	1%	0%	0%	0%	0%	0%	1%	93%
3	109	45%	3%	0%	1%	0%	0%	0%	1%	51%
4	79	17%	2%	0%	0%	1%	0%	0%	3%	76%
5	144	35%	1%	0%	0%	0%	0%	0%	2%	61%
6	155	33%	1%	0%	1%	1%	0%	0%	2%	62%
7	79	21%	2%	0%	2%	0%	0%	0%	2%	73%
8	73	25%	4%	0%	0%	1%	0%	0%	7%	62%
Total	**910**	**26%**	**2%**	**0%**	**1%**	**1%**	**0%**	**0%**	**3%**	**68%**
Value		**51108**	**4435**	**63**	**1052**	**1433**	**264**	**0**	**6424**	**126911**

Table 5 displays the distribution of Status events throughout the harvested fields. In the case of the Krone baler, a summation of the Production Status concluded that tractor spent 66% of its time operationally baling. Using the UP diagram, the total Production Status for a season can be quantified by combining columns “F” and “I”. Once calculated using Equation 7, the duration of productivity can be compared as the time spent to harvest a known area. Through this method a baler’s productivity represented on a acres per hour basis can be calculated. The Krone baler was verified as having a harvesting capability of 25.7 acres per hour. This higher productivity, means that the Krone baler has the ability on average to harvest and addition 9.5 acres in the same amount of time it would take the AGCO baler to harvest 16.2 acres. Information on the harvest capabilities of an equipment set is of dire importance to developing supply chain logistic models. A 56% increase of productivity between machine models means the difference between owning one machine and having to buy two.

Operational Organization

In a similar fashion, the operating crew of the baler can be evaluated. The evaluation process for the baler’s operator is achieved using Equation 8.

Equation 8: Operator Utilization

$$Operator\ Utilization = 1 - \left[\frac{\sum Idle\ Status}{\sum Idle, Transport, Production\ Status}\right]$$

Equation 8 identified that in the 2011 season the baler’s operator was only utilized 60% of the time. Operator utilization means that the operator was inside the tractors cab 60% of the time. Summation of the Idle Status (columns A, C, E, and H), concluded that the tractor spent 40% of its time in the Idle Status. 37% of the combined Idle events were contributed from column “A”. Column “A” is comprised of tractor events where the PTO is below 650 rpms with an engine speed less than 1700 rpms. In addition, the third attribute of GPS speed is below 2 kph. All of these attribute point to the likely scenario that the tractor was parked in a stationary position, with the engine running at lower rpms. Of the time spent not baling this operator was costing the harvest crew time and money.

To quantify this cost, variable costs, such as fuel, labor and equipment, must be defined. The fuel consumption of column "A" can be quantified using a filtered query with SMS Advanced. As a result, the query reported an average fuel consumption of 4.3 liters per hour. Converted to gallons per hour, 35.6 hours of Idle time the tractor consumed 40.5 gallons of diesel fuel. When using the March 28, 2013 price of off-road diesel to be $3.30, $133.70 was spent on the consumption of fuel (GasBuddy.com, 2013). According to Iowa State University's Ag Decision Maker, the rental cost of a 335 horsepower tractor is $90.45 an hour, not including fuel or labor. Labor accounts for an additional $13.30 an hour (Ag Decision Maker, 2013). Fuel is just a fraction of the variable cost. Tractor rental cost and labor account for 96% of the total column cost. By individualizing machine Statuses with UP, areas needing the most improvement are clearly identified. For example, eliminating all the Idle time in column "A", would result in savings of $3827.20 or approximately $4.57 an acre. In a similar fashion the operating crew of the Krone baler can be evaluated. This results from the Operator Utilization identified that in the 2011 season the Krone baler's operator was utilized 70% of the time. The summation of the Idle Status (columns A, C, E, and H), concluded that the tractor spent 30% of its time in the Idle Status. 27% of the combined Idle events were contributed from column "A". Using the same method defined earlier in the chapter for the AGCO baler, the Idling of the Krone crew used 19.3 gallons of diesel fuel, a cost $63.71. Labor cost the operation $256.69 and the tractor rental cost $1745.67, an additional cost of $2066.06, to the harvesting system. In comparison the Krone baling crew would add approximately $2.27 an acre worth of poor utilization to the stover harvesting system, a difference of $2.33 an acre compared to $4.57 of the AGCO crew. Having the option to pay harvest crew on a pay scale based on performance is an effective way to financially incentivize the productivity of the harvesting operation. Without the operator utilization equation, decisions and evaluations on efficiently would be highly inaccurate and not as precise as if using the actual GIS data collected through this method.

Operator Evaluation

The processing of the 2011 stover data thus far has provided the information and parameters necessary to conduct a detailed analysis of productivity and downtime, on large square balers in corn stover. Through this process, isolation of variables, such as equipment operator and baler manufacturer was made possible. The ability to distinguish between the factors contributing to a machine's efficiency, allows for an evaluation of performance and utilization. The most effective method of identifying and comparing the factors of efficiency is seen in Baler Operator Evaluation. The interval plot in Figure 18 identifies a tractor's utilization represented in the three Active Statuses of Idle, Transport and Production. The Idle duration is a valid representation of the equipment's operator's productivity. In the plot, the AGCO's operator, identified in red, is non-productive 37% of the time. The Krone's operator is only non-productive 29% percent of the time, proving that the Krone operator better utilizes the equipment. These results are accepted as being correct, based on the knowledge and experience that both operators demonstrated.

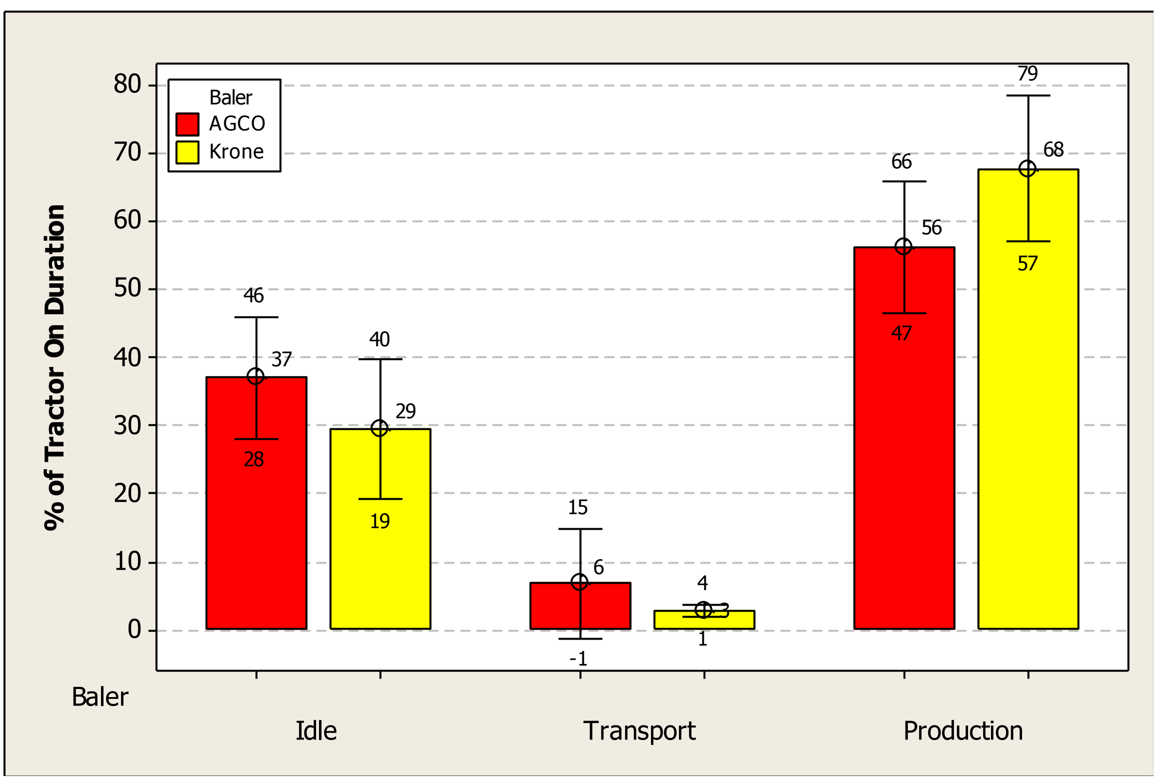


Figure 18: Interval Plot for Baler Operator Evaluations during the 2011 stover harvest

The AGCO baler was operated by a novice employee, who had never operated a large square baler before, while the Krone baler was operated by as seasoned, custom harvester, baling hay and forage crops all across the United States. The experience difference between these operators explains why the AGCO baler would have a lower efficiency. A test between the percentage of Idle duration and Baler manufacturer was performed to identify if any statistical correlation exists between the two. The results can be seen in the One-way ANOVA Table: Idle versus Baler in Table 6.

Table 6: ANOVA Idle versus Baler

Source	DF	Sum of	Mean Square	F Ratio	Prob.>F
Baler	1	.0233	.0233	1.76	.206
Error	14	.1855	.0132		
Total	15	.2078			

In this ANOVA, the probability of obtaining a test statistic (p-value) is .206. Since the p-value is greater than .05, this value means that there is no statistical difference between the Idling durations and the baler operators. The Status of Transport is another metric used to describe an operator's efficiency. Transport refers to the time when the equipment is being relocated from one area of the field to another, while the PTO is non-operational. This time is classified along with Idle as non-productive. In a similar fashion, the AGCO baler has a higher percentage of duration, accounted for as the extra time spent in transport the field. Based on three years of experience harvesting corn stover in central Iowa, the Transport duration is most likely caused by the method in which a mechanical breakdown of the baler has occurred. When a breakdown would arise, the novice AGCO operator would stop the baling operation and return to the field outer edge, seeking additional assistance in repairing the baler. The professional operator of the Krone baler could repair the majority of the baler's problems in the field with any assistance. This experience is represented by 50% reduction in transport time, between the Krone and AGCO balers. The One-way ANOVA Table: Transport versus Baler, (Table 7), revealed that the processed Transport data had a p-value of 2.66. This value revealed that there is no statistical difference between the baler's operator and the percentage of Transport.

Table 7: ANOVA Transport versus Baler

Source	DF	Sum of	Mean Square	F Ratio	Prob.>F
Baler	1	.00628	.00628	1.34	.266
Error	14	.06549	.00468		
Total	15	.07177			

The final Status evaluated in Figure 18, is Production. The Krone baler spends on average 68% of its duration in the Production Status. This efficiency is 12% higher than what the AGCO's operator typically spends. Since all maintenance was performed with the tractors engine turned off, the Production Status cannot be used to compare the baler's performance in corn stover but instead, the operators ability to keep the machine operational. The effect between Production and the Baler/Operator was significantly stronger than other levels of utilization. Here Table 8 had a p-value of .078. This value was still above the .05 needed to make a statistical correlation but, the value of .078 is much closer than the other two levels of utilization.

Table 8: ANOVA Production versus Baler

Source	DF	Sum of	Mean Square	F Ratio	Prob.>F
Baler	1	.0537	.0537	3.62	.078
Error	14	.2077	.0148		
Total	15	.2614			

A test between Production and Idle was performed to identify any correlation between the two Statuses. The results of the test can be viewed in Figure 19. Here the R-Squared value of 72.7% means that the data closely fits the regression line.. This relationship means that the as Idle time increases Production decreases. Understanding the relationship between the Production and Idle Status means that the Status of Transport is constant. The data in Figure 19 was calculated using all data in the Active State. The removal of the Dormant State allowed for a comparison of how the equipment was utilized when the operator was present in the tractors cab.

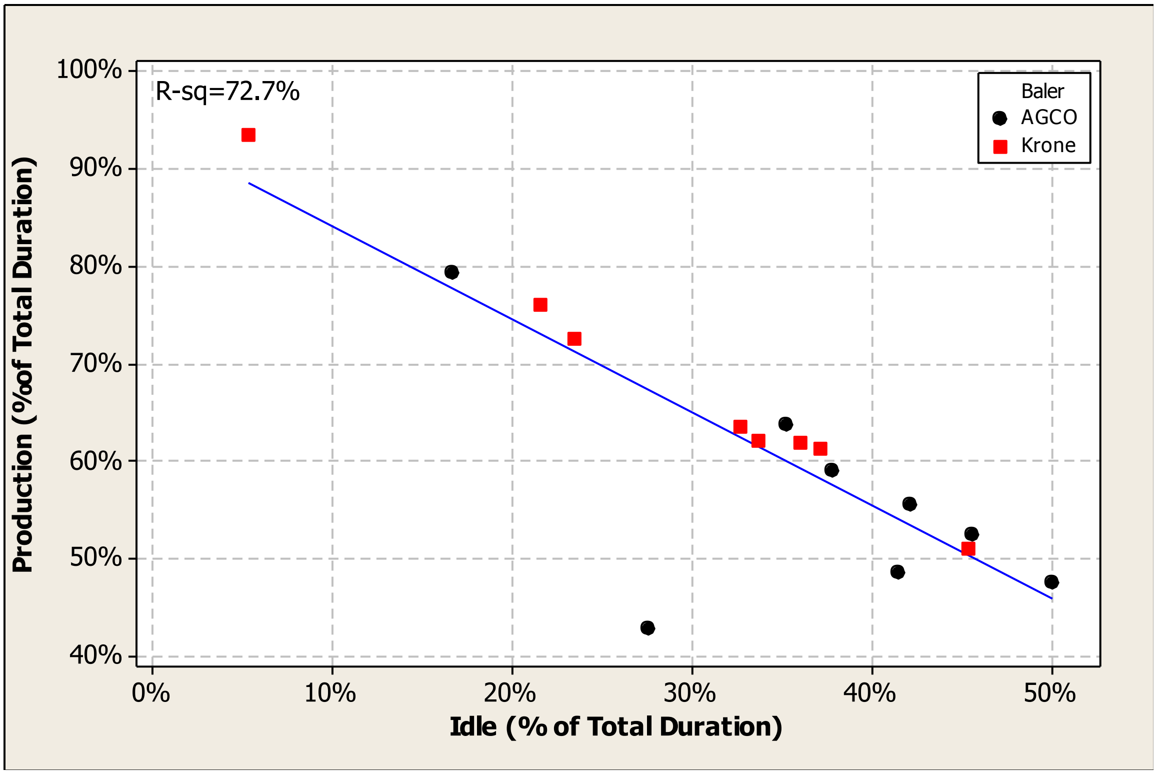


Figure 19: Scatter Plot of Production versus Idle during the 2011 stover harvest

In a very similar fashion the percentage of Production was compared to the percentage of Downtime. Being classified in two different States, this test was conducted to see how Production was impacted by Downtime. The results as seen in Figure 20 were not as strong as Production and Idle time, but a correlation of 66.7% does exist. The Krone data appeared to be very contestant following the trend that more Downtime means a decrease in Production.

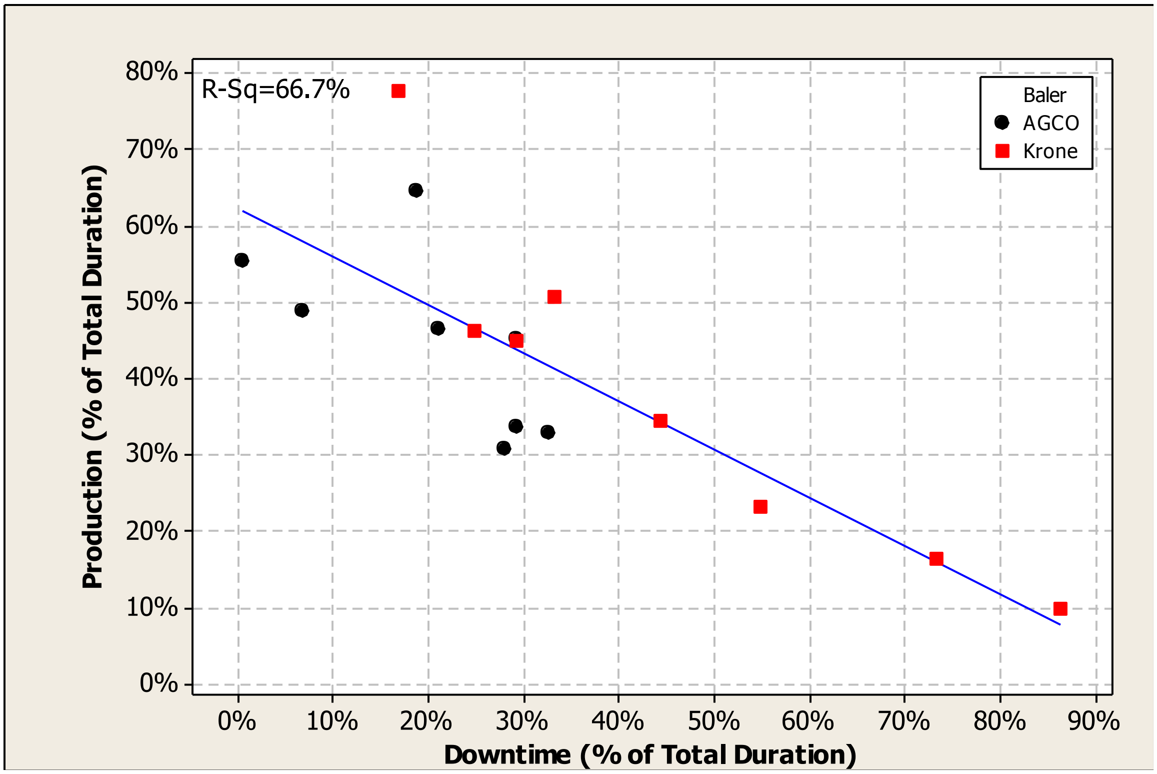


Figure 20: Scatter Plot of Production versus Downtime during the 2011 stover harvest

Baler Evaluation

Many commercially available production balers create similar sized large square bales, but it is important to consider bales from different machines as unique. Differences in design and operation of each baler suggest that the bales are different and should be evaluated separately (Peyton, 2012). It is with this understanding that a comparison between balers was used to quantify individual machines performance. Figure 21, is of an Interval Plot, representing of the data produced in the One-way ANOVA Table: Downtime versus Baler (Table 9). For this particular analysis, the percentage of Downtime is compared for each baler.

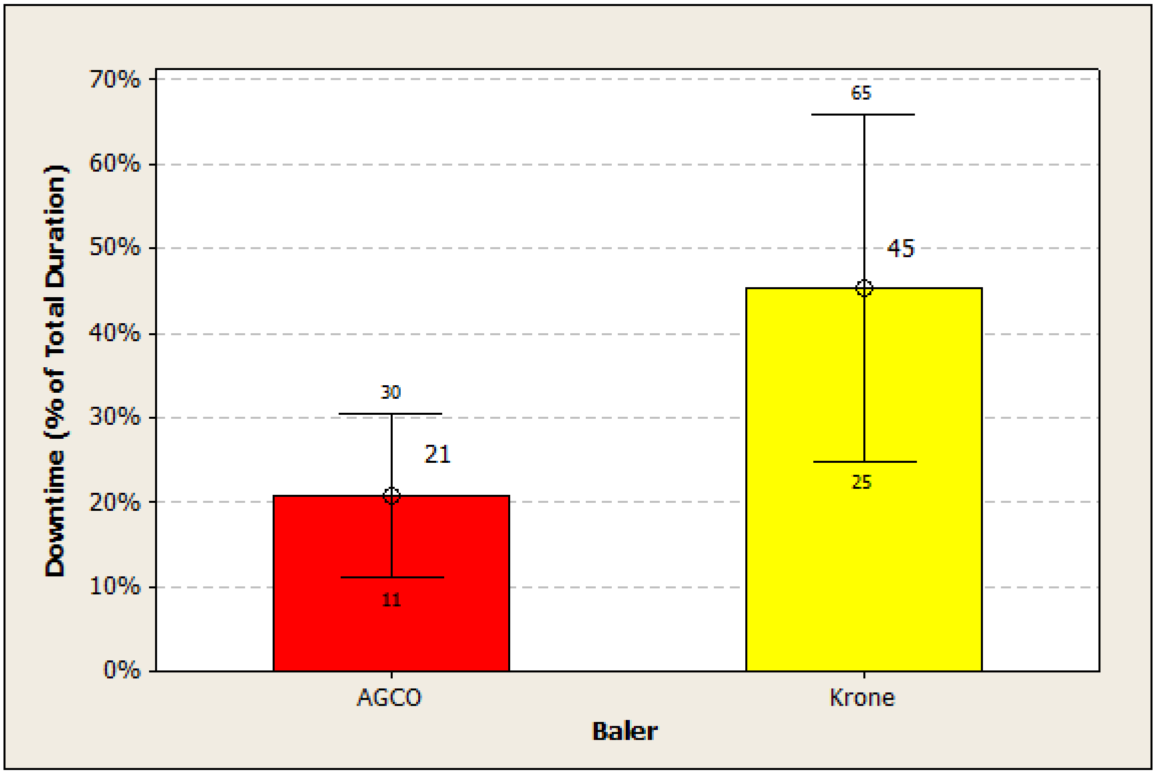


Figure 21: Interval Plot of Downtime versus Baler for the 2011 stover harvest

The interval bars on the plot represent the 95% confidence interval that the data will fall in-between the bars. The AGCO baler is in the Downtime Status on average 20% of the time. A comparison of the tractor off events was performed to capture any differences that one band of baler had over another. The ANOVA table proved the null hypothesis of to be true and accepted the p-value of .022. This value proves that there is a statistical difference between the Downtime associated with the AGCO and Krone balers. Here the Krone is in the Downtime Status 45% of the time. The statistical difference between balers is important information that is used to quantify the Downtime associated with large square balers in a stover harvest.

Table 9: ANOVA Downtime versus Baler

Source	DF	Sum of	Mean Square	F Ratio	Prob.>F
Baler	1	.2419	.2419	6.58	.022
Error	14	.5147	.0368		
Total	15	.7565			

With today's modern agriculture machinery being much larger than the equipment used twenty years ago the, a common question poses itself, "is bigger really better"? In the terms of stover harvesting in central Iowa a question from an equipment management standpoint might be, "is a machinery set more efficient in a larger field?" The thought process behind this question is that a larger tract of land would require less turning on the headlands and improve the efficiency of the operational. In order to answer this question the Production Status and Field size must be factored together. Figure 22 shows the correlation between field size and Production. In this case the R-squared value of 3.9% proves that there is no correlation.

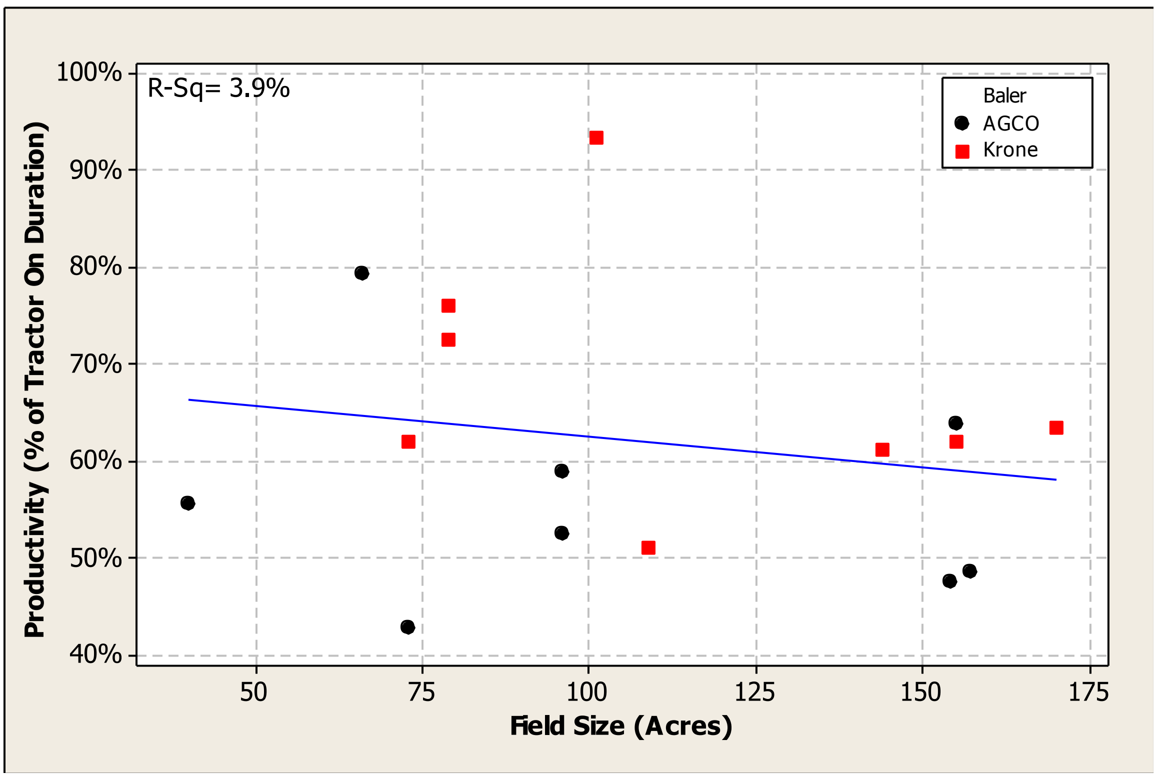


Figure 22: Production versus Field Size

The ANOVA table of the comparison, seen in

Table 10, revealed that the null hypothesis that they are statistically different is rejected. Since the p-value is greater than .05, then there is no statistical way to predict a production efficiency using the size of the field.

Table 10: ANOVA Production versus Field Size

Source	DF	Sum of	Mean Square	F Ratio	Prob.>F
Acres	11	.24004	.02182	4.09	.093
Error	4	.02133	.00533		
Total	15	.26137			

State Change

The final evaluation performed was on the duration and frequency of State changes between the Active and Dormant State. This evaluation was made possible by using the SMS data in the form of a data grid as seen in Figure 15: Feature ID and UTC Time Stamp Data Grid. This data identified when the tractor was turned on and off and for how long it was in each State. Having this knowledge and data enabled calculations of distribution and frequency of each event between baler. The reason behind comparing the frequency between baler, stems from firsthand accounts of machine performance. Unlike operating in a grass hay, a baler has a difficult time tying the knots in the twine that holds the bale together. The material properties of the stover increase the probability that a knotter will have a miss tie and will result in frequent stopping events to repair and reset the knotter. During this repair process the tractor will be turned off. The goal of this test was to identify the frequency and duration of State changes. This will identify on average how long a baler can be operated before being turned off. It is important to remember that the test was conducted using Total Duration data including all the times that the tractor was with in the field boundary. The results of this test are shown in Figure 23 and Table 11 in the Appendix in the back of the chapter. Figure 23 is of a boxplot comparing the Active and Dormant States. Here the AGCO baler can be seen having an average Active duration of 49 minutes, an increase of 60% over the Active duration of the Krone baler. While in the Dormant State the AGCO baler on average has a shorter Dormant duration of approximately five minutes.

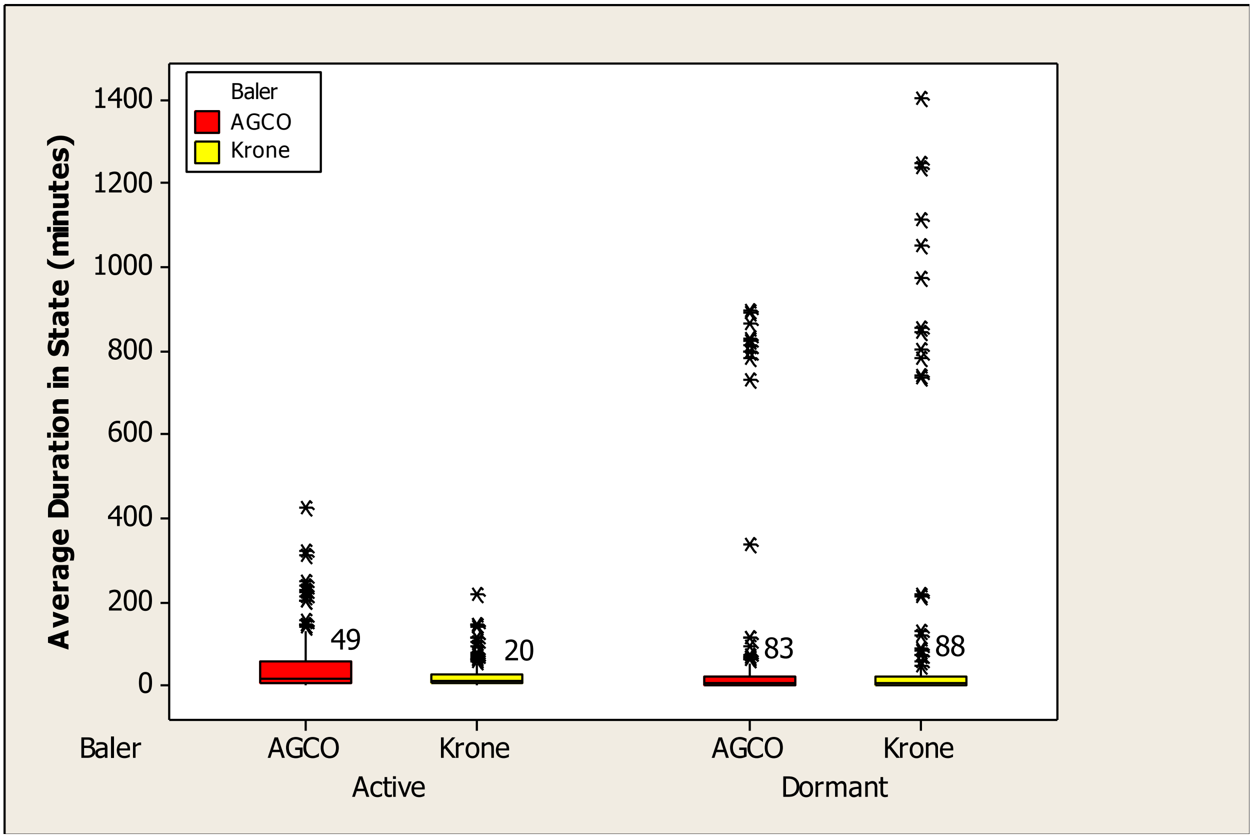


Figure 23: Boxplot of Active – Dormant Frequency and Duration

While the average Duration of each State is helpful in understanding the performance of the balers, a five number summary like the one in Table 11 proves to be extremely useful. In this table, the AGCO baler can be seen having a Median on duration of 13.5minutes. The Krone's median duration is approximately half of the AGCO's falling short at 7.1 minutes. That means that typically a Krone baler can only operate for 7 minutes before the operator turns the tractor off. The maximum duration can also be quantified for both balers. The AGCO's max duration being 423 minutes or approximately 7 hours, an increase of 48% above the Krone's 3.6 hour duration. Of the acres harvested the frequency of State changes was 117 times for the AGCO baler and 159 times for the Krone.

Conclusion

After analyzing the 2011 stover harvest, the Dormant State consumed the majority of the time the tractor was in the field. The lack of knowledge about Dormant State led to further development of data collection to determine why the tractor was off. Since there are different reasons for the tractor to be off, an additional two Status were created to categorize these events, Prep Time and Hibernating. Prep Time uses bale drop events to answer the question of whether or not the baler had produced more than five bales since the start of the day. If the baler has not produced more than five bales that day then this off duration is known as Prep Time. Prep Time generally occurred in the morning when the operator performed service and maintenance to his machine. Often times this Prep Time involved driving the tractor over to the stationary fuel station and filling the tractor before the day started. If the tractor had not turned on the tractor previously then the Status of the tractor is considered to be Hibernating. The Hibernating Status was created to account for any overnight time in which the operators didn't use the equipment since the previous calendar day or as default, the past 6 hours. If the Dormant event doesn't fit within either one of these criteria then the event continues to bare the Status of Downtime. Downtime now hones in on those events where the tractor was turned off to performed maintenance or repairs the baler. Downtime also consumes those events that are related to operator attentiveness such as lunch breaks, restroom stops along with any other stopping event. This new level of data accuracy is critical in understanding the Tractor Off Duration. The CyCAN logging software was updated to have the ability to capture the time and location of bale drops over the tractors CAN Bus. The 2012 model of the UP shows the alterations that were made to the 2011 model utilizing the bale drop information. Modifications to UP can be seen on the right hand side of Figure 24.Note the addition of columns "I", "J", and "K". This new level of data accuracy is critical in understanding the Tractor Off Duration. Another addition made to the UP diagram is the combination of the production F and Transport G columns. After the seasonal analysis was performed with the generic filtering parameters column, G representing the Status of Transport did not out put any values after the category process was performed. This column was necessary when the data was filtered using statistical parameters; however the values were never above 1% of the total duration. With such as small number of events having a high PTO speed, low engine speed and a high GPS speed, this Status was absorbed into the next possible Status of Production. When this column was removed the columns labeled “A” –“I” were rearranged to fill the void.

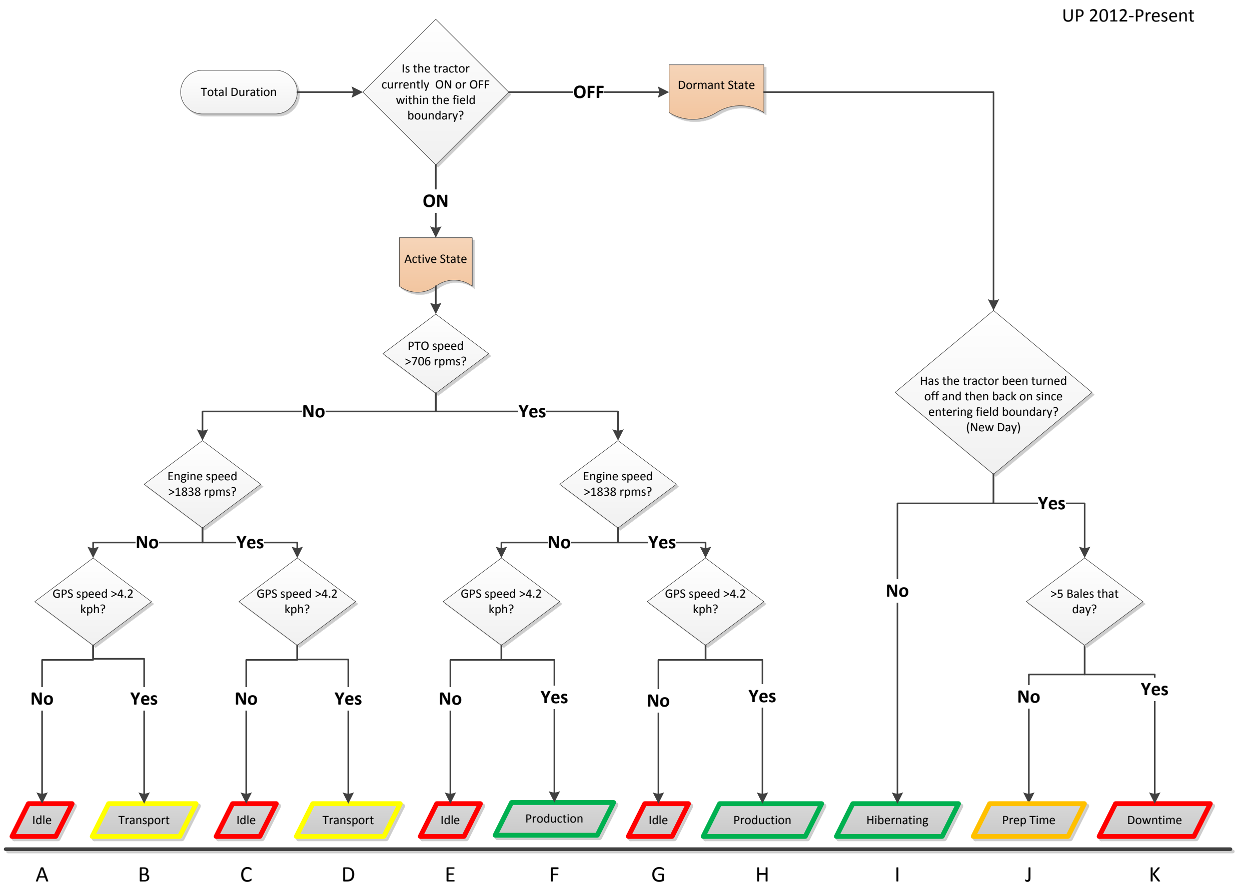


Figure 24: 2012 Utilization Paradigm Decision Tree

One of the advantages to these new modifications is that the Hibernating or overnight time can be identified as seen in Figure 25. This line graph identifies the change in state between being Active and Dormant. A line graph was selected to show the change in percent of the area harvest. Figure 25 displays the two days that it took to harvest F92. The vertical lines represent when the tractor was in the Active State, while the horizontal line represents the duration when the tractor was in the Dormant State. With the UP diagram having the ability to identify the overnight time allows for a better assessment of the Downtime spent in the field. The line graph is also uses to represent the frequency of the State change as seen in Figure 25 as the red dots. Every time the tractor is either turned on or off, a dot will represent either the beginning or the ending of the State. Figure 25 is able to identify the Hibernating State as any Dormant duration lasting longer than six hours.

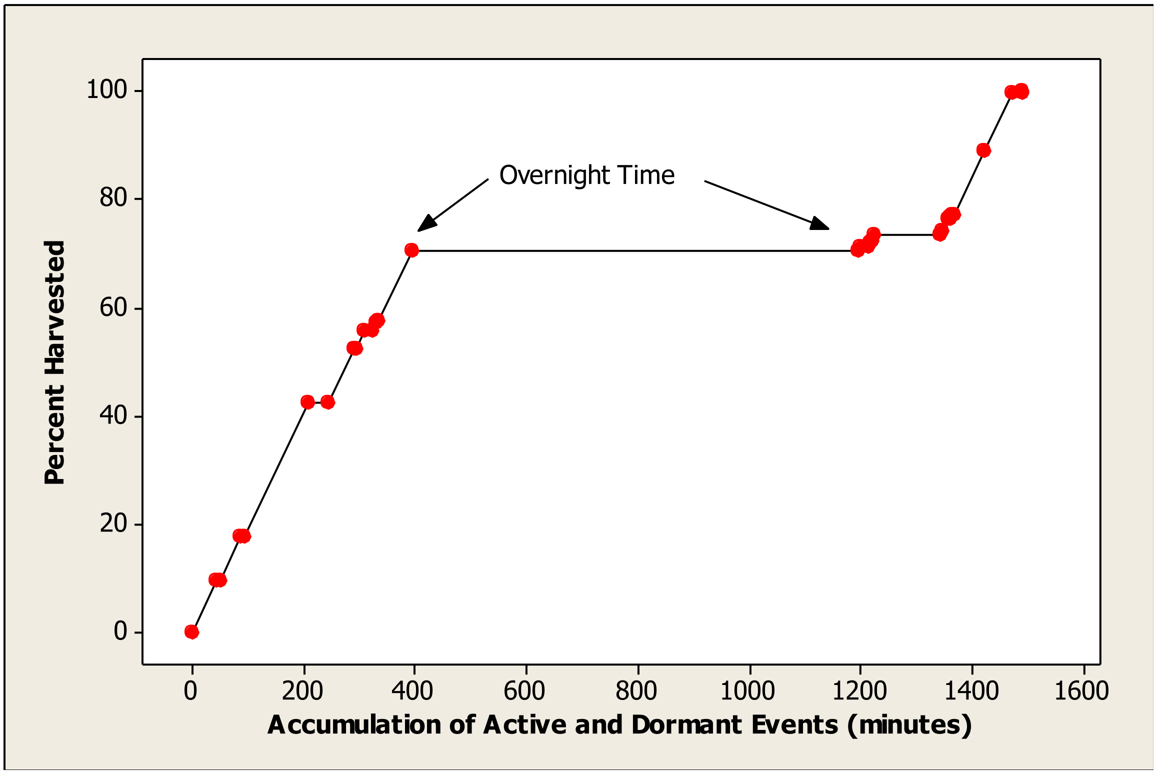


Figure 25: Accumulation of Active and Dormant States of F92 versus Percent of Field Harvested

When the Hibernating State is removed from the line graph, individual events can be displayed as in Figure 26. This line graph shows the productivity of the baler on the first day harvest. At first glance it is interesting to note that the when the baler entered the field it immediately began baling and did not stop until an hour had past. After that the baler changed States five more times before stopping at the end of the day. During this time the baler was able to harvest close to 70 percent of the field. Knowing the size of F92, it approximately 6.5 hours to harvest 56 acres.

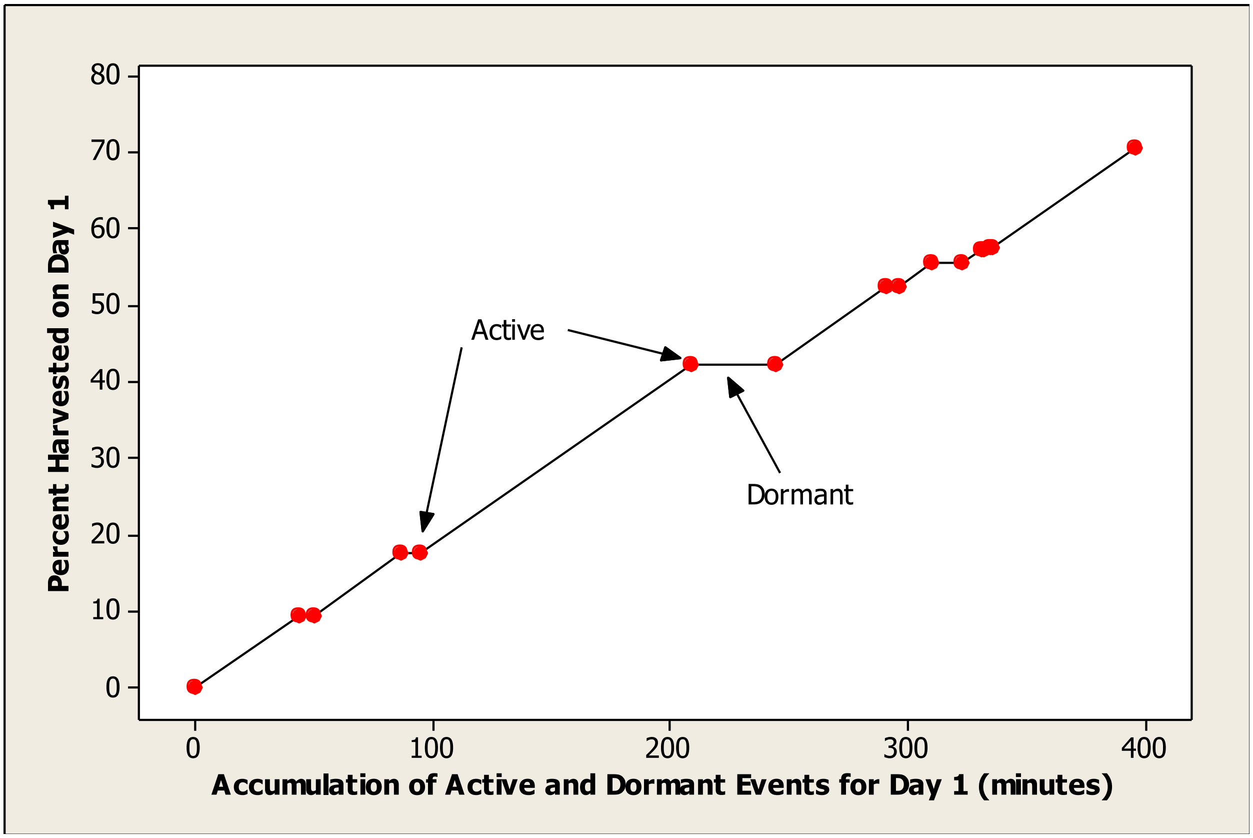


Figure 26: Accumulation of Active and Dormant States of F92 versus Percent of Field Harvested with Hibernation Removed – Day 1

Analysis of the second day starts off with several State changes, viewed in the "Event Analysis" box of Figure 27. Figure 27 shows the start of the day when the operator first started the tractor. The duration of this event was short, probably because the operator had to move the tractor to begin his morning fueling and service. Once the tractor was properly maintained it was turned off and left in the Dormant State for approximately 120 minutes or 2 hours. This Dormant State is an exact replication of crop conditions. In the mornings, dew lingers on the stover residue making it unfit to bale. The two hour in the Dormant State means the operator was most likely waiting for the sun to come out and burn off the dew. Once the stover was fit to bale, the operator baled for a short duration and then got out of the tractor to check on the quality of his bales. Once satisfied with the quality, he was able to bale the remainder of the field only stopping once. Using the Utilization Paradigm the time spent waiting for crop conditions to improve is known as Prep Time. Having this knowledge the Status of Downtime can be further analysis to understand actual machine breakdown events.

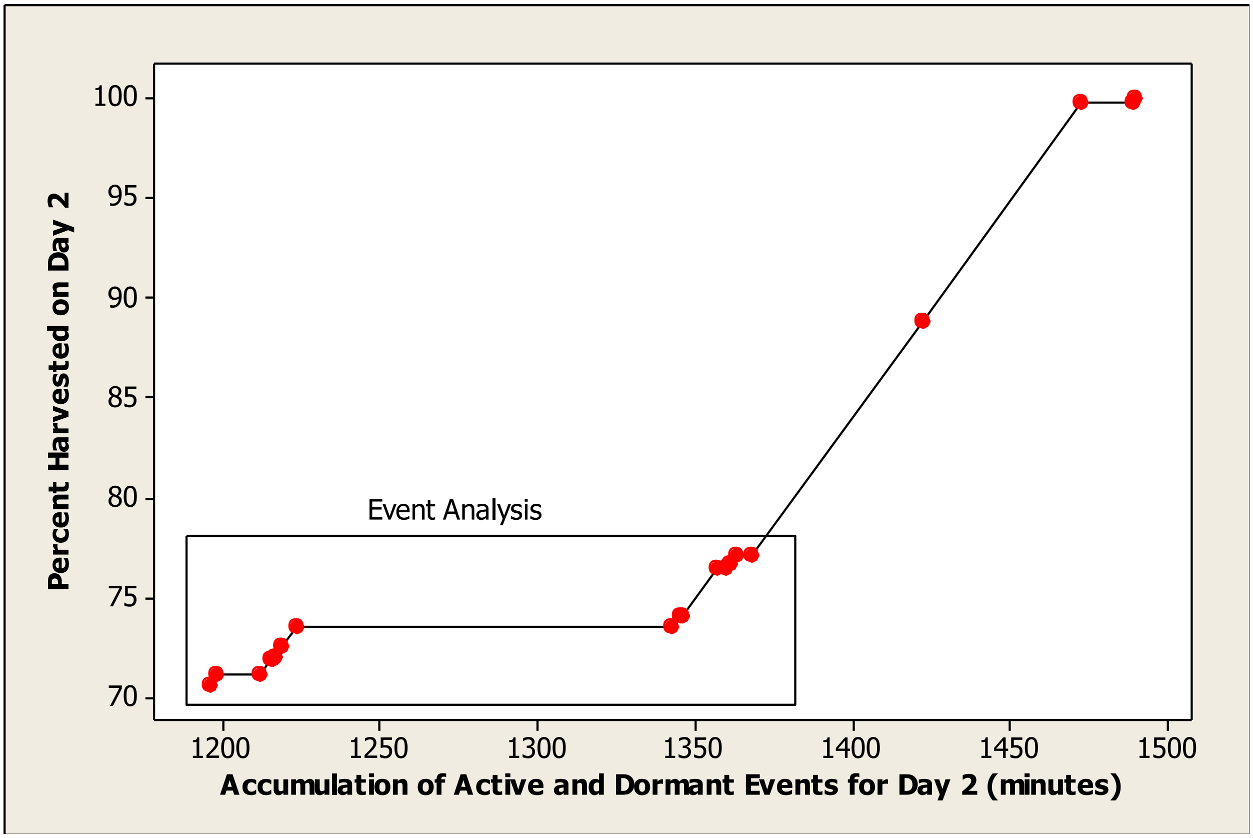


Figure 27: Accumulation of Active and Dormant States of F92 versus Percent of Field Harvested with Hibernation Removed – Day 1

The use of Global Positioning Systems has brought about a new era of machinery management and data collection. The ability to accurately time and track equipment spatially eases and improves the data collection process. This information is further improved by harnessing the operational data streams available on controller area networks. Linking a position to operational data allows for more in-depth analysis than previously possible. GIS software can be used to perform queries and extract data for machine and crew performance analysis. Having the ability to gather the necessary information to estimate the amount of time on different field activities that a harvest crew can expect to spend can help the improvement of crew organization and accurately modeling supply chains and scale up of equipment needed for production biorefineries. Development of this spatial analysis procedure was an important part of the accomplished research.

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CHAPTER 3. GENERAL CONCLUSION

General Discussion

It is clear that cellulosic ethanol is part of the solution in reducing our nation's consumption on foreign oil. Corn stover is a renewable feedstock that is readily available in the Midwestern that has the potential to ensure transportation fuel independence in the United States. In order for this new industry to be successful, efficient and sustainable, the supply chain of stover must be enhanced and refined as much as possible. Understanding how the harvest equipment is utilized will lead to a reduction in stover harvesting expense and development of supply chain economic and impact models.

In Chapter 2, *Determining the Productivity and Downtime associated with large square balers in a corn stover biomass harvest systems using GIS software,* methods were developed to collect and analyze tractor utilization. The GIS software has the capability to filter large data sets and calculate accurate duration of both the Machine Active and Dormant States. CAN based attributes such as PTO Engine and GPS speed were analyzed creating threshold levels that could be used as parameters in auto processing of entire fields data set. The Utilization Paradigm was also introduced as a decision tree used to categorize the machine's Status in levels of tractor utilization. The production scale harvest, like the one seen in 2011, provided the information necessary to make data based equipment selections. The baler type also plays a significant role in determining the number of machines needed in a corn stover harvesting system. Both balers were evaluated on using the calculated Effective and Theoretical Harvest Capacity along with Field Efficiency. Also in Chapter 2, Generic, non-baler specific filtering parameters were established and validated using the Utilization Paradigm. Using the paradigm allowed for a detailed analysis of both the baler and its operator. An evaluation was conducted on the operator's ability to work in the State of Production. The Krone's operator outperformed the AGCO's by being productive 68% of the time compared to 56%. An analysis was also performed on the time when the operators were not productive. This resulted in the

72% correlation between Production and Idle time. The economic effects of Idle time on a harvest system was also quantified. Using Iowa State Universities Ag Decision Maker, the AGCO's operator can be seen adding an additional cost $4.57 an acre to the operational cost. The experienced Krone operator however only adds $2.27 an acre. A correlation between Productivity and Downtime was established with a correlation of 66%. The baler was evaluated in this study on its productivity and Downtime. An ANOVA of the Downtime versus Baler proved that the two balers were statistically different and Krone baler typically 45% of its time in the Dormant State. With the modification to the Utilization Paradigm, this percentage is expected to be lower with the classification of Hibernation or overnight time. Finally the Change in States from Active to Dormant was analyzed for both balers. The AGCO baler can be seen having a longer Active duration of 49 minutes compared to Krone's 20 minutes. Both balers however spend an average of 80 minutes in the Dormant State, with the AGCO baler changing between States 117 times and the Krone 159 Times. This knowledge is very helpful in supply chain development because it can be used to predict the time it would effectively take to harvest an acre.

Performance metrics provide harvest operators and industry managers with the information necessary to plan and organize field operations. The importance of accurate, realistic information is increasingly important as operations are scaled to multiple machines and larger harvesting areas. This type of information is essential to the continual development and improvement of agricultural

APPENDIX

One-way ANOVA: Idle versus Baler

```
Source  DF      SS      MS     F      P
Baler    1  0.0233  0.0233  1.76  0.206
Error   14  0.1855  0.0132
Total   15  0.2087

S = 0.1151   R-Sq = 11.14%   R-Sq(adj) = 4.80%


                          Individual 95% CIs For Mean Based on Pooled StDev
Level  N    Mean   StDev    +---------+---------+---------+---------
AGCO   8  0.3703  0.1065              (------------*-----------)
Krone  8  0.2940  0.1231    (-----------*-----------)
                            +---------+---------+---------+---------
                          0.210     0.280     0.350     0.420

Pooled StDev = 0.1151
```

One-way ANOVA: Transport versus Baler

```
Source  DF       SS       MS     F      P
Baler    1  0.00628  0.00628  1.34  0.266
Error   14  0.06549  0.00468
Total   15  0.07177

S = 0.06839   R-Sq = 8.75%   R-Sq(adj) = 2.23%


                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level  N     Mean    StDev  ------+---------+---------+---------+---
AGCO   8  0.06773  0.09601            (------------*------------)
Krone  8  0.02810  0.01174  (------------*------------)
                            ------+---------+---------+---------+---
                                0.000     0.040     0.080     0.120

Pooled StDev = 0.06839
```

One-way ANOVA: Production versus Baler

```
Source  DF      SS      MS     F      P
Baler    1  0.0537  0.0537  3.62  0.078
Error   14  0.2077  0.0148
Total   15  0.2614

S = 0.1218   R-Sq = 20.55%   R-Sq(adj) = 14.88%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev   -+---------+---------+---------+--------
AGCO   8  0.5620  0.1150   (----------*-----------)
Krone  8  0.6779  0.1282                (-----------*----------)
                           -+---------+---------+---------+--------
                          0.480     0.560     0.640     0.720

Pooled StDev = 0.1218
```

One-way ANOVA: Downtime versus Baler

```
Source  DF      SS      MS     F      P
Baler    1  0.2419  0.2419  6.58  0.022
Error   14  0.5147  0.0368
Total   15  0.7565

S = 0.1917   R-Sq = 31.97%   R-Sq(adj) = 27.11%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev   ------+---------+---------+---------+---
AGCO   8  0.2074  0.1163   (---------*---------)
Krone  8  0.4533  0.2450                   (--------*---------)
                           ------+---------+---------+---------+---
                               0.15      0.30      0.45      0.60

Pooled StDev = 0.1917
```

One-way ANOVA: Production versus Acres

```
Source  DF       SS       MS     F      P
Acres   11  0.24004  0.02182  4.09  0.093
Error    4  0.02133  0.00533
Total   15  0.26137

S = 0.07302   R-Sq = 91.84%   R-Sq(adj) = 69.40%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N    Mean   StDev   ---------+---------+---------+---------+
 40    1  0.5561       *      (-------*-------)
 66    1  0.7941       *                (-------*-------)
 73    2  0.5249  0.1359       (-----*-----)
 79    2  0.7439  0.0246                (-----*----)
 96    2  0.5579  0.0459         (----*-----)
101    1  0.9339       *                     (-------*-------)
109    1  0.5116       *    (-------*--------)
144    1  0.6134       *        (--------*-------)
154    1  0.4763       *   (-------*-------)
155    2  0.6291  0.0129           (-----*-----)
157    1  0.4867       *   (-------*--------)
170    1  0.6354       *         (-------*--------)
                           ---------+---------+---------+---------+
                                  0.50      0.75      1.00      1.25

Pooled StDev = 0.0730
```

Table 11: Frequency and Duration of Active (On) and Dormant (Off) States in Minutes

Baler	Mean On	Mean Off	Q1_On	Q1_Off	Median_On	Median_Off	Q3_On	Q3_Off
AGCO	49.0	83.5	3.2	0.5	13.5	1.5	56.3	21.8
KRONE	20.1	88.3	1.8	0.3	7.1	5.9	22.5	18.5

Q3_Off	Sum_On	Sum_Off	Min_On	Min_Off	Max_On	Max_Off	Count_On	Count_Off
21.8	5737.5	9771.4	0.0	0.0	422.5	896.0	117.0	117.0
18.5	3180.4	13953.1	0.0	0.0	215.9	1403.5	159.0	159.0

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