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The feasibility of using GPS technology for continuous time studies of rubber-tired grapple skidders

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THE FEASIBILITY OF USING GPS TECHNOLOGY FOR CONTINUOUS TIME STUDIES OF RUBBER-TIRED GRAPPLE SKIDDERS

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Abstract

Skidders are one of the most common timber harvesting machines used on mechanized logging operations in the southern United States and can represent the greatest single capital investment for a logging contractor. Time studies of skidders have been conducted on nearly every type of mechanized logging operation and are a key part of the productivity studies conducted on logging operation. GPS technologies have enabled researchers to move away from the typical manual time data collection for productivity studies and start conducting unattended time studies on skidding equipment. For this study a Trimble GeoXT with external antenna was installed in a skidder conducting a second thin of plantation loblolly pine. The GPS was set to record line data on a 5 second and 1 second time interval to determine which type of line file was easiest to analyze. Time data from the skidder was compared to time data collected manually on the ground to test for accuracy of the data recorded by the GPS unit. Statistical analysis was used to compare travel empty, grapple time, travel loaded, un-grapple time and total cycle time between the two methods of time data collection. It was found that GPS times were not significantly different for travel empty and grapple time, but travel loaded and un-grapple time showed significant differences between the two techniques. GPS was shown to be a useful tool for collecting data on trail work, idle time and searching for logs unsuccessfully. Also, the 5 second time interval proved to be easier and quicker to analyze that the 1 second time interval. Ideally GPS in combination with some manual time data collection on the logging deck would give the most reliable and accurate time data for productivity studies on rubber-tired grapple skidders.

Introduction

Skidders are one of the most common timber harvesting machines used on mechanized logging operations in the southern United States. Skidders can be found operating on nearly every type of mechanized logging operation in the South, from first thinning of pine plantations to clearcutting of bottomland hardwoods. Skidders are the primary link between the woods and the deck and constitute a major part of the stump to truck costs for a typical logging operation (Klepac and Rummer, 2000).

The main function of a skidder is to transport bundles of trees that have been laid down by a feller-buncher to the log deck where the trees are loaded on a truck and transported to the mill. Transportation of timber from the woods to the deck is not the only function a skidder performs on a logging operation. Skidders will also delimb trees on the way to the loader, clean the deck when too much debris has accumulated, perform trail work and maintenance along the roads and skid trails and clear areas to put new logging decks. Skidders are also useful for pulling machinery or trucks out of the mud, moving logging mats, repositioning the delimbing gate, and moving the delimber and slasher saws when used.

Productivity of grapple skidders is important for logging contractors since skidding machinery can represent their greatest single capital investment (Kluender et al., 1997). Skidders are generally a highly productive part of a logging operation (Greene and Corely, 1996). Skidder productivity is determined by the volume of timber moved per haul, the length of the haul, travel empty time, grapple time, travel loaded time, un-grapple time, delimb time and idle time, and varies based on timber type, stand conditions and weather.

Productivity analysis of a skidder can be divided into two main parts: the first part is collecting the tree count and bundle volume per haul, and the second part consists of conducting a time study on the skidder movements. Bundle volumes can be collected by measuring all the trees in the bundle and getting an average volume per bundle. Typically, regression analysis is used in this step to get volume of trees in the center of the bundle, where one cannot measure the trees accurately. The second step of the productivity analysis is a continuous time study of the skidder, which is the most hazardous step and takes the most time to conduct.

A continuous time study of a single skidder requires at least 2 people to conduct the study. One person will sit on the log deck with a stopwatch and 2-way radio and record the movements of the skidder on the deck, while the other person will be located in the woods to record the movements of the skidder as it picks up the bundles of logs. The researchers stay in contact with the 2-way radios and notify each other when the skidder leaves the woods to return to the deck and when the skidder leaves the deck to get another bundle. The 2-way radios are necessary for collecting travel empty and travel loaded times. The person on the deck will also record such times as idle time and time spent cleaning the deck, but the main focus of the time study is on travel empty, travel loaded, grapple time, un-grapple time and total cycle time.

When detailed production and cost estimates of any type of operation are desired there are 2 acceptable methods of collecting this information and they include work sampling and continuous time studies (Stenzel et al. 1985). According to Stenzel et al. (1985) Continuous time studies are considered to be better than work sampling. Continuous time studies are generally conducted over a number of days in order to get accurate information on the logging operation and are done with stop watches that can record to the nearest 1/100 of a minute (Stenzel et al., 1985).   Continuous time studies have been the most popular way to gather data on the productivity of forest machines.

Time studies on forestry operations have been around for a long time (Gardner, 1963), and during this time harvesting operations have experienced many dramatic changes. Harvesting equipment has also undergone some major changes, as have the techniques and methods used to harvest timber. During this time major advances in technology have increased the productivity of mechanized forest operations. However, the techniques used to collect productivity data on these mechanized forest operations have changed little and still remain an expensive process (Olsen and Kellogg, 1983).

Global positioning systems (GPS) have created new and simple ways to track the movements of all types of vehicles from agricultural machines such as tractors and combines to military equipment such as bombers and tanks. GPS is widely used in the trucking industry to track cargo, find routes and locate the trucks' next load. GPS has also become commonplace in new vehicles for driving directions, even in the most remote locations. Agricultural equipment such as tractors and sprayers use GPS to maintain uniform lines when plowing fields or spraying herbicides. The uses for GPS are endless, yet the logging industry has been slow to incorporate this technology in their operations.

Global positioning systems calculate position by measuring the distance from a point on earth to satellites in space. Distances are calculated by measuring the time it takes for a signal to travel from the satellites to a receiver on Earth. Clocks on the GPS satellites and receivers are synchronized to generate identical codes simultaneously which makes it possible to determine the exact time the signal left the satellite and arrived at the receiver (Spruce et al., 1993). Latitudinal and longitudinal positions only require measurements from three satellites whereas three dimensional positions such as elevation require four satellites. Position accuracy increases with an increasing number of satellites. GPS clocks use coordinated universal time as the measure for calculating positions. Coordinated Universal Time (UTC) is maintained by the National Institute of Standards and Technology (NIST) and its military counterpart and the U.S. Naval Observatory (USNO). Readings from the clocks of these agencies contribute to world time or Coordinated Universal Time and never differ by more than 0.000001 seconds.

GPS signal disturbance can be a major issue when using GPS to collect scientific data. The disturbance of GPS signals can occur for many reasons. Atmospheric and ionospheric delays as well as deflection of the signal from forest canopies can all contribute to the disturbance of the GPS signal and cause position errors. This disturbance of the signal, also known as noise and a signal-to-noise ratio can be used as a measure of signal quality. The geometry of the satellite constellation can also affect the signal quality. Position dilution of precision (PDOP) is an indication of satellite geometry. Low PDOP values means good satellite geometry and occurs when satellites have the greatest separation in the skyview (Gerlach and Jasumback, 1990). High PDOP values means there is greater variation between the GPS position and the true position.

Differential GPS (DGPS) uses a ground based unit to improve the position accuracy of GPS receivers. The ground based unit is stationed at a precisely known location and serves as a reference location. Comparisons are made between the ground based station and the receiver or rover and the errors in position can be corrected through computer software at the base station and sent to the rover unit. Clock errors, position errors and atmospheric and ionospheric errors can all be corrected through DGPS. The units available today have a differential correction function built in the unit that can be turned on or off. Wide area augmentation system (WAAS) is simply another form of differential correction and it enables the GPS unit to record more precise measurements. Wide area ground reference stations (WRS) receive the signal from the GPS and determine if any errors exist. Each WRS in the network relays the information to the wide area master station (WMS) where correction information is computed. A correction message is prepared and sent to the satellite and broadcast from the satellite on the same frequency as the GPS to the handheld receivers.

This study used GPS along with Pathfinder Office™ software to analyze the difference between the traditional method of collecting time data for a continuous time study of rubber-tired grapple skidders and collecting time data using a GPS for a continuous time study of rubber-tired grapple skidders. The purpose of this study is to determine whether or not one can use GPS accurately for an unattended time study of rubber-tired grapple skidders.

If this technique proves feasible there will be numerous advantages to using GPS to collect time data for a continuous time study of rubber-tired grapple skidders. The advantages include:

1.) The number of people required to conduct the data collection is reduced to one. It would only take one person to program the GPS receiver to collect line data, put the receiver in the skidder and connect the GPS antenna. An operator could easily be trained on how to do this part of the data collection so that at the end of the shift the data recorders could be picked up from the machines and downloaded at the office.

2.) The amount of time needed to collect the data is reduced to the amount of time it takes to set up the GPS in the skidder. Since the time needed to collect the data is reduced, one person could collect data from a number of different operations at one time or in one day. Also one person could collect data on any number of skidders working on an operation at one time.

3.) A much more detailed view of the skidders activities could be analyzed. On a five second interval for collecting GPS points one can see where and when the skidder is doing trail work, positioning the machine to grapple, using the delimbing gate, searching for bundles unsuccessfully and picking up miscellaneous drags that would have been missed if one had been on the ground. All of these details are easily missed when collecting the data manually.

4.) The danger to personnel collecting data in the forest is reduced. One very important reason for using GPS to collect the data is that you do not have to have someone in the forest next to the machine collecting data. By taking that person out of the equation, the chances for someone getting hurt collecting data are greatly reduced.

5.) Often when collecting data in the field the skidder operators are aware of the fact that you are watching them and will often work faster than they normally would, so you do not get an accurate representation of the operation. GPS units are small and can be tucked away behind the seat and out of the sight of the operator and therefore will not cause the operator to be aware that you are collecting data on his machine.

6.) Skidding distances can be obtained with the click of a mouse instead of having to measure the distances on the ground with a logging tape. PDOP values are shown for each point so the accuracy of each point is known and error rates, depending on the GPS unit, can be as small as a few feet.

7.) Accuracy of data is not subject to the fatigue factors that arise during the traditional method of data collection.

8.) Costs associated with conducting productivity studies on rubber-tired grapple skidders will be reduced since the number of people required to conduct the time study will be reduced to one.

Review of Literature

Skidder Productivity

Time-motion studies are the essential way to collect productivity information on forest machines. Textbooks that include details on how to properly conduct time-motion studies have been written by Miyata et al. (1981), Barnes (1980) and Niebel (1988).

Miyata et al. (1981) analyzed the stopwatch technique for continuous time studies on logging operations. Miyata et al (1981) described how to collect productivity data using the stopwatch method in the textbook "Logging and Pulpwood Production", and also noted some key advantages and disadvantages of the stopwatch technique for collecting time data. According to Miyata et al. (1981) continuous time studies have distinct disadvantages such as:

1.) Requires highly skilled observers.
2.) Requires tedious recording of data over long hours for observers and operators.
3.) Becomes costly because you need at least as many observers as there are pieces of equipment and often two observers per machine.
4.) Following logging equipment through a stand is hazardous.
5.) Reducing data is difficult and time consuming.
6.) Accuracy of data gets questionable at the end of a long, exhausting day.

Barnes (1980) and Niebel (1988) also detailed the stopwatch technique for collecting time data on equipment in a textbook called "Motion and Time Study: Design and Measurement of Work" which explains to readers how to properly conduct a time study using the manual time data collection technique. These textbooks set up the basis for how all time studies will be conducted. Over the years many researchers have used the manual time data collection techniques for collecting time-motion data for productivity studies of skidding machines. The studies using this manual time data collection technique on rubber-tired grapple skidders include: Gardner 1978, Blake 1987, Miller et al. 1987, Moore 1987, Tufts et al. 1988, Robe et al. 1989, Gingras et al. 1991, Kluender and Stokes 1994, Brinker et al. 1996, Lanford and Stokes 1996, Hartsought et al. 1997, Kluender et al. 1997, Hartsought et al. 1998, Spinelli and Hartsought 1999, Klepac and Rummer 2000, and Wang et al. 2004a. These studies all used a stopwatch and 2-way radios to time the skidders as they performed their various tasks. Times were written down for each task and the data analyzed to determine productive machine hours and overall system productivity.

The first part of the study I have conducted was a time study of a rubber-tired grapple skidder using the manual time data collection technique which was described in detail and has been repeatedly used in the studies listed above. This type of time study is the most common type of study when conducting time-motion research, although there have been some variations to this type of study as technologies advanced, but the basis of the study has remained the same.

Time-motion studies are now using computer software to collect the time data for productivity studies of forest machines. However this software does not collect the time data automatically, one still has to follow the machines through the timber and press a button to record the time when the machine finishes the task. This type of software may alleviate some of the problems of missing the start of tasks by not having the researcher write out the times, but it still requires multiple observers and working in very close proximity to large harvesting machines, which is a safety hazard. "Siwork 3" is a new type of time study software created by the Danish Institute of Forest Technology. Siwork 3 was run on Husky Hunter computers and all of the time and productivity information was analyzed using this software. Productivity studies of skidders using Siwork 3 time study software include Visser and Stampfer (2003) and Spinelli and Hartsought (1999).

Wang et al. (2004b) used a Windows CE-based data logger to record elemental times and other harvesting related factors for a time-motion study of a Timberjack 460. These studies, even though they are using new software to collect time data, still follow the same guidelines of the time-motion studies outlined by Miyata et al. (1981).

The software based time study programs differ from the study I have conducted because they require actually being on the site and watching the machines work in order to collect the time data. The study I am proposing will use a GPS receiver and GPS computer software to collect and analyze the time data from a rubber-tired grapple skidder. The time data will be collected by the GPS unit on site and the elemental time will be recorded and analyzed at a later date and at an office or home computer away from the logging site and heavy equipment in a more comfortable, less distracting setting.

GPS Literature Review

Continuous time studies using GPS technology are not very common but have the greatest potential for reducing the costs of the traditional time studies and increasing the accuracy of the data collected. Until recently the accuracy of civilian GPS units was questionable due to the effects of selective availability on position accuracy. Position accuracy is the difference between the GPS location and the true location (Liu, 2002). In 2000 selective availability was turned off and the accuracy of civilian GPS units immediately increased. Selective availability was a way of producing significant clock errors in the course acquisition (C/A) code transmitted by the satellites (Spruce et al., 1993). Selective availability affected the time measurements used by the receivers to calculate positions thus causing position errors (Spruce et al., 1993). Liu (2002) performed a comparison study of selective availability and post selective availability position accuracy under a forest canopy. Liu (2002) found that with selective availability deactivated one can walk directly into the intended location under canopied conditions. Liu (2002) also noted that horizontal accuracies increased from 73.3 m with selective availability activated to 8.3 m with selective availability deactivated.

A few studies have bee conducted using GPS for continuous time studies rubber tired grapple skidders. Continuous time studies using GPS to record and measure cycle times have been documented by Spruce et al. (1993), McDonald (1999), McDonald et al. (2000), Taylor et al. (2001), Veal et al. (2001), Holden et al. (2001), and McDonald and Fulton (2005).

Spruce et al. (1993) studied the potential of using GPS to track forest machines under canopied conditions and under open sky conditions. Spruce et al. (1993) found that GPS accuracy decreased under canopied conditions due to the deflection of the GPS signal from branches, needles and stems, which increased the incoming signal travel time from the satellites to the receivers and thus introducing significant errors in position determination. Spruce et al (1993) also noted that there were position errors from the tractor working under canopied conditions because of constantly changing PDOP values from the changing satellite visibility and because sometimes there would be no signal to the GPS and the receiver would interpolate the tractor position.

The study conducted by Spruce et al. (1993) was done at a time when global positioning systems were still in their infancy. Selective availability, which automatically introduced some large PDOP errors into the system, has been turned off since then, so PDOP values will not be as high as they were in this study and will not affect distance or position accuracy. Also, GPS antennas will be used to ensure satellite connectivity is maintained at all times and PDOP values stay small.

McDonald (1999) used GPS to develop and test a data analysis system for calculating machine productivity. The study conducted by McDonald (1999) used a technique where positions were filtered to locate specific events that were independent of what actually traveled the path, then were combined using specified rules into machine functions. This study concluded that this technique was successful in producing gross-time study data, but not successful in providing detailed elemental times. McDonald et al. (2000) also conducted research using GPS and GIS analysis for an unattended time study of skidders. During this study a time study was conducted using the traditional stopwatch method and compared to times recorded by a GPS receiver and analyzed using a GPS pattern matching program. The GPS data was reduced to movement defined events such as travel loaded, travel empty, delimbing, grappling and un-grappling. McDonald's 1999 and 2000 studies used the same reduction analysis system. The system uses a 2-phase process that begins with a site specific identification of movement defined events and in the second phase combines a series of movement events into elemental times. This system automatically identifies skid cycles through the reduction analysis system but leaves little room for interpretation of anomalous skidding events because everything is done automatically.

This study is different from the McDonald (1999) and the McDonald et al. (2000) studies in that it will not use a reduction analysis system to try to automatically filter all the time data. It will use a single person to scroll through all the points and try to identify each task the skidder is conducting. The reason for using human perception as the tool in identifying all the elements of the skidders cycle is that this would be more accurate than using computer codes and will not take any technical computer skills to conduct the study. Also, by going through the data manually one is able to identify certain functions of the skidder that would have previously gone unnoticed. For example I included the time element 'searching for logs unsuccessfully' which had previously gone unnoticed, but by going through the line data from the skidder manually I picked up on that time element by observing this happen.

Veal et al. (2001) studied the accuracy of GPS position data on rubber tired grapple skidders. The Trimble ProXR and GeoExplorer II were used to track the skidders under different canopy conditions and different speeds. Veal et al. (2001) found that as canopy densities increased accuracy of the GPS receivers decreased which was attributed to multipath effects and the switching of satellite constellations. Veal et al. (2001) also found that machine speeds did not significantly affect the accuracy of the two GPS receivers. This was a study conducted on the accuracy of GPS units. Position accuracy bases on speed, canopy, and receiver effects were all tested with these two units and found not to be very different from each other. This shows that for a GPS unit with an external antenna position accuracy can be very accurate which is useful in productivity studies when measuring the length of skid trails and finding distances to bundles. Although this study did not use GPS to track forest machines for a productivity study, it does prove that GPS can be used accurately under closed canopy conditions for distance and position measurements.

McDonald and Fulton (2005) conducted a study using GPS on skidding equipment for an unattended time study of advanced harvesting equipment. McDonald and Fulton (2005) reduced the raw GPS data to a set of simple, measurable events and interpreted these sequences of simple events as machine functions. McDonald and Fulton (2005) evaluated the stream of simple events using a pattern-matching system that combines events into machine functions such as travel empty and travel loaded and concluded from the field trials that it is capable of reducing measurements obtained from field crews. McDonald and Fulton (2005) noted that a three-element cycle, which includes travel empty, grapple and travel loaded, was identified 33 of the 36 cycles with differences between the two systems (clock measurements and automated measurements) measuring less that 10%.

The pattern matching system which is described in this study is similar to the one used in the studies by McDonald (1999) and McDonald et al. (2000) and the differences between the study I have conducted and the pattern matching time studies have been stated previously. Also, the study I have conducted used a 10 element cycle. The elements in the study I conducted include trail work, travel empty, grapple time, travel loaded, un-grapple time, deck work, haul slash, idle time, looking for logs unsuccessfully and total cycle time. I will sometimes include a miscellaneous time element for those time elements which are unexpected and not defined here.

Taylor et al. (2001) conducted a study reviewing all the research and operational applications of using GPS as a tool to monitor forest machines travel patterns, performance and productivity, as well as site prep equipment. Taylor et al. (2001) essentially reviews all the research that has been done up to this point using GPS and skidding equipment. The programs that have been used and that are being used to translate the line files into elemental times are not recognizing all the tasks the skidder performs and it also misses complete cycles. There needs to be a way to collect all elemental time data on skidders using GPS, and be able to collect the data as accurately as one would collect the data manually in the field using the traditional time-motion study techniques.

This study used the same methods that were outlined by Miyata et al. (1981) for conducting time studies on forest machines, but with some slight modifications to the way times are taken. Elemental times for all tasks a skidder performs were collected using both the manual time data collection techniques and GPS. The data were analyzed and comparisons were made for each time element in the study. The results explain which method is the best to use for time-motion studies on rubber-tired grapple skidders and why.

Objectives and Methods

Objective 1

Determine whether or not a GPS receiver with an external antenna set to record data on a 5 second time interval could be used to collect data accurately for a continuous time study of a rubber-tired grapple skidder working on a second thin in a loblolly pine plantation.

Objective 2

Determine whether or not a GPS receiver with an external antenna set to record data on a 1 second time interval could be used to collect time data accurately for a continuous time study of a rubber-tired grapple skidder working on a second thin in a loblolly pine plantation.

Methods

The methods for objective 1 and 2 were identical except for the GPS settings. The GPS was set to collect line data on a 5 second and a 1 second time interval. The study was conducted on a second thin of a loblolly pine (*Pinus taeda*) plantation that was being harvested by Slaughter Logging LLC. Slaughter Logging LLC. is a timber harvesting company owned by Dennis Aucoin and is based out of Clinton, Louisiana. The operation is a typical mechanized logging operation that operates with one Cat 525 B skidder, one Tigercat 750 feller-buncher, and one Tigercat 230B Loader. This thinning crew produces between 6 and 8 truck loads of chip and saw or pine pulp logs per day. The crew I was working with is the shortwood crew that normally conducts first and second thins of pine plantations in southeast Louisiana.

Figure 1. Picture of a Cat 525B Rubber-Tired Grapple Skidder.

For this study a Trimble GeoXT GPS unit with an external antenna was used to record the data. The antenna is a Trimble Geo3 mini antenna which is 1.5 inches wide by 1.9 inches long by 0.5 inches high. The small size of the antenna prevented it from being knocked off by branches or brush while operating in the stand. The GPS unit was set up in the skidder with the antenna wire running out of the door and connected to the roof of the skidder. The GPS unit was set to record line data on a 5 second time interval with WAAS enabled. A limit on the PDOP was set to 80 so anything with a PDOP of 80 or greater was filtered out.

While the GPS was recording the movements of the skidder I stationed 1 person on the deck to manually record the skidder as it arrived on the deck with trees and as the skidder worked on the deck. One person was stationed in the forest stand to manually record the movements of the skidder as it worked in the stand away from the deck. The manual data collection portion of the study was conducted using the UTC time on the

GPS units that each person involved in the study carried. Times were written down when the skidder finished performing a certain task. The written time would mark the end of one element and the beginning of another (e.g. travel empty time would be written down when the skidder began positioning for the grapple, this would mark the end of travel empty and the beginning of grapple time) so there was no missed time between tasks. Times recorded in the field were then calculated in seconds and listed in a Microsoft Excel worksheet for further analysis.

In order to have some consistency between the two methods of recording productivity data I have define each time element in which comparisons were made. Each of these elements was timed manually using the traditional time study techniques and digitally using the line file created by the GPS receiver. The time elements include:

1. Trail Work – starts whenever the skidder operator stops to work on a section of the skid trail and ends when the skidder continues on to the next bundle. Trail work will include any time spent spreading slash on the skid trail to fill holes, using the blade to smooth bumps, or pushing brush out of the skid trail.
2. Travel Empty – starts when the skidder leaves the deck for the woods to pick up another bundle of trees and ends when the skidder starts to position for the grapple. Travel empty excludes any time spent on trail work.
3. Grapple Time – starts when the skidder begins positioning to pick up the bundle of trees. Usually this is evident when the skidder operator pulls off the trail and starts backing up to the load. Grapple time ends when the skidder leaves for the deck, if the skidder operator stops to reposition the load after he started for the set all the time up until then will be considered grapple time.

4. Travel Loaded – starts when the skidder starts for the set with a load of trees and ends when the skidder crosses a designated boundary when entering the set. The boundary was marked with flagging as well as a digital polygon in the GPS unit. The polygon was marked prior to putting the GPS unit in the skidder.
5. Delimb Time – begins when the skidder crosses the line mentioned in the previous statement and ends when the skidder starts forward to position the bundle for the loader. If the skidder skips delimbing, un-grapple time starts when the skidder crosses the boundary.
6. Un-grapple Time - starts when the skidder is leaving the delimbing gate or it is started when the skidder crosses the set boundary, and ends as soon as the skidder drops the bundle for the loader.
7. Deck Time – starts after the skidder drops the bundle for the loader and will include cleaning slash from around equipment, moving equipment, repositioning the delimbing gate, cleaning truck deck, etc. If no deck work is performed, travel empty starts as soon as the bundle is released for the loader.
8. Hauling Slash – starts when the skidder leaves the deck with a load of slash and delivers it to the woods, crossing the set boundary line and returns empty to the set. If the skidder hauled slash as part of its empty travel then the haul slash element was ignored and the time was tallied as travel empty.
9. Idle Time – is the time the skidder spends not moving. The engine is idling.
10. Wait on Loader –the amount of time the skidder spends waiting on the loader.
11. Searching for Logs – is all the time that the skidder operator spends looking for logs unsuccessfully. This is evident when the skidder travels down a skid trail

that has no logs on it, and has to travel back up the skid trail and continue on down to the next skid trail to get to the next bundle.

12. Total Cycle Time – will sum all the time between travel empty times.
13. Miscellaneous Time - will be for unexpected time elements that arise and comments on skidder activities that don't fit into the normal routine.

Once the data was collected with the GPS Microsoft Active Sync was used to link the GPS unit with a computer. The program GPS Pathfinder Office™ 3.0 was used to download the line file from the GPS unit. Once the line file was downloaded with the pathfinder software the line was displayed in a map view which could be manipulated. A position properties box was also displayed with the line file showing the selected point with time, latitude, longitude, and PDOP value associated with the selected point. Arrows on the position properties box designated forward and backward movement and clicking on the arrows would move the pointer to the next point collected by the GPS unit. By scrolling through each point the movements of the skidder were easily recognized and times were recorded from the times shown on the position properties box and recorded in an excel file.

Changes to Methodology after the Initial Trial Data Collection

After collecting data for a day by both the manual and GPS methods simultaneously, some problems were discovered. The following elements of the methodology were learned as a result of the initial trials.

1. Boundary lines will be set up to designate when to stop travel loaded. The boundaries will be marked on the deck with flagging tape on all the skid trails leading into the deck.

2. The set boundary line was digitized with the GPS in order to mark the start/stop locations for the time elements.
3. Un-grapple time will be broken down as follows:
    a. Un-grapple time ends as soon as the bundle is dropped for the loader and deck time will begin immediately unless the skidder goes straight to the next bundle without picking up slash.
    b. Deck time will include cleaning limbs from around machinery, cleaning the set and repositioning the delimbing gate. If the skidder does not do any deck work the instant the skidder drops the bundle in front of the loader that will start travel empty time.
4. Hauling slash will constitute the skidder operator picking up a load of slash (limbs and debris), leaving the set to drop them in the woods and returning to the set empty.
5. Wait on loader will be combined with idle time since with the GPS method one is not able to tell the difference when the skidder is waiting on the loader or idling.

<u>Statistical Analysis</u>

Null Hypothesis 1: A GPS unit with external antenna set to collect line data on a 5 second time interval in a rubber-tired grapple skidder is just as accurate as collecting time data manually.

Alternative Hypothesis 1: A GPS unit with external antenna set to collect line data on a 5 second time interval in a rubber-tired grapple skidder is less accurate than collecting time data manually.

Null Hypothesis 2: A GPS unit with external antenna set to collect line data on a 1 second time interval in a rubber-tired grapple skidder is just as accurate as collecting time data manually.

Alternative Hypothesis 2: A GPS unit with external antenna set to collect line data on a 1 second time interval in a rubber-tired grapple skidder is less accurate than collecting time data manually.

Statistical analysis could only be performed on complete data, so there had to be values in every cell in order to make comparisons. Travel empty, grapple time, travel loaded, un-grapple time and total cycle time were the only time elements in which statistical analysis was used to make comparisons. The GPS times were sorted by task and half day. Task refers to the actual task being performed, such as trail work, travel empty, travel loaded etc. There are a total of 6 half days since each day was broken down into data collected in the morning and data collected in the afternoon. For the remainder of the study the half day of 3/24 am is referred to as HD1, 3/24 pm is HD2, 3/25 am is HD3, 3/25 pm is HD4, 8/10 am is HD5 and 8/10 pm is HD6.

P-values were calculated for the difference between the times collected manually and by GPS for travel empty, grapple time, travel loaded, un-grapple time and total cycle time. The p-value is the probability of committing a type 1 error if the actual sample value of the statistic is used as the rejection value. A p-value is the smallest level of significance for which the null hypothesis would be rejected with that sample. For this study p-values of less than or equal to 0.05 would fall into the rejection region and the null hypothesis would be rejected. P-values of greater than 0.05 would prove no difference between the two methods of collecting time data and I would fail to reject the null hypothesis. Type 1 errors occur when a true null hypothesis is rejected.

The Shapiro-Wilks test was conducted on the residuals of the four time elements discussed to test if the differences were normally distributed. The Shapiro-Wilks test produces a p-value that describes how normally distributed the differences between the two methods of time data collection are. P-values of less than0.05 mean the data is not normally distributed while p-values of greater than or equal to0.05 mean the data is normally distributed.

The general linear model was used to test whether there was a significant relationship between the tasks (travel empty, grapple, travel loaded, and un-grapple) and the half days. The general linear model also displayed the most extreme values, the values that were skewing the data left. I used these values to find out if there was a reason why the values were so different from each other by looking at the original dataset and maybe even delete the values if there was evidence that there was some operator error involved in collecting the data. Points that were deleted will be noted in the results. The homogeneity of the residuals was graphically shown using a graph similar to a bar graph which tested the homogeneity of the residuals for each task. As the bar gets more spread out the less homogeneous the residuals are for that task. This test shows which tasks were subject to large outliers and the largest differences between the two methods of time data collection.

The remaining time elements were not performed on every cycle. Therefore, I could not perform statistical analysis on the differences between times. Time elements such as trail work, deck work, idle time, haul slash and looking for logs were compared by looking at how many times these tasks were performed each half day between the two methods of collecting time data. I analyzed the differences between these time elements by determining why one method missed a time element and the other method did not and I also made comparisons of the averages and standard deviations from the amount of time spent performing a certain task.

The statistical analysis for this project was conducted using Statistical Analysis Software (SAS, 2004). The SAS version 9.1 code used is as follows:

```
Data one;
input Tman Tgps Task HD;
Diff = Tman-Tgps
Datalines;
---
proc sort;
by Task HD;
run;
proc freqN;
Tables Task*HD;
run;
Proc univariate;
by task HD;
var diff;
run;
Proc glm;
class task HD;
model diff = task HD Task*HD / outpm=glmout;
random HD task*HD/test;
lsmeans task/stderr pdiff adjust = tukey;
output out=glmout p=pred r=resid stdr=eresid;
run;
proc univariate data=glmout plot normal;
var resid;
run;
proc gplot data=glmout;
plot resid*task;
run;
```

Tman refers to the time collected manually and Tgps refers to the time data collected through GPS analysis. Task refers to a specific time element being performed by the skidder and HD refers to half day.

'Proc freqN' was used to perform two way analysis of categorical data. The 'tables' statement showed a frequency table and is an excellent way to check the data. 'Proc freqN' was used for this research specifically for the frequency tables showing task*HD.

The 'proc univariate' statement in SAS was used for basic hypothesis testing with the crucial element being the p-value or 'Pr>|T|'. 'Proc univariate' tests the distribution of the differences against zero. 'Var diff' means I am testing the difference between Tman and Tgps to determine if the difference between the two methods of collecting time data is significantly different than zero. The 'tukey' adjustment used is a more conservative test of significance.

The general linear model or 'proc GLM' was used to test whether there was a significant relationship between the tasks (travel empty, grapple, travel loaded, and un-grapple) and the half days. The general linear model is a block design that tests the significance of half days and an interaction term (task*HD). The block design was used to get a more reliable estimate of error.

The 'proc univariate data=glmout' statement plots the residuals and tests for normal distribution. The Shapiro-Wilks test is part of this statement and it gives a p-value which tells whether or not the data is distributed normally and I was looking for probabilities greater than 0.05 to prove good normal distribution. The residual values are plotted against a straight line and should be normally distributed around this straight line in a normal probability plot.

The 'proc gplot resid*task' statement creates a bar graph of the residual values of the tasks. This command is another test for homogeneity.

The proc univariate command in SAS was run on total cycle times for all of the half days to determine whether the difference between total cycle times for the two methods of time data collection was significantly different than zero at $\alpha = 0.05$. The output from the proc univariate command will give a p-value, and, based on this p-value, I can conclude whether or not using GPS to collect time data on rubber-tired grapple skidders is an acceptable method of time data collection for productivity studies. The SAS code used for this procedure is as follows:

```
Data one;
input Tman Tgps HD;
Diff = Tman-Tgps;
Datalines;
Proc univariate;
by HD;
var diff;
run;
```

Results

March 24 and 25 Time Study

Slaughter Logging LLC. was conducting a second thin in a loblolly pine (*Pinus taeda*) plantation owned by Sotera, a forestry company out of Mississippi that owns timber lands in Louisiana. Working on the set was a Tigercat 230B loader, a Cat 525B skidder, a Tigercat 750 feller-buncher, and a Chambers Delimbinator flail delimber. Three contract log trucks transported the timber to the Port Hudson mill. The loader was dividing up the piles into 3 categories: chip-and-saw, pine pulp and hardwood pulp. Mike Hayden was operating the Cat 525B skidder and remained the skidder operator throughout the study.

A Trimble GeoXT GPS receiver was set up in the cab of the skidder with the external antenna attached to the roof of the skidder. The GPS receiver was set to record line data on a five second time interval with the WAAS enabled. Dr. de Hoop stayed on the deck to collect skidder time data manually while I went into the woods to manually record the skidder as it worked away from the deck. UTC times were written down when the skidder finished performing a certain task, which also marked the start of the next time element. For example: when the skidder began positioning for the grapple the time was written down which marked the end of travel empty and the start of grapple time. After the crew stopped for lunch we stopped the GPS from recording and started a new file to collect all the data for the afternoon. After lunch was finished Dr. deHoop stayed on the deck to continue recording the skidder operations and I returned to the woods to continue recording the skidder as it worked away from the deck. After the workday was over the GPS receiver was removed from the machines and brought back to LSU and the line file created by the skidder was downloaded onto a computer using GPS Pathfinder Office^{TM} 3.0.

The data that was collected manually was analyzed and the amount of time it took the skidder to perform each task was calculated. To do this I subtracted the starting time from the finishing time of that specific element to get the amount of time spent performing the task. All of the elemental times for that cycle were written down in a single row in order to calculate total cycle time. The times were recorded in separate columns for travel empty, grapple time, travel loaded, un-grapple time, idle time/wait on loader, deck work, hauling slash, trail work and looking for logs.

After analyzing all the times from the manual data collection I analyzed the line file created by the GPS receiver. I scrolled through each point that was created and noted when I perceived the skidder to be starting and ending a new time element. Then the time it took to perform the task was calculated and the value recorded on a Microsoft Excel spreadsheet. Figures 2 and 3 show the extracted line file from the GPS that was taken the morning and afternoon of March 24, 2005, respectively. The log deck is easily discernable from the line file created by the GPS unit. The points where the skidder operator pulled off the trail to back up to the bundles are also easily discernable from the triangle shaped lines protruding from the main trail.

The skid trails and logging deck are clearly discernable from the line file produced by the GPS receiver. The one odd looking skid trail that extends west and south is actually where the skidder had to pull the feller-buncher out of the mud. When reviewing the line file it was easy to recognize that the skidder was not picking up a bundle but doing something else. This type of event is commonly missed during the manual time data collection process, but with GPS I was able to get exact times for the trip to and from the feller-buncher.

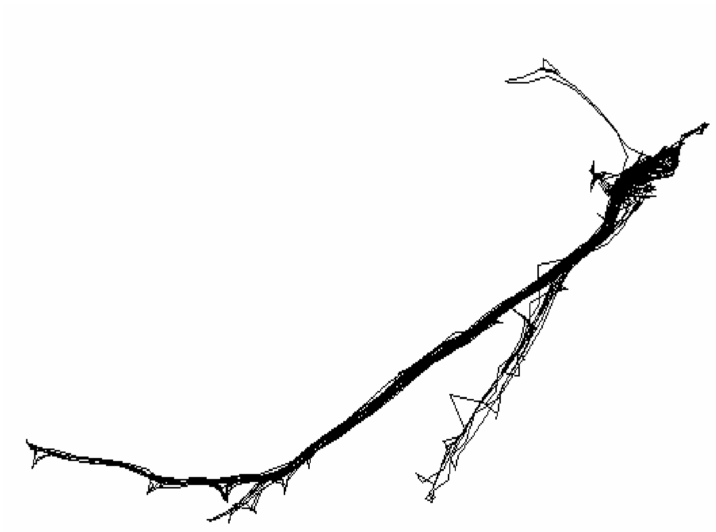

Figure 2. GPS line file of skidder activities on the morning of March 24, 2005.

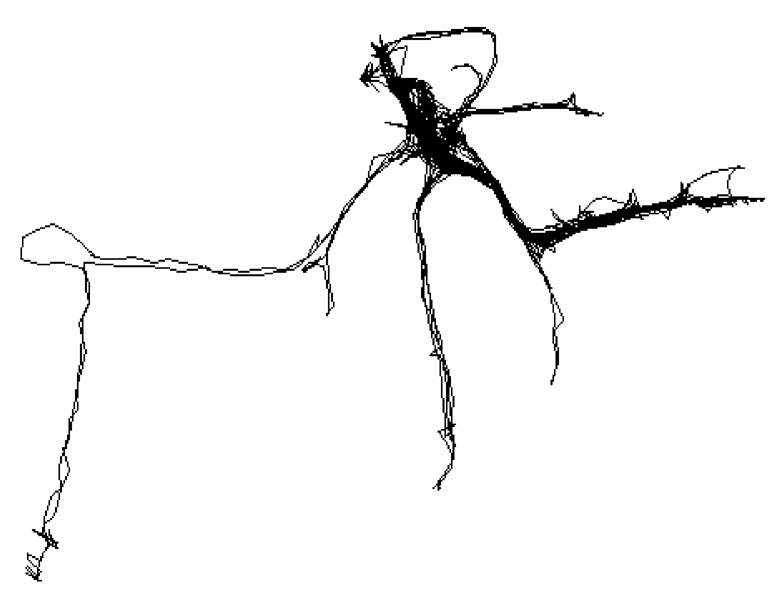

Figure 3. GPS line file of skidder activities on the afternoon of March 24, 2005.

Figure 4 below shows the location and precision of each of the points as well as the time the point was taken. From these files I would scroll through the points, essentially following the skidder as it worked, recording the amount of time it took to perform each of the defined events set forth in the methods. Dates and times of each point as well as the horizontal precision of each point are given in the summary page, which makes timing the defined events easy and quick. The 68% Precisions page shows the North, East, and Altitude precision of the specific point, as well as the ellipse major and minor axis and the ellipse orientation. The DOPs' page shows horizontal dilution of precision (HDOP), position dilution of precision (PDOP), vertical dilution of precision (VDOP), time dilution of precision (TDOP) and shows the satellite numbers that the receiver is getting signals from. The 68% Precisions page also shows the accuracy of the points collected, with high PDOP values being less accurate than points with low PDOP values.

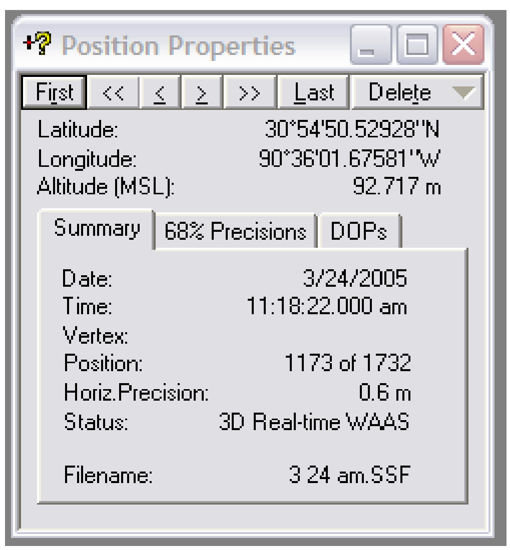

Figure 4. Position properties dialogue box shows the position, location and time data for each point is listed in a chart for quick reference.

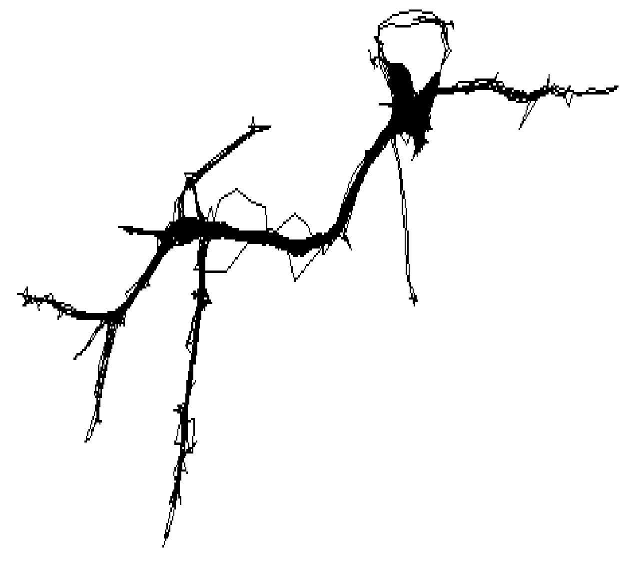

Figure 5. GPS line file of skidder activities on March 25, 2005.

<u>August 10 Time Study</u>

The Slaughter Logging crew was conducting a second thin in a loblolly pine (*Pinus taeda*) plantation on non-industrial private forest land south of Jackson, Louisiana which belonged to Sonny Goodsides. Again, Mike Hayden was operating the Cat 525B rubber-tired grapple skidder.

The GPS antenna was connected to the GPS unit and attached to the roof of the skidder. The GPS receiver was setup in the skidder to collect line data at an interval of 1 point per five seconds. The WAAS correction was turned on, max PDOP was set to 80.

Dr. de Hoop and I used the UTC time on the GPS in order to manually record the skidder times. I proceeded to follow the skidder out to the timber to begin recording skidder times as the skidder picked up the bundles to bring to the deck. Dr. de Hoop remained on the deck to record the skidder as it dropped off the bundles at the deck and returned to the woods.

The line file created by the skidder on the morning of August 10 is shown in Figure 6. The log deck and skid trails are clearly shown from the map that was created that morning. Distance to the farthest bundle picked up by the skidder was .22 mi as measured along the path using Pathfinder Office™ 3.0.

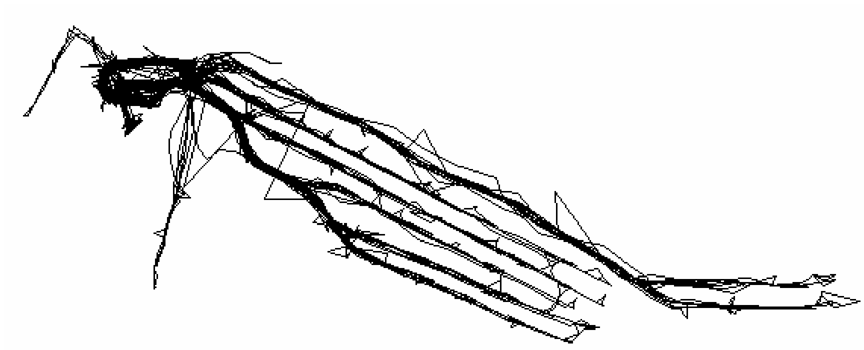

Figure 6. The GPS line file created by the skidder the morning of August 10, 2005.

After lunch I set the GPS unit was set to record line data on a 1 point per second time interval with the WAAS enabled and the max PDOP set at 80. I returned to the woods again with another GPS receiver to manually record skidder times using the UTC time. Dr. de Hoop remained on the log deck to manually record skidder times also using the UTC time on a GPS unit. The line file created by the GPS receiver is shown in Figure 7.

Figure 7 clearly shows the log deck and all of the trails used by the skidder. Using Pathfinder OfficeTM 3.0 I was able to note that the 1st skid trail on the map was 0.081 mi from the deck and the farthest grapple made that afternoon was 0.176 mi.

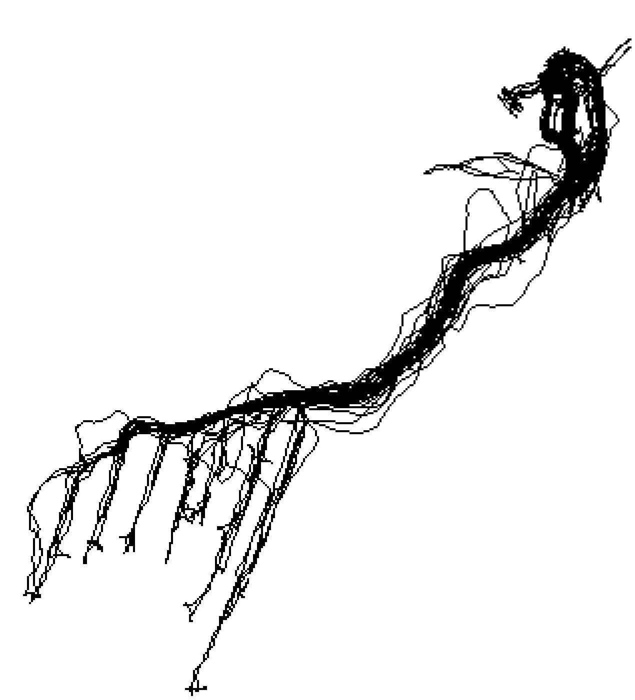

Figure 7. The GPS line file created by the skidder the afternoon of August 10, 2005. The GPS receiver was set to record a line on a 1 second time interval.

Once all the data was collected from the two days I started to filter through the data that was collected manually to extract the elemental times I wanted to compare. I divided each day into half days (am and pm) in order to make the comparisons easier and it would limit the amount of data I had to compare. Once I finished analyzing the 6 half days (March 24 am and pm, March 25 am and pm, August 10 am and pm) of data that was collected manually using the traditional time study techniques I would start analyzing the data that was collected with the GPS receiver. Once all the half days were finished I began making comparisons between the number of observed events and the differences in times.

Statistical analysis of the results was only conducted on the time elements that we had complete data for, so if there was a task that I did not record a time for on a certain cycle we could not conduct statistical analysis on the differences between the two data collection methods for that half day. For example, there were only 3 cycles where trail work was being performed on HD3 using the manual data collection method and 12 cycles where trail work was performed gathered from the GPS record, therefore no statistical analysis could be performed on the difference between the times recorded using the two methods.

HD1, HD2, HD3, HD4 and HD5 all had line files created on a 5 second time interval. HD6 had a line file created on a 1 second time interval.

Time Study Results

Total Points

There was a total of 1,732 points collected by the GPS receiver set to record line data on a 5 second time interval on HD1 with 19 points that were deleted due to high PDOP values. HD2 had a total of 2,807 total points with only 11 points deleted. There were 4,123 total points on HD3 with 57 points being deleted due to high PDOP values. There were 3,008 total points on HD4 and 22 points were deleted form position errors. There were 3,852 total points recorded by the by the GPS receiver on HD5 with only 4 of the points being deleted due to position errors. On average less than 1% of the points were deleted on the 5 half days of data collection under canopied conditions with a GPS receiver set to record line data on a 5 second time interval and an external antenna. The small average of deleted points can be attributed largely to the external antenna which was attached to the GPS receiver in the cab of the skidder. The antenna was located about 3 meters above ground level giving the GPS unit obviously improved reception over identical hand-held units.

There was a total of 13,211 total points recorded by the by the GPS receiver set to collect line data on a 1 second time interval with 23 points that were deleted due to position errors. This represents a 0.17% error rate in collecting points under canopied conditions with an external antenna connected to the GPS unit. Again this low error rate was attributed to the height of the GPS antenna from the ground.

Trail Work

Trail work is usually performed on the skid trails when there are deep ruts from the skidder or where there are large mounds of dirt and debris that slow the skidder down as it hauls logs from the woods to the deck. The Cat 550 skidder was outfitted with a blade located on the front of the machine that could push dirt and debris out of the way and smooth the skid trail to make it smoother and faster. The skidder would also use this blade to push piles of dropped slash into the holes along the skid trail. Trail work generally takes place along the skid trail between the set and the bundles and usually out of the sight of the researchers. I was able to identify when the skidder was performing trail work using GPS since the skidder would have multiple GPS points in the same location on the skid trail between the deck and the next bundle. The GPS points would move back and forth at a certain location on the skid trail when the skidder was conducting trail work. When the skidder finished the trail work it would continue on with the travel empty task. Often, when the skidder would perform trail work, it would be conducted at the same point on the skid trail on nearly all cycles.

On HD1 and HD2 I did not observe the skidder performing any trail work using the manual time data collection technique. Using GPS I noted the skidder performing trail work on 2 cycles during HD1 and 2 cycles during HD2. During HD1 and HD2 the skidder was making up to 0.25 mile hauls and I could not see the entire length of the skid trail through the timber so I was unable to see when the skidder stopped to perform trail work.

Table 1. A List of the total number of observations for trail work observed each half day of the study by each method of time data collection. Includes the total number of seconds for all observations along with averages and standard deviations for the amount of time spent performing this time element.

Trail Work		Total Observations	Total Seconds	Average Seconds	Standard Deviation
HD1	Manual	0	0	0.0	0.0
	GPS	2	65	32.5	31.8
HD2	Manual	0	0	0.0	0.0
	GPS	2	110	55.0	56.5
HD3	Manual	3	123	41.0	26.9
	GPS	12	765	63.8	26.2
HD4	Manual	1	107	107.0	0.0
	GPS	1	55	55.0	0.0
HD5	Manual	27	489	18.1	17.3
	GPS	23	535	23.3	33.0
HD6	Manual	12	144	12.0	3.8
	GPS	14	143	10.2	5.5

On HD3 I noted the skidder performing trail work on cycles 2, 3, and 4 during the manual data collection. Using GPS, I noted the skidder performed trail work on 12 cycles during HD3 and this included the trail work on cycles 2, 3, and 4 as in the manual data collection.

On HD4 I observed the skidder performing trail work on 1 cycle using the manual time data collection technique and I also noted trail work being performed on 1 cycle during HD4 using GPS. With the manual data collection technique the skidder was observed performing trail work after the last cycle (cycle 17) was complete and the skidder was cleaning the deck. Using GPS the skidder was observed performing trail work on cycle 11 and the work that was done after the last cycle I classified as deck work.

On HD5 I observed the skidder performing trail work on 27 cycles during the manual time data collection. There were 23 observations where I noted trail work being done when analyzing the GPS line file. The reason there were so many observations of trail work with the manual time data collection was that the skidder was working right up next to the deck and I could see the entire length of the skid trails. The skidder would very often drop the logging slash on the skid trail to smooth out rough spots.

On HD6 the GPS receiver was set to record a line file on a 1 second time interval. On HD6 I observed the skidder performing trail work on 12 cycles during the manual time data collection. There were 14 cycles where I observed trail work being performed from analyzing the GPS line file. The cycles where trail work was observed were all the same except with GPS there were trail work observations made on cycles 11 and 18.

Travel Empty, Grapple Time, Travel Loaded, Un-grapple Time

The 4 major elements of a time study on a skidder include travel empty, grapple time, travel loaded, and un-grapple time. I was able to run statistical analysis on the data collected for each of these time elements since there was data for every cycle. Travel empty, grapple time, travel loaded, un-grapple time, were analyzed and their p-values were used to determine if the differences between the manual time data collection method and the GPS method were significantly different from zero at $\alpha = 0.05$. The results of univariate procedure are shown in Table 2. P-values less than 0.05 means the difference between the recorded times from the two methods of data collection is significantly different than zero. If the p-values are greater than 0.05 than the difference between the two methods of time data collection are not significantly different than zero.

Table 2. P-values for the differences between tasks and half days for travel empty, grapple time, travel loaded and un-grapple time. The differences between the manual time data collection and GPS times were analyzed and p-values were used to determine if the difference between the two methods was significantly different than zero at $\alpha = 0.05$.

Univariate Procedure

	P-Values					
Element	**HD1**	**HD2**	**HD3**	**HD4**	**HD5**	**HD6**
Travel Empty	**0.3779**	**0.7955**	0.0125	**0.1690**	**0.3186**	**0.1972**
Grapple	**0.2239**	**0.8085**	**0.0738**	**0.8827**	**0.7354**	**0.2371**
Travel Loaded	0.0019	0.0238	**0.4890**	**0.1590**	0.0001	0.0046
Un-grapple	0.0330	0.0003	0.0043	0.0023	**0.7568**	0.0027

Travel empty was found to have significant differences between the manual and GPS methods of collecting time data on only one half day (HD3) of the study.

Grapple time showed there were no significant differences between the two methods of collecting time data for all half days of the study.

Travel loaded showed there were only two half days (HD3 and HD4) where the differences between the manual and GPS times were not significantly different and there were four half days (HD1, HD2, HD5 and HD6) where there was found significant differences between the manual and GPS methods of collecting time data.

Un-grapple time showed only one half day (HD5) where the differences between the manual and GPS times were not significant. All other half days showed significant differences between the two methods of collecting time data.

On HD1 and HD2 travel empty and grapple times were not significantly different than zero at $\alpha = 0.05$. Therefore I failed to reject my null hypothesis and concluded that the GPS times were equal to the manual data collection times. Travel loaded and un-grapple times were significantly different at $\alpha = 0.05$ so I rejected the null hypothesis and concluded that for travel loaded and un-grapple times the difference between the manual and GPS times are significantly different than zero.

On HD3 grapple times and travel loaded times were not significantly different from zero at $\alpha = 0.05$. Therefore I failed to reject my null hypothesis and concluded that the difference between the GPS times and the manual data collection times were not significantly different than zero. Un-grapple and travel empty times were significantly different at $\alpha = 0.05$, so I rejected the null hypothesis and concluded that for un-grapple times and travel loaded the manual and GPS times are significantly different than zero.

On HD4 elemental times for travel empty, grapple time and travel loaded were not significantly different from zero at $\alpha = 0.05$. Therefore I failed to reject my null hypothesis and concluded that the difference between the GPS times and the manual data collection times were not significantly different than zero. Un-grapple times were significantly different at $\alpha = 0.05$, so I rejected the null hypothesis and concluded that for un-grapple times the difference between the manual data collection method and GPS times are significantly different than zero.

On HD5 travel empty, grapple time, and un-grapple time were not significantly different than zero between the two methods of time data collection. Only travel loaded was showed a significant difference from zero between the two methods of time data collection. Using GPS, travel loaded times were overestimated on nearly every cycle by an average of 13.1 seconds.

On HD6 travel empty and grapple times showed no significant differences between the two methods of time data collection at $\alpha = 0.05$. Un-grapple time and travel loaded showed significant differences between the two methods of time data collection at $\alpha = 0.05$. Travel loaded was overestimated in every cycle using GPS by an average of 10.1 seconds while un-grapple time was underestimated using GPS by an average of 11.7 seconds. When analyzing the GPS data it seems I would stop travel loaded too late and in doing so grapple time would start too late as well which would account for the significant differences between the two methods of time data collection.

Idle Time/Wait on Loader

Idle time was included as a time element in this study because this is one of the necessary time elements in a productivity study in order to get productive machine hours. Idle time was classified as any time spent with the machine not moving and the engine idling. The skidder operator would sometimes have to get out the skidder and move some trucks or use the bulldozer to get the log truck unstuck and would leave the skidder idling; this would be counted as idle time. Very often the skidder operator would have to wait on the loader to finish clearing the logs from where the skidder needed to drop his grapple load. This time was classified as wait on loader time, but was grouped with idle time for the purposes of this study.

On HD1 there was 1 cycle where idle time was recorded with the manual time data collection technique. There were 3 cycles where the skidder idled on the log deck which was observed using GPS. I examined the data and found that 2 unrecorded times

Table 3. Total observations, sum of seconds and measures of dispersion for idle time conducted on each half day of the study.

Idle Time		Total Observations	Total Seconds	Average Seconds	Standard Deviation
HD1	Manual	1	960	960.0	0.0
	GPS	3	1260	416.7	457.9
HD2	Manual	4	2336	548.0	465.5
	GPS	6	4208	767.7	755.8
HD3	Manual	5	1023	204.6	118.1
	GPS	4	1155	288.7	198.8
HD4	Manual	0	0	0.0	0.0
	GPS	0	0	0.0	0.0
HD5	Manual	16	2725	170.3	129.7
	GPS	17	2060	121.2	102.7
HD6	Manual	11	1911	173.7	98.3
	GPS	12	2268	189.0	93.2

were included as part of the un-grapple time during the manual data collection. The reason given for the recorded idle time was waiting on a truck. The skidder was sitting idle during this time however with GPS you are not able to see reasons why the skidder is idling. The idle time collected with GPS showed the skidder idling for 960 seconds while the manual data collection had the skidder waiting on the truck for 940 seconds.

On HD2 the skidder was observed idling on 4 cycles during the manual data collection. There were 6 cycles where the skidder was observed idling using GPS. Once again differences in idle times between the two methods can be attributed to more time getting added to un-grapple time with the manual data collection method as well as some of the un-grapple time getting added to some other time elements such as cleaning set or miscellaneous. The difference between these two methods is once again with GPS you are unable to see what the skidder is doing on these idle times. There were 2 cycles where GPS recorded idle time but the manual data collection listed the times as miscellaneous because in one instance the skidder operator had to get off the skidder and direct traffic and for the other instance there was no reason written down for the miscellaneous time.

On HD3 the skidder was observed idling 5 times on 4 cycles using the manual time data collection technique. On 1 cycle the skidder idled in 2 separate locations so this was treated as 2 separate idle times. Using GPS I noted the skidder idling 4 times on 3 cycles. The difference in the number of idle times is because one of the idle times was very short (14 seconds manually collected) and was counted as part of the cleaning set time element during the GPS data collection.

On HD4 there were no cycles where the skidder was observed idling using either method of time data collection.

On HD5 there were 16 cycles where idle time was recorded using the manual time data collection technique. Using GPS I observed the skidder running idle on 17 cycles. Between the two methods of time data collection there were 9 cycles where only one of the time data collection methods picked up idle time. The manual time data collection technique did not have any observed idle time recorded on cycles 19, 23, 28, 39 and 40 and the GPS method had idle times recorded on these cycles. Conversely, the GPS method did not have any observed idle times recorded on cycles 3, 7, 26 and 27 and the manual data collection method did.

On HD6 there were 11 cycles where idle time was recorded with the manual data collection method. There were 12 cycles where idle time was recorded using GPS. All idle times were observed on the same cycles except the GPS method had recorded an idle time on cycle 9 and the manual data collection method did not.

Haul Slash

One of the elements of a skid cycle I wanted to examine was the haul slash time and whether or not I could discern when the skidder was hauling slash. The skidder operator would often pick up a load of slash either from near the delimber or from under the delimber on the loader and move it off the deck one direction then return to the deck empty and then continued with his normal cycles. For the purposes of this study we attempted to time the haul slash element of the cycle.

Table 4. Total observations, sum of seconds and measures of dispersion for haul slash conducted on each half day of the study.

Haul Slash		Total Observations	Total Seconds	Average Seconds	Standard Deviation
HD1	Manual	1	125	125.0	0.0
	GPS	0	0	0.0	0.0
HD2	Manual	4	682	170.5	75.2
	GPS	3	418	138.0	31.0
HD3	Manual	1	192	192.0	0.0
	GPS	1	50	50.0	0.0
HD4	Manual	1	126	126.0	0.0
	GPS	1	120	120.0	0.0
HD5	Manual	4	870	217.5	148.8
	GPS	3	640	213.3	77.5
HD6	Manual	1	290	290.0	0.0
	GPS	2	216	108.0	59.4

On HD1 there was 1 cycle where the skidder was observed hauling slash with the manual data collection method. I did not note any haul slash times on HD1 using GPS. Since the boundaries of the deck were not defined at the start of the study it was difficult to see when the skidder left the deck to haul slash. The one instance of hauling slash on HD1 was recorded as deck work when I analyzed the GPS data.

On HD2 the skidder was observed hauling slash 4 times using the manual data collection method. The skidder was observed hauling slash 3 times using GPS on HD2.

One of the instances of hauling slash during HD2 was recorded as deck work when I analyzed the GPS data.

On HD3 the skidder hauled slash 1 time which was noted with both the manual data collection method and GPS. The manual data collection had the skidder hauling slash for 192 seconds and the GPS had the skidder hauling slash for 50 seconds. The reason there is such a large difference is because with GPS I recorded the skidder performing deck work on that cycle and with the manual data collection there was no recorded deck work so I can speculate that the deck work the skidder performed was included in the haul slash during the manual data collection.

On HD4 the skidder was observed hauling slash 1 time which was noted by both methods of time data collection. The manual data collection recorded 126 seconds of haul slash time and with GPS I calculated 120 seconds of haul slash time. The two methods of data collection recorded nearly the same amount of time spent hauling slash by the skidder.

On HD5 there were 4 cycles where the skidder was observed hauling slash with the manual data collection method. Using GPS I observed the skidder hauling slash on 3 cycles during HD5. During the manual data collection haul slash was recorded on cycle 5, 20, 27 and 42. From the GPS line file I observed the skidder hauling slash on cycle 5, 15, and 42. The 2 short haul slash times on cycle 20 and 27 with the manual data collection were recorded as deck time when I analyzed the GPS line file. The haul slash on cycle 15 that was recorded with the GPS was missed during the manual data collection.

On HD6 the skidder was observed hauling slash on 1 cycle using the manual data collection method. I observed the skidder hauling slash on 2 cycles using GPS. Haul slash was recorded on cycle 20 for both methods of time data collection and I observed the skidder haul slash on cycle 13 using GPS.

Deck Time

The deck time element of this time study included all the time spent on the deck after un-grappling. The skidder operator would often move slash around and push slash into piles along the outside of the deck, or reposition the delimbing gate before continuing on the next cycle. All of the time spent working on the deck was counted towards deck time, until the skidder moved off the deck. In almost every cycle the skidder would pick up a load of slash from under the Chambers Delimbinator, or from the delimber attached to the loader, and drop it in the woods or on the skid trail on the way to the next bundle. Also, deck work was easy to collect with the GPS because you can scroll back and forth between the points to get a more accurate assessment of the time spent cleaning the set or moving slash around.

Table 5. Total observations, sum of seconds and measures of dispersion for deck time conducted on each half day of the study.

Deck Time		Total Observations	Total Seconds	Average Seconds	Standard Deviation
HD1	Manual	2	394	197.0	24.1
	GPS	9	1223	135.9	116.5
HD2	Manual	5	1828	365.6	316.1
	GPS	14	2975	197.1	187.4
HD3	Manual	1	272	272.0	0.0
	GPS	15	1871	124.7	109.1
HD4	Manual	1	382	382.0	0.0
	GPS	11	2350	181.0	266.2
HD5	Manual	42	3580	85.2	95.0
	GPS	28	3925	135.3	118.5
HD6	Manual	20	1960	98.0	89.8
	GPS	16	1914	119.6	90.3

On HD1 there were 2 cycles where deck time was recorded using the manual data collection method and 9 cycles where deck time was recorded using GPS. The large difference in the numbers of recorded deck times for this day is that during the manual data collection deck work was most often included in un-grapple time, or missed all together.

On HD2 there were 5 cycles where deck time was recorded with the manual data collection method and 14 cycles where deck time was recorded using GPS. Again most of the cycles where deck time was missed with the manual data collection method it was included at least in part in the un-grapple time.

On HD3 there was only 1 cycle where deck time was recorded with the manual data collection method and with GPS there were 15 cycles where deck time was recorded. Most of the deck times that were missed with the manual data collection were included in the un-grapple time. The 1 cycle where deck time was performed by the skidder was 272 seconds collected manually and GPS calculated 290 seconds of deck work on the same cycle.

On HD4 there was 1 cycle where deck time was recorded with the manual data collection method and 11 instances of deck time being performed on 10 cycles with the GPS method. Much of the deck time on this half day was included with un-grapple time using the manual data collection method. The one cycle where deck work was recorded using the manual data collection method calculated 382 seconds of deck work being performed while the GPS method calculated 540 seconds of deck work being performed on the same cycle.

On HD5 deck time was recorded on all 42 cycles with the manual data collection method. Using GPS I observed deck work being performed on 28 of the 42 cycles. The reason there are so many more instances of deck work during the manual time data collection is that is was better defined after the March 24 and 25 studies.

On HD6 deck time was recorded on 18 of 20 cycles using the manual data collection method. Using GPS I observed the skidder performing deck work on 16 of 20 cycles. There were 20 cycles performed by the skidder on HD6 but there was 1 record of deck time being performed on both methods of time data collection before the skidder started the first cycle. The manual data collection method had recorded deck time on every cycle except cycle 19. Using GPS there were no records of deck time on cycles 3, 4, 6, 11 and 15.

Looking For Logs Unsuccessfully

Looking for logs was a part of the study that I included after the first day when I noticed the skidder going down skid trails where there were no bundles. This time element is difficult to isolate with the manual data collection method of collecting time data since it is often missed because you cannot see the skidder when this happens. The looking for logs element is timed from when the skidder operator passes up the next bundle and goes down a skid trail that had previously had all the bundles removed and the time is stopped when the skidder operator accesses the main skid trail or the skid trail with the next bundle.

On HD1 there were no recorded instances of looking for logs unsuccessfully using either method of time data collection.

Table 6. Total observations, sum of seconds and measures of dispersion for looking for logs conducted on each half day of the study.

Looking for Logs		Total Observations	Total Seconds	Average Seconds	Standard Deviation
HD1	Manual	0	0	0.0	0.0
	GPS	0	0	0.0	0.0
HD2	Manual	0	0	0.0	0.0
	GPS	3	1418	473.0	628.7
HD3	Manual	0	0	0.0	0.0
	GPS	0	0	0.0	0.0
HD4	Manual	0	0	0.0	0.0
	GPS	1	110	110.0	0.0
HD5	Manual	1	85	85.0	0.0
	GPS	2	150	75.0	14.1
HD6	Manual	2	92	46.0	22.6
	GPS	2	124	62.0	21.2

On HD2 there were no instances of looking for logs unsuccessfully recorded manually and there were 3 instances of the skidder looking for logs that was recorded using the GPS.

On HD3 there was no record of the skidder looking for logs unsuccessfully using either method of data collection.

On HD4 there was no record of the skidder looking for logs unsuccessfully using the manual data collection method, and 1 cycle where the skidder was observed looking for logs unsuccessfully which was collected with GPS. The skidder spent 110 seconds looking for logs unsuccessfully on HD4.

On HD5 the skidder was observed looking for logs unsuccessfully only once on cycle 31 with the manual data collection method. The skidder was observed looking for logs unsuccessfully on cycles 4 and 31 using GPS. For both methods of time data collection the skidder spent 85 seconds looking for logs unsuccessfully on cycle 31.

On HD6 the skidder was observed looking for logs unsuccessfully on 2 cycles using the manual data collection method. Using GPS I observed the skidder looking for logs unsuccessfully on 2 cycles. The 2 cycles where the skidder was observed looking for logs unsuccessfully were both on cycles 4 and 7 on both methods of time data collection.

Miscellaneous

Miscellaneous time events are those time events that don't fall into any time category listed in the methods. Miscellaneous times are for unexpected events that cannot be classified normally and fall outside the normal cycle pattern for the skidder.

Table 7. Total observations, sum of seconds and measures of dispersion for miscellaneous times conducted on each half day of the study.

Miscellaneous Time		Total Observations	Total Seconds	Average Seconds	Standard Deviation
HD1	Manual	1	272	272.0	0.0
	GPS	1	195	195.0	0.0
HD2	Manual	3	2384	794.0	43.9
	GPS	1	775	775.0	0.0
HD3	Manual	2	1035	517.5	137.9
	GPS	0	0	0	0
HD4	Manual	0	0	0	0
	GPS	0	0	0	0
HD5	Manual	0	0	0	0
	GPS	0	0	0	0
HD6	Manual	0	0	0	0
	GPS	0	0	0	0

On HD1 there was one miscellaneous time event observed where the skidder made a trip to the back of the set to pull the feller-buncher out of the mud. This miscellaneous time event was recorded using both the manual time data collection method and the GPS method.

On HD2 there were 3 cycles where miscellaneous time events were recorded with the manual data collection method. There was 1 cycle where a miscellaneous time event was recorded using GPS on HD2. The manual data collection observed 1 instance where the skidder picked up a wooden logging mat from the old deck, one instance where the skidder operator had to get out of the skidder to direct traffic and the third miscellaneous time event had no comments. Using GPS I noted the amount of time it took for the skidder to pick up the logging mat and for the cycle when the skidder operator was directing traffic I recorded that time as idle time.

On HD3 there were 2 miscellaneous time events recorded with the manual data collection method. There were no miscellaneous time events recorded using GPS during HD3. The first miscellaneous time event was when the skidder operator got out of the skidder to talk to the landowners; using GPS I recorded that event as being idle time. The second miscellaneous time event was when the skidder operator got out of the skidder to move some vehicles that were blocking the skid trail.

On HD4 there were no miscellaneous time events observed using either method of time data collection.

On HD5 there were no miscellaneous time events observed using either method of time data collection.

On HD6 there were no miscellaneous time events observed using either method of time data collection.

Total Cycles

The total cycles element compares the total number of skid cycles observed using each method of time data collection.

Table 8. The total number of skid cycles observed each half day of the study using each method of time data collection. The numbers of cycles observed are shown in conjunction with the actual number of cycles performed by the skidder.

Total Cycles		Cycles Observed	Actual Cycles
HD1	Manual	15	19
	GPS	19	
HD2	Manual	16	17
	GPS	17	
HD3	Manual	26	26
	GPS	26	
HD4	Manual	16	16
	GPS	16	
HD5	Manual	42	42
	GPS	42	
HD6	Manual	20	20
	GPS	20	

On HD1 I recorded 15 skidder cycles with the manual data collection techniques and 19 cycles using GPS. The actual number of skid cycles performed was 19. The difference between the manual data collection and GPS was because the skidder made 3 drags before we could get to the back of the set where he was working. Also, while the skidder was working he made a short drag which missed with the manual data collection because it was not on the same skid trail where he had been previously pulling bundles.

On HD2 I recorded 16 skid cycles using the manual data collection technique and 17 skid cycles using GPS. The number of skid cycles actually performed was 17. The reason why I only collected 16 skid cycles with the manual data collection is because the skidder made a short drag that was missed with the manual data collection. I new it was a missed drag because during the manual data collection I had seen the skidder pulling a bundle out of the woods near the deck and I made a note of this. During the GPS time data collection I observed the skidder travel empty, grapple and travel loaded during the same cycle.

On HD3 I recorded a total of 26 skid cycles using the manual time data collection technique and 26 skid cycles using GPS. I was able to correctly identify all skid cycles on HD3 using GPS.

On HD4 I recorded a total of 16 skid cycles manually and 16 skid cycles using GPS. Once again I was able to correctly identify all skid cycles during HD4.

On HD5 I recorded a total of 42 skid cycles with the manual time data collection technique and 42 skid cycles using GPS. All skid cycles were correctly identified by both methods of time data collection. Using the manual time data collection technique there were 4 partial cycles where travel empty and grapple times were missed due to the skidder changing direction unexpectedly and picking up a different drag. The travel loaded and un-grapple times on the partial cycles were collected by the observer on the log deck.

On HD6 I recorded a total of 20 skid using the manual time data collection technique and 20 skid cycles using GPS. All skid cycles were correctly identified by both methods of time data collection. Using the manual time data collection technique there were 2 partial cycles where travel empty and grapple times were missed due to the skidder changing direction unexpectedly, but with the manual data collection the travel loaded and un-grapple times were collected by the observer on the log deck on these two cycles.

Total Cycle Times

The two methods of time data collection were tested to determine if the differences between the times collected were significantly different than zero at $\alpha = 0.05$. The results, listed in Table 9, show that the total cycle times are not significantly different than zero at α = 0.05 between the manual time data collection and GPS time data collection.

Table 9. The P-values testing the differences between the total cycle times for each method of time data collection.

Univariate Procedure	
Half Day	**P-Values**
HD1	0.8303
HD2	0.9108
HD3	0.4979
HD4	0.3506
HD5	0.1111
HD6	0.0880

The p-values for total cycle times show that the manual time data collection technique and the GPS method of time data collection are not significantly different than zero at α = 0.05. The difference between values from total cycle times collected using the manual time data collection technique and the GPS method which was set on a 5 second time interval is not significantly different than zero at α = 0.05(HD 1-5). The difference between values from total cycle times collected using the manual time data collection techniques and the GPS method which was set on a 1 second time interval is not significantly different than zero at α = 0.05 (HD6). The p-value for HD6, which was the line data collected on a 1 second time interval, is not as strong as the p-values from the other half days. This could mean that with the increased number of GPS points the accuracy of time data collection decreases, although it is still within acceptable limits.

General Linear Model

The results from the general linear model showed that half days were not significant for half days 1 – 4 or for half days 5 and 6 with p-values of 0.5550 and 0.9279 respectively. Since there is no half day effect on each of the 2 study periods I combined all the data and analyzed the data using the general linear model. The p-value for the half day effect was 0.2213 which is not significant at $\alpha = 0.05$. With no significant half day effect there is no half day that is any different than any other half day and I can forgo block design and use the lsmeans for error estimation. Since there is no half day effect I combined the data for all half 6 half days and conducted the tests again. The results from the general linear model test are shown in Table 10.

The least squared means of the differences (Table 10) tell me that for travel empty the manual data collection technique was on average 5.72 seconds greater than the GPS method for time data collection. Grapple time was on average 3.62 seconds greater using the manual data collection technique when compared to GPS. Travel loaded was an average of 11.69 seconds greater using GPS when compared to the manual data collection technique. Un-grapple time, which from the p-values showed the largest difference between the two methods of data collection, was on average 43.79 seconds greater using the manual data collection technique when compared to GPS.

The Shapiro-Wilks test tests the homogeneity of the distribution of the residual values of the manual and GPS methods for collecting time data by assigning a p-value to the results. The results from the Shapiro-Wilks test had a p-value of $<.0001$ at $\alpha = 0.05$. The p-value shows that the differences between the manual time data collection method

Table 10. Results from the least squared means statement showing average differences in seconds between the two methods of time data collection. A positive number means the manual times were greater than GPS times and a negative number means GPS times were greater than the manual times.

Task	Diff LSMean
Travel Empty	5.72
Grapple Time	3.62
Travel Loaded	-11.69
Un-Grapple Time	43.79

and the GPS method are not homogeneous. The kurtosis of the residuals is the reason the Shapiro-Wilks test showed a significant p-value. The majority of the residual values were located around zero, which caused the normal probability curve to be very high in the center (Figure 9). The distribution of the residual values was not the normal bell shaped distribution as one would expect from normally distributed data.

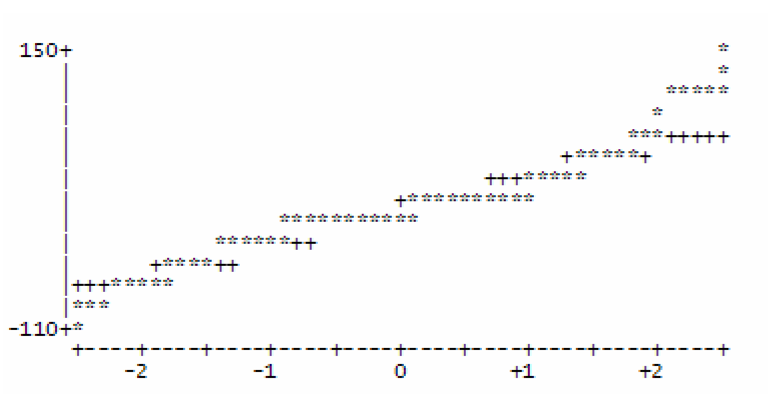

Figure 8. The normal probability plot of the residuals of travel empty, grapple time, travel loaded, and un-grapple time.

The normal probability plot, which should be on a straight line, looks pretty normal but with a slight curve upwards at the end, which is caused by high residual values. The normal probability plot looks normal because all the residual values are centrally located around zero, but with some large outliers. The kurtosis of the normal probability curve (Figure 9) and the large outliers is the reason why the Shapiro-Wilks test was significant.

There were eight large outliers that I examined in the original dataset to see if the values could be deleted to improve the normal distribution of the residuals. Of the eight values examined two were deleted because of observer errors. The first point was on HD1, task 4, cycle 4, Tman = 410, Tgps = 30. After checking the handwritten times I deleted the point because there was a question mark next to the recorded time, which tells me that the time written was a guess and not the actual time the skidder finished un-grappling. The second point was on HD1, task 4, cycle 12, Tman = 447, Tgps = 50 after checking the handwritten times I deleted the point because there was written in the comments section that the skidder did slash maintenance and fixed the delimbing gate which was combined in the un-grapple time. With GPS I recorded 395 seconds of deck work on cycle 12 on HD1 and there was no recorded deck time on that cycle for the manual data collection.

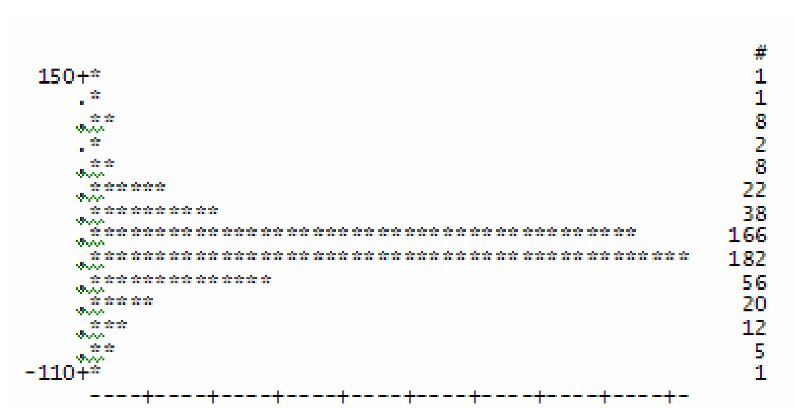

Figure 9. Histogram of the residual values from travel empty, grapple time, travel loaded, and un-grapple time.

The histogram in Figure 9 shows graphically that the residual values are not normally distributed. The shape of the graph is known as kurtosis since most of the residual values fall on or around zero. The histogram in figure 9 is symmetric which means that the distribution of residual values will be approximately normal for smaller sample sizes. Since the histogram is kurtotic this tells me that the majority of the residual values are precise and that for most of the residuals the differences between the two methods was small.

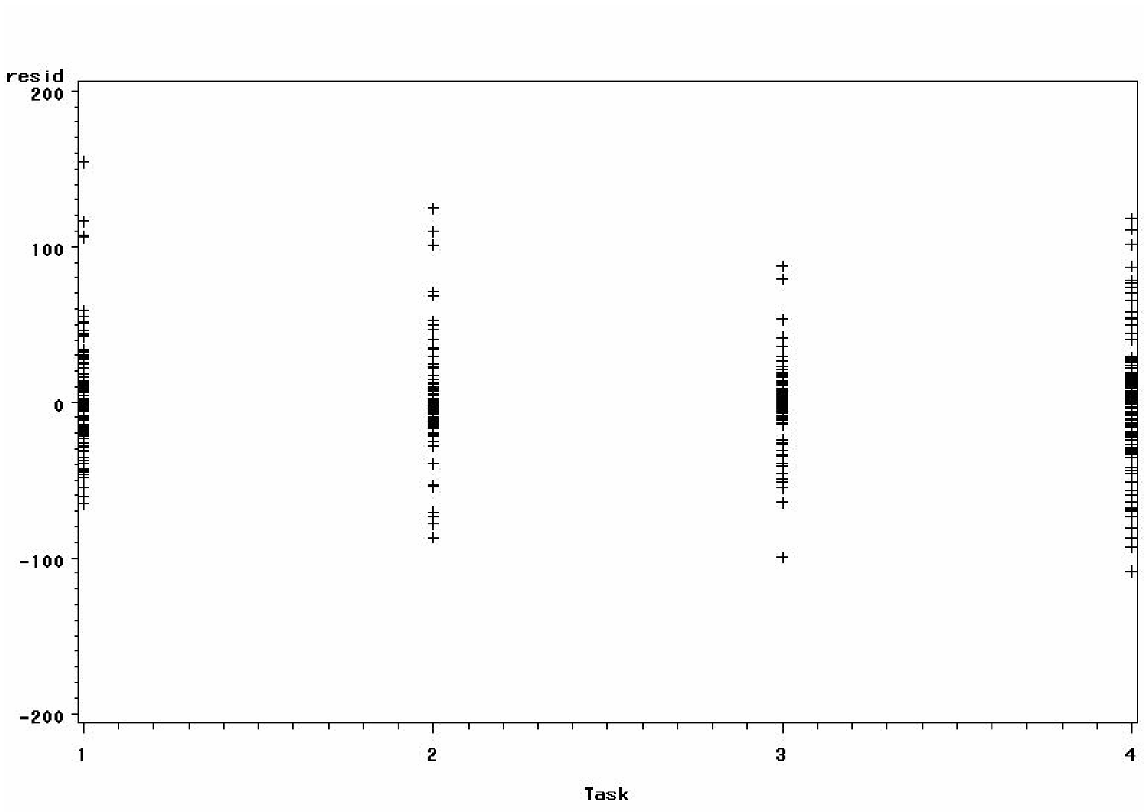

Figure 10. The g-plot of the residuals for the tasks travel empty, grapple time, travel loaded, and un-grapple time.

A g-plot is a graph that shows the distribution of the residual values for each task. As the bars of the g-plot get longer there was a greater difference between the manual times and the GPS times. The g-plot of residual times from the tasks show that Task 1, travel empty, has a few large outliers, but there is a relatively tight dispersion of the residuals around zero. These large outliers in travel empty could probably be due to observer error, but there wasn't enough evidence in the handwritten times to justify deleting the points. The g-plot shows that Task 2, grapple time, had a high number of large outliers meaning the residuals between the two methods of time data collection were subject to some large errors. However these errors were not large enough to cause a significant difference between the two methods. Task 3, travel loaded, also shows a few large outliers, but it also has a relatively tight dispersion of residuals around zero. Task 4, un-grapple time, was subject to some of the largest differences between the two methods of time data collection and has the most and the largest outliers of the four tasks. None of the extreme values in Task 4 were discarded since there was not any one that significantly affected un-grapple time.

Discussion

Total Points

The total number of points differed greatly between the 5 second and 1 second time intervals where the GPS would record a point on a line file. When the GPS was set to record 1 point every 5 seconds there would be between 2,000 and 4,000 total points for each half day. When I set the GPS to record 1 point every second there were over 13,000 points recorded for that half day. The number of points increased drastically when the time interval was changed from the 1 second time interval to the 5 second time interval with little to no benefits. As the number of points increased from the 5 second time interval to the 1 second time interval transitions from one task to another task became blended and it was more difficult to notice when certain tasks were starting, such as trail work. The increased number of points increased the time it took to analyze the line file created by the GPS and the difficulty in pinpointing transitions between tasks also increased the data analysis time. Statistically the 1 second time interval was equally as accurate as the 5 second time interval for travel empty, grapple time, travel loaded, un-grapple time and total cycle time. The largest difference between the two time intervals was the amount of time it took to analyze the time data collected by the GPS and the ease at which one can analyze the time data.

Tasks

Trail Work

Trail work is often difficult to record, especially when using the traditional method of collecting time data since most of the time trail work is performed between the set and the next load and is often done out of sight of the researchers. Trail work can be easy to pinpoint with GPS if the operator spends time on the trail going back and forth, but if the operator just slows down and drops slash on the trail and then continues it can be more difficult to collect using GPS. The more time that is spent on trail work the easier it is to collect with GPS.

Travel Empty, Grapple Time, Travel Loaded, Un-grapple Time

Differences between un-grapple times in 5 of six half days (HD's) were significantly different from zero. One of the reasons for this could be that the boundaries for the deck were not defined on half days 1, 2, 3 and 4. Also, deck time was frequently included in the un-grapple time with the manual data collection method, which was one of the main reasons why differences between un-grapple times were significantly different from zero.

Digital and physical boundaries can be set up on site in order to best determine when to start and stop travel loaded, un-grapple, haul slash and travel empty times. Digital boundaries could be included in the skidder line file by walking around the perimeter of the log deck before putting the GPS in the skidder cab, or by walking the perimeter of the set after the skidder has finished for the day. Creating a physical boundary around the perimeter of the set with flagging tape will help in collecting time data manually by showing the researcher a precise location where to stop and start different time elements

Even with un-grapple time broken down into smaller components such as delimbing, deck work and slash hauling, the differences between the two methods of time data collection were significantly different than zero in all of the half days of the study. I believe that this is because in many instances idle time on the deck or wait on loader time got included into the un-grapple with the manual data collection method. Using the manual data collection method, it was difficult to break up un-grapple time because the skidder would arrive on the deck, which would start the un-grapple time, but then stop as soon as it got close to the loader to wait for the loader to finish, which would start the idle time/wait on loader then quickly start moving to finish un-grappling. With the manual data collection technique there was often a lot of overlap between different tasks on the deck. Using GPS it was much easier to break up the time because you could go forward and backwards along the GPS line file as needed and really get a good idea of when one task ended and another task began. Thus, GPS-collected data seems to be superior in this regard.

From looking at the results of this study for travel loaded and un-grapple it would be necessary to have someone stationed on the logging deck making notes of the times that different tasks started and ended to check the accuracy of the GPS times collected. The accuracy of travel loaded and un-grapple time could be greatly improved by using a combination of GPS and manual time data collection. However, this is still a big improvement over the manual time data collection technique because the observer stationed in the timber recording travel empty and grapple time is no longer needed, which is an important safety improvement as well as an economic improvement.

Idle Time

The main problem with using GPS to collect idle time is that the researcher is unable to discern why the skidder is idling; all you are able to tell is that the skidder is not moving. This would cause a problem if the skidder was stopped for maintenance work since it would look as if the skidder was idling. If the skidder were stopped for a prolonged period, say 1-2 hours, it would be obvious that there was a problem and one would know that was not idle time.

However, idle time is easier to collect with the GPS since you are able to get a more precise assessment of how long the skidder has been idling. Using GPS one is able to scroll through the points so when the skidder is not moving the points stay in the same place which allows you to be able to calculate exactly how long the skidder has been sitting idle.

Haul Slash

For this element of the time study it is important to mark the boundaries of the deck digitally with the GPS and also with flagging tape for the manual data collection method. In a couple of cases the skidder left the deck with slash, made a short haul into the timber and returned empty. In both of these cases I had recorded that time as deck work because the boundaries of the set were not established. I also believe that by identifying boundaries you will shrink the difference in haul slash times between the two methods of data collection.

Haul slash was easy to recognize using GPS from skidder movements since the skidder wouldn't position to pick up a load and when the skidder returned to the deck there would be no un-grapple, most often the skidder would go right around the deck and back down the normal skid trail where the bundles were laid out or would go straight back to cleaning the deck.

Deck Time

The large differences in recorded deck time between the two techniques could be that the deck time element wasn't defined well enough at the start of the study and was very often included in the un-grapple time during the manual data collection. Deck time was difficult to collect using the manual data collection method because the skidder performed many tasks on the deck while waiting to un-grapple near the loader. For instance, the skidder would often come onto the deck with a drag and stop to wait for the loader to finish sorting and loading the last of the logs. The skidder would then drop the load, perform deck work, then grapple the bundle again and move it to the loader. When this was done the skidder would then go back to performing deck work. When all these time elements get meshed together in a short amount of time there will inevitably be some overlap between the time elements. I believe it was easier to get a more accurate assessment of deck time by analyzing the GPS file because I was able to go back and forth between points to get a more accurate time for each element of the skid cycle that was being performed. With manual data collection you only get one shot at getting the time right and if you are not paying attention and miss the end of a task you either mark it down right then, which is not the right time, or guess at when the task ended, which is also wrong.

The accuracy of deck time could be greatly improved by using a combination of the two time data collection techniques. A few manually recorded times would be helpful to double check the time data collected using GPS and notes taken on the deck could help clarify what you are seeing on the GPS line file when things get messy.

Looking For Logs Unsuccessfully

The time spent looking for logs unsuccessfully is a time element that has not been discussed in other research papers on skidder productivity which I believe is because most of the time the researcher who is collecting the data will not see it happen. I observed the skidder looking for logs unsuccessfully only twice in the field during the study because I was sitting on a skid trail where all the bundles had previously been removed and observed the skidder pass me by and continue to the end of the skid trail, realize there were no bundles, turn around and continue on to the next skid trail for the next load.

The task looking for logs unsuccessfully is more accurately collected when it is collected with a GPS receiver. The reason for this is that when you are in the field you do not notice that the operator was looking for logs unsuccessfully unless you can see all the way down the skid trail to know for yourself that there are no bundles at the end of the trail. Also, with GPS you are able to scroll back and forth between the points to get a more precise measurement of the amount of time the skidder operator spent looking for logs unsuccessfully. This is because when you are in the field the time is being recorded as travel empty until you make the realization the skidder operator is looking for logs. Then you stop travel empty and start time for the looking for logs time element then you have to stop looking for logs when the skidder gets back on the correct skid trail and restart travel empty (Figure 3).

<u>Miscellaneous</u>

Miscellaneous time elements are easier to note in the manual time data collection technique because one is able to make notes about what you see happening on the deck. With GPS if something looks out of place you are not able to actually see what is happening one has to guess what is going on and then find out later from the operator or someone who was there what was actually happening. For instance, if you see the skidder go way off course, away from the normal skid trail you cannot tell what he is doing. This happened in one instance on HD4 where the skidder took off to go pull the feller-buncher out of the mud and from the GPS line file all you could see is that the skidder went way off course.

Total Cycles

I was able to accurately identify every skid cycle on each half day of the study using GPS and I was also able to differentiate skid cycles from slash hauling off the deck. GPS also allowed me to measure skid cycles that were misses during the manual data collection as well as measure the lengths of drags made by the skidder. For total cycle time data it is easier, more cost effective, safer than and just as accurate as the manual time data collection technique to use GPS.

General Linear Model

The general linear model was only useful to test the half days to determine if they were significantly different from each other. Since the general linear model showed no significance for the half day effect, a simple least squared means of the differences statement could be used to examine error rates between the two methods. The general linear model also included a Shapiro-Wilks test for normality, which showed the data was not normally distributed because the distribution of the residuals was kurtotic. I believe the large outliers and the kurtosis of the normal probability plot contributed to the significance of the Shapiro-Wilks test. I had expected the distribution of the residuals to be kurtotic since the two tests were very close to each other on many of the times taken. This means that the differences between the two data collection methods were very small in very many of the observations, which is what I had originally expected from the results. The large number of small residuals is also strong proof that the GPS method is a good tool to use for collecting time data on rubber-tired grapple skidders.

Summary

Productivity studies on rubber-tired grapple skidders have been conducted on logging operations since the 1970's. The same technique has been used to collect time data on rubber-tired grapple skidders since this time. The technique which has been used entails timing the skidder with a stopwatch as it brings bundles of trees from the woods to the deck. This study requires at least 2 researchers to watch the skidder work, and requires the researchers follow the skidder on its daily routine for multiple days. This type of study is not only time consuming and costly, but hazardous to the researchers in the field when working in this close of proximity to industrial machines.

New technologies have enabled us to conduct time studies on rubber-tired grapple skidders without having to work near large forest machines and without having to have multiple researchers conduct the study. GPS is a tool that can be used to unintrusively study rubber-tired grapple skidders, but can the data collected by the GPS be used accurately enough for a productivity study where accurate detailed information is needed?

In this study I used a Trimble GeoXT GPS receiver installed in the cab of a skidder to compare the data collected with the GPS to time data collected using stopwatches or clocks in the traditional manner of collecting time data. I compared the times collected for each element of a skidder's cycle, comparing times for trail work, travel empty, grapple time, travel loaded, un-grapple time, deck time, haul slash, looking for logs unsuccessfully, idle time and total cycle time. I compared the differences between the two methods for travel empty, grapple time, travel loaded, un-grapple time and total cycle time using statistical analysis. The other time elements were compared

using simple comparisons of averages and standard deviations as well as comparisons between when they were observed and when they were missed between each method of collecting time data.

GPS was concluded to be a good tool to use for collecting time data on trail work and looking for logs unsuccessfully because these elements of a time study on rubber-tired grapple skidders often go unseen when using the traditional method of collecting time data. Statistically, the differences between GPS times and manual times did not differ from zero at $\alpha = 0.05$ on nearly all the tests. However, for travel loaded and un-grapple time in all but 1 test the difference between the two methods was significantly different than zero at $\alpha = 0.05$. There are a few reasons why travel loaded and un-grapple times were significantly different than zero at $\alpha = 0.05$. They can be contributed to digital and physical boundary errors as well as manual errors on the ground. Other time elements often were included into the un-grapple time such as idle time and deck work.

GPS is a good tool to use for deck work and haul slash times, but has some costs and benefits when it comes to collecting idle time data. The costs include the inability to see why the skidder is idle, whether it be maintenance work, waiting on the loader, directing traffic, etc. The benefits for using GPS to collect idle time data is that the researcher can collect this time data quickly and efficiently without having to be present on site.

Differences between total cycle times for the two methods of data collection were found not to be statistically different than zero at $\alpha = 0.05$. GPS can be used accurately for collecting total cycle times on rubber-tired grapple skidders on both the 5 second time interval or the 1 second time interval although the p-value for the 1 second time interval was not as strong as the p-values for the 5 second time interval.

I collected line data with GPS using a 5 second time interval between GPS points and a 1 second time interval between GPS points. The main difference is that in using the 1 second time interval there were 5 times more points to scroll through when analyzing the time data from the GPS, which took twice as long as when analyzing the points on the 5 second interval. Also, since there were so many points collected with the 1 second time interval the transition between tasks became blended and it was not as clear when the skidder was ending one task and starting another. Using the 5 second time interval transitions between tasks were more obvious, which made the analysis of the data go quicker.

The general linear model showed that there was no significant difference between half days so the block design was not necessary, and I could use the least squared means as the tool to measure error rates between the two methods of time data collection. From looking at the least squared means the manual data collection times were greater than the GPS times for travel empty, grapple and un-grapple times by 5.72, 3.63 and 43.79 seconds respectively. GPS times for travel loaded were greater than the travel loaded times measured manually by an average of 11.69 seconds.

The normal probability plot showed that the residuals were close to normality but the large outliers had a significant effect on the normality of the residuals. The histogram of the residuals showed that most of the values were centrally located, hence the kurtosis of the graph and more reason why the values were not completely normally distributed.

The best, most accurate way to collect time data on rubber-tired grapple skidders is to use a combination of GPS and the traditional technique of manually timing the machine as it works on the deck. I have come to this conclusion because where I had the most problems with GPS was on the logging deck and by using both techniques you would be able to make notes and time the skidder on the deck to check the data collected by GPS. Also, the number of people required to conduct the study is still reduced to 1 and takes the researcher that was in the woods out of the equation. By reducing the number of researchers to 1 the cost of conducting the study will decrease.

Conclusions

The Trimble GeoXT with external antenna is a good tool to use for collecting time data on rubber-tired grapple skidders operating in second thin loblolly pine plantations. In fact a GPS unit could be used for a completely unattended time study of grapple skidders because the mistakes associated with the manual time data collection method and GPS method offset each other. Ideally a combination of 1 researcher plus a GPS unit could collect very accurate time data on rubber-tired grapple skidders operating on a second thin in plantation loblolly pine. The researcher should stay on the logging deck to record movements of the skidder since this is where I found there to be the most difference between the traditional methods for collecting time data and GPS. GPS has shown to be a very useful in collecting time data on trail work, travel empty, grapple time, searching for logs unsuccessfully, idle time and deck time. A researcher would be needed to make notes on haul slash, travel loaded, un-grapple time and deck work, as well as make notes on why the skidder is idling in order to check the accuracy of the GPS. Also, line data collected on a 5 second time interval is easier and quicker to analyze that line data collected on a 1 second time interval.

Future Research

Unfortunately, because of hurricane Katrina, I was unable to collect as much data as I had intended to for this project. I believe future work should take a look at collecting the GPS line data on distance intervals, such as a 20 foot point interval and a 50 foot point interval and compare the data to the line files I collected using the 5 second and 1 second time intervals.

Future research should also look into a system which locates bundles for the skidder operator in order to reduce the amount of time spent looking for logs unsuccessfully. A pushbutton in a feller-buncher could mark each bundle and transmit the point location to the skidder in order to help the skidder operator locate all bundles. This type of information would also help the logging managers know how much wood is cut and sitting in the timber if the average bundle volume is already known.

Future research should also look into having a more automated productivity study. This could be done by automating the calculation of volume hauled from the grapple diameter. A pushbutton located in the cab of the skidder could be pushed when the operator grapples a bundle, this would mark the grapple diameter and associate the diameter of the grapple to an average tree volume. This type of study could have the potential to greatly reduce the amount of time needed to conduct this type of study and reduce the costs of conducting productivity studies on rubber-tired grapple skidders.

To further increase the automation of this type of productivity study I believe that time data collection could be gathered from a GPS line file using and expert system. The expert system could use a series of if-then statements to analyze the skidders line file and extract time data.

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Vita

Robert Dupre was born August 31, 1978, in Lafayette, Louisiana. During his childhood he lived in Ville Platte, Louisiana, and attended grammar school in Opelousas, Louisiana, at Westminster Christian Academy. In 1997, he graduated high school from Westminster Christian Academy and started his undergraduate program in forest management at Louisiana State University. During this time Robert interned with the United States Army Corps of Engineers as an assistant to the Natural Resources Specialist in Port Barre, Louisiana. Robert graduated from Louisiana State University with a Bachelor of Science degree in forest management in December, 2002. After completing his undergraduate program Robert worked at Everglades National Park in Homestead, Florida, as a forestry technician/firefighter. In 2004, Robert left the Park Service to pursue a Master of Science degree from Louisiana State University in forestry. Robert will receive his Master of Science degree in forestry from Louisiana State University in May 2006.