Abstract
Herbaceous weed control and planting of southern pines share a common attribute in that they are both implemented using primarily hand labor in the southern US. Contractors providing these services have had problems documenting the amount and quality of work performed by individual laborers, and in providing auditable data to landowners of the extent of services provided. Electronic systems were developed to resolve these problems. The ‘SmartPak’ system recorded location while a worker sprayed herbicide and the ‘SmartDibble’ documented location when a tree was planted. Both systems provided information useful to contractors for operational management and documentation, and data on which land management decisions could be based.

1. INTRODUCTION
Temporary seasonal workers are commonly used in forest management in the US South, primarily in two specific tasks: regeneration planting, and herbaceous weed control. There are many reasons for this reliance on human labor, but the primary driver has been that costs tend to be lower. Mechanical alternatives are not available that provide as consistently good results across the broad range of conditions found in the region.

There are questions, however, surrounding the employment of this temporary labor force, and the work they produce, that have caused some controversy. Large landowners, and the silvicultural contractors they employ, are seeking ways of improving the quality and accountability of work produced using seasonal laborers. This report will outline the authors’ efforts to create information systems for documenting the output of manual labor in herbaceous weed control and hand planting.

2. BACKPACK HERBACEOUS WEED CONTROL
Woodland Specialists, a silvicultural services contractor located in Chapman, AL, developed, in association with Auburn University Biosystems Engineering Department, a backpack spray system to reduce concerns with employee safety and quality assurance for clients. Design changes resulted in a new type of spray rig that addressed health concerns and added monitoring electronics to record spray system performance. Their objectives in creating the new system were:
1. Create a safer, healthier work place for their employees to reduce turnover and increase awareness of job performance standards, and

2. Develop a data collection system to document worker activity and chemical spray coverage over an entire tract.

The system they produced has been dubbed the ‘SmartPak’ and has been deployed in the field for one full season.

Worker safety concerns arose because of the nature of the work being performed. Herbicides are used extensively in forest stand management in the US, especially in the South, where an estimated 93 percent of silvicultural herbicides are sold annually (Shepard and others 2004). Their use in silvicultural stand management can be broken down into three primary objectives: site preparation, herbaceous control, and release (woody competition control). Site preparation and release treatments are typically broadcast applied using mechanized aerial or ground-based systems. Herbaceous weed control is usually applied a short time after planting to provide a window of time within which the seedlings can become established without competition. Applications are usually sprayed in bands directly over the seedlings, saving chemical and providing equal benefit to broadcast application. Dubois and others (2003) reported estimates of silvicultural chemical usage from the four largest herbicide distributors in the South. Their data indicated about 950,000 ha of pine plantation were treated with some form of herbicide in 2002, with nearly 25 percent representing herbaceous competition control.

The application of herbaceous competition control at stand establishment seems to be currently in favor, and one common means of implementing this type of prescription is through banded spray using backpacks. Miller (1998) reported that, during the mid 1990’s, only about one percent of herbicides used in the South for silvicultural purposes were applied using backpacks. That figure has certainly increased over the ensuing years. Dubois and others (2003) found in their survey that backpack application was used on about 16 percent of total pine plantation acres treated in 2002. The increase can be attributed to reduced chemical use compared to broadcast applications, lowering costs, plus a decrease in acreage mechanically site prepared, reducing the area on which spray machinery can subsequently operate cost effectively.

Chemical application by hand can be a risky business, for both the person carrying the backpack and that person’s employer. For the worker, the risks are primarily associated with inadvertent contact with the chemicals being applied. In the past, backpack applicators consisted of a tank and a wand with which the worker sprayed the chemical. Spray pressure was typically maintained using a hand-powered pump, a significant physical burden. From a safety standpoint, this system forced the operator to walk through vegetation that had just been sprayed.

Shepard and others (2004) reported that 90 percent of herbaceous weed control chemicals used in the South were classified as imazapyr, metsulfuron methyl, or hexazinone, which are relatively nontoxic (LD$_{50}$ about 10 to 30 times that of caffeine, Campbell and Long 1995). Significant exposure of workers is possible, however, because of the nature of the typical backpack sprayer and how it is used. Long-term exposure effects are not known, and neither is the effect of inert ingredients used in commercial forms of the herbicides. Most herbicide manufacturers do not reveal exactly what additives their products contain, but enough is known to further discourage exposure of workers.
Besides having to control exposure of workers to herbicides, application contractors must provide their clients with evidence of the quality of the services rendered. Ideally, a contractor should be able to provide an auditable record of the amount of chemical applied at what locations. These data are useful for billing clients and in resolving disputes over efficacy of the treatment.

2.1 Modified Spray System Design

Spray system changes implemented by Woodland Specialists included mounting the tank on an ergonomic backpack frame to increase worker comfort, and conversion of the hand-powered spray system to use an electric pump, reducing physical demands placed on the worker. Spray nozzles were mounted in a fixed, rearward-facing direction so the worker was not constantly moving through chemically treated vegetation. These modifications reduced the level of exertion required while spraying and freed the worker’s hands to help maintain balance when moving through thick vegetation and slash. A photo showing the SmartPak system in use is found in figure 1.

A spray monitoring system was used to record the state of the spray pump and location of the worker over time (a photo of which is also shown in figure 1). A microcontroller sensed the pump being switched on and began recording position output from a global positioning system (GPS) attached through a serial port. Data were recorded at 1-s intervals on a compact flash card. Garmin model 18 and 16 GPS units have been used, and both have proved successful.

Included in the monitoring system was an LCD screen through which the microcontroller could provide information to the operator. Output included updates on the state of switches and the GPS (satellite and WAAS availability), plus an error field that reported problems with data storage and other high-level system functions. The microcontroller also kept track of travel speed of the worker and gave constant updates via the LCD screen. The operator would typically be given a target speed at which to walk in order to apply the herbicide at the prescribed rate.

Figure 1. Workers using SmartPaks to apply herbicide for banded herbaceous weed control. On the right is a photo of the SmartPak electronics, including the microcontroller housing, LCD screen, and GPS.

2.2 Field Experience Using the System
Woodland Specialists employed the SmartPak system in herbaceous competition control contracts on over 6000 acres during the 2005 spray season. About 20 total units were in use over that period, most on backpack units, but a few were used on mechanized spray equipment to track their application coverage. In general, the systems were deemed a success and plans are to use them again in the coming spray season.

Worker satisfaction with the SmartPaks was generally good, with the exception of a perception that, perhaps, productivity was not as high as desired. Wages were calculated on a linear distance application basis, so workers were very sensitive to any changes that affected their ability to cover ground. Although some spray system modifications enhanced productivity (the electric pump, hands-free operation), spray tank size had to be reduced in order to accommodate batteries, pumps, and other components. Most hand-powered spray units have a 19-liter tank. That volume was reduced by about 20 percent on the SmartPak, requiring additional trips to refill. The electronic components added 850 grams to the SmartPak, the battery about 3.5 kg more, but wet weight of the units (hand-powered and SmartPak) was roughly equivalent.

Operation of the SmartPaks required the workers to pay close attention to the feedback provided by the microcontroller, especially regarding battery status and walking speed. There was some concern on the part of field technicians that the feedback given workers on speed did not have enough resolution. The speed data were extracted from the GPS information and were only available to the nearest 1/10th mph. The technicians, and presumably workers, felt this level of accuracy might not have been sufficient to ensure uniform spray coverage.

As one might expect, the SmartPak units deployed in the 2005 season proved not quite as durable as hand-powered units. Field technicians working with the spray crews felt the 2005 units would work reliably for about 3 to 4 months in the field. Spray season might last 6 months in that region of the country. Some of the failures observed had to do with the backpack carrier systems, which were essentially hiking pack frames that could not sustain the abuse suffered in field work over long periods of time. Units used later in the season were strengthened. Vibration and impacts during transport to and from the field were thought to decrease reliability of some of the electronics, but contamination from water or dirt was not a problem. Some of the components to be used in units for the coming spray season will be modified to increase the service life of the systems.

Workers were required to charge enough batteries every evening for the next day’s work. The packs required at least two batteries per day in normal operation. Workers were not always happy with the responsibility of dealing with batteries, but seemed to accept it.

In the field, the SmartPaks worked about as well as could be expected for a prototype system. One area of operation that proved to be somewhat burdensome, however, was handling the constant stream of data being generated. This task required an estimated 30 to 40 hours per week for each of two technicians supervising seven spray crews. Over the course of the season, about 6 gigabytes of information were downloaded from the spray units, summarized, and transferred into a geographic information system (GIS). There was consensus among technicians that this process could be improved greatly.

2.3 SmartPak Conclusions

After one season of extensive field testing, the management of Woodland Specialists felt the enhanced spray systems were worth the extra effort required to keep them operating. They
cited the auditable documentation of work performed as the single greatest benefit of the systems. The data derived from the Smartpaks were used in settling accounts with landowners concerning number of acres treated and in resolving disputes over spray efficacy. Being able to show exactly where chemical had been applied proved a significant business advantage for the company. A map, such as that in figure 2, established a basis from which disputes could be resolved. The maps also provided a means of distinguishing Woodland Specialists from their competition and contributed to an atmosphere of trust with clients. When disputes arose over the level of herbaceous control in a particular tract, the company was able to show that they had in fact applied the chemical at the prescribed rate and that the prescription, or the chemical itself, must have failed.

![SmartPack Map Example](image)

Figure 2. The as-applied map on the left shows herbicide coverage for a tract by 4 workers using the SmartPak. On the right is a detail of the map showing areas of over- and under-spray.

Although other expected benefits, such as reduced chemical use through accurate application, were not as readily apparent, the SmartPak proved to be a useful tool in managing and educating workers. Maps of over sprayed and missed areas gave field technicians an unequivocal means of expressing concerns about poor performance to workers that most often did not speak English. Figure 2 also includes a detailed depiction of an area from the map on the left. Areas of over- and under-spray, as well as the identity of the person responsible for the errors, are easily seen.

3. HAND PLANTING

Every year, US law allows issuance of 66,000 H2B guest worker visas to help companies involved in businesses other than agriculture hire workers they cannot recruit locally. In recent years, the majority (over 20 percent) of the visas issued have been for forest management activities (McDaniel and Casanova 2005). Regeneration planting of southern pines has been the largest single use to which H2B visas have been applied. McDaniel and Casanova (2005) reported that only about 8 percent of tree-planters working in the southern US were citizens, and about 84 percent were working with H2B visas. The remainder was on other types of visas, or undocumented.
A series of reports in the Sacramento Bee newspaper published in 2005 alleged serious mistreatment of workers hired for forestry work under H2B visas (Knudson and Amezua 2005). The articles reported many types of abuses, most involving taking advantage of the workers’ dependency on the employer to maintain their status in the country. This publicity has focused a great deal of attention on the tree planting industry in the US. Some of the most critical has involved payment of planters. It has been alleged that workers were defrauded by unscrupulous employers that manipulated production figures, and the Southern Poverty Law Center of Montgomery, AL has filed a legal complaint on behalf of guest workers against the three largest contract planters in the country seeking redress (Linn 2005).

These legal troubles have created a tense atmosphere among companies involved in regeneration services. As in the case of herbaceous weed control, those companies that do their best to treat workers fairly and in compliance with laws feel they should be rewarded for the extra costs that effort entails. Unless they can fully document that compliance, however, their claims of unfair competition from other, less scrupulous, employers have no basis.

Woodland Specialists has, again working with Auburn University Biosystems Engineering, begun to investigate the use of electronic monitoring systems to document worker activity, this time involving tree planting. The concept, as in herbaceous weed control, was to create the technology to map all activity carried out by workers on a site. For planting, this meant showing placement of all trees across an entire stand. Such technology would form the basis of a fair piece-rate pay incentive program for workers, create an auditable record of work done for a landowner, and be a tool available to implement the concepts of ‘precision forestry’. Given data on every tree in a stand, including its location, managers can focus attention and resources to the level of the individual tree, rather than the population. Managing for average conditions on a site will produce average results over time, but, as the technology becomes available, optimizing the growth potential of every individual should maximize the output of the entire stand.

The objectives of the work have been to

1. Create a wearable device that accurately records the location and time of a tree-planting event, and to
2. Use that device to map tree locations in hand planting operations.

A prototype version of such a device, the ‘SmartDibble’, was subjected to limited tests in the 2005-2006 planting season.

3.1 The SmartDibble

Trees are hand planted using one of two implements, a dibble or hoedad. Both are designed to create a hole in which the seedling is placed, the difference is in the motion required by the worker to use them. The hoedad uses an over-the-head swinging motion, much like an axe, while the dibble is an impact-type device, punched in a downward motion into the ground. While hoedads are used quite extensively in the southern US, dibbles are recognized as being superior from a quality of planting standpoint and were the focus of this research.

The tree planting event ‘sensor’ developed for the project took advantage of the fact that every tree required a rather abrupt motion on the part of the worker to create a hole in the ground. An accelerometer was used to detect impacts of the dibble with the ground, and a
microcontroller, when an impact was observed, recorded the event along with a time stamp and a position from a GPS.

The proof-of-concept system built used a modified SmartPak data collection system to monitor planting activity, seen in figure 3 below. The dibble was outfitted with a short section of steel pipe, welded perpendicularly to the shaft, housing an accelerometer, a voltage comparator, and a wireless communication system. When acceleration exceeded a threshold value, an 'event' notice was radioed to the SmartDibble controller, which was carried by the planter. Upon receiving notice of the planting event, position was read from a Garmin model 18 GPS, interfaced through a serial connection, and the information stored on a compact flash card. The SmartDibble interface also included an LCD screen that reported number of events observed, information on GPS status, and battery condition.

Figure 3. The SmartDibble, a tool to collect information on tree location while planting, is being carried in the right hand of the gentleman on the right in the photo. The accelerometer electronics are housed in the small pipe attached to the dibble shaft. Impact events are radioed to a modified SmartPak unit carried in a pack on the operator’s back. The system monitors position information output from a GPS attached to the operator’s right shoulder.

Unfortunately, the prototype SmartDibble system was not ready for deployment until near the end of the planting season and received only limited testing. Preliminary tests of the system were conducted under field conditions using professional planting crews. Modifications were made to suit the operators, mainly re-positioning of the acceleration sensor housing on the dibble itself. After modifications, the system was more thoroughly tested for a single day of planting – the last day of the season for the crew doing the work.

Planting tests were made using a single member of a cooperating crew of about 12 workers. This particular crew normally used hoedads for planting and had only limited experience using dibbles. The operator using the SmartDibble system, in fact, had never used a dibble before. The first part of the test, therefore, involved training the worker in how to plant using a dibble. Once the training was completed, the worker began planting on a portion of the site away from the remainder of the crew. The site had been bedded and trees were planted at a 2-by-5 m spacing. The worker adapted quickly to the dibble and wound up planting 619 trees using it.
Planting a tree with a dibble, or hoedad for that matter, involves at least two impacts of the instrument with the ground: one to open a planting hole, and one to close it. In actual practice, the number can be much higher, depending on soil conditions, or the presence of rocks or roots. Testing of the dibble, therefore, was intended to answer three main questions. First, was it practical to use? Second, could a single planting event be detected from a sequence of multiple dibble impacts? Third, was the position associated with each planted tree accurate enough to add value to future management activities? Practicality was assessed qualitatively – the operator was simply asked for his feedback about using the system. Accuracy of the tree location was measured by associating a ‘true’ tree position with each dibble impact. The true position was established using a Trimble GeoXT GPS using post-processed correction. Finally, the question of multiple impacts was investigated by direct observation of the SmartDibble while being used. For a subset of planted trees (171), the data collection system was removed from the operator and carried by another person. That person could observe, and record, when the system detected an impact event by watching the event counter increment. In this manner, an impact event could be directly correlated to a true tree position.

Figure 4 is a map showing all impact event positions recorded by the SmartDibble, as well as actual tree locations as established using the Trimble GPS. It was evident from the map that positional accuracy of the SmartDibble system was quite variable over time and errors were of a relatively high magnitude in general.
Figure 4. Map of planting locations established using two positioning systems: the SmartDibble, and a Trimble GeoXT GPS system. Green dots are the ‘true’ positions from the Trimble. The black and red markers are those positions from the SmartDibble. The black markers indicate those taken without independent evidence of the microcontroller recording an impact. The red markers indicate those positions for which the impact information was also recorded by a human observer.

For the 171 trees for which detailed knowledge of impact event timing were available, it was found that, for the conditions tested, the characteristic two-impact scenario for each planting event (one each for opening and closing the hole) only occurred about 1/3 of the time (36 percent). In slightly over half the cases (53 percent), only one impact was detected for each tree. No impacts were detected for 11 percent of trees. This result was likely due to the relative ease with which the dibble could be inserted into the ground. The bedding of the site made planting very easy, and the operator, to conserve his energy for the day, did not exert more force on the dibble than necessary to plant the tree. The comparator used to monitor accelerometer magnitude was probably set at too high a threshold, and these soft impacts were missed. Data in figure 4 tended to support this since those trees for which no impact was detected tended to be clustered in small areas, even between rows. This was likely due to locally high moisture content, organic matter content, or soil textural differences.

Those same 171 tree positions were sorted by hand and assigned to a true tree location. The assignment was made using notes taken in the field on what dibble event number was associated with what tree, and, when there was some doubt, based on time of the event relative to other events. In some cases, the assignment based on this information was overridden because it just did not ‘look’ right. In those cases, a discretionary choice was made regarding to which tree the event was assigned. The average deviation of the SmartDibble and true positions was about 2.3 m for the 171 trees in the sample. This level of accuracy was considered insufficient by the landowner to implement tracking of genetically improved seedlings, an application being considered at this time. Some of the accuracy was undoubtedly a bias introduced because of how the system was carried and used. The operator was working on bedded ground and, because he was right-handed, tended to walk along the left side of the beds in order to avoid soft footing. The GPS antenna was also mounted on the left shoulder of the operator. Both of these practices tended to impose an offset to the measured positions.

Practically, the SmartDibble seemed to work fairly well. The workers that used it did not complain about the monitoring system, but complained quite strongly about the dibble itself. They were accustomed to a particular style and size and were reluctant to depart from that in any way. Perhaps their dissatisfaction with the dibble masked any feelings about carrying the monitoring equipment, but this was hard to judge. We observed no decrease in productivity because of the system, but, again, this was hard to judge accurately. Although no problems were encountered, the most vulnerable part of the system was likely the wireless antenna. Modifications will be made to this before using the system next year.
4. CONCLUSIONS

Manual operations are used widely in forest management in the southern US and likely will be in the future. Many concerns have been raised about the quality of work performed by hand and the systems presented in this report were developed to document the rate and spatial attributes of two forms of manual labor. The SmartPak system documented application of herbicides for herbaceous weed control, providing maps of where and when chemical was sprayed, as well as who performed the work. Although collecting the data was problematic, it has proved its value to contractors in documenting for landowners work performed and in resolving efficacy disputes. Although it has not been applied in practice as of yet, similar benefits should accrue from use of the SmartDibble system.

5. LITERATURE CITED

Linn, M. 2005. SPLC sues forestry companies, Montgomery Advertiser, Montgomery, AL. August 27.