Application of Radio-frequency Identification to Improve Forest Transportation Logistics

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Introduction

Forest harvesting in the U.S. is a very mature industry that faces increasing economic pressure. Global competition for commodity products like paper and lumber has led to structural changes such as mill closures and regional shifts in production. Changing land ownership and management have also shifted forest production from historically forest-dependent areas. These dynamic forces confront logging businesses with significant economic challenges. Stuart et al (2006) developed a Logging Cost Index based on detailed reporting from a group of contractors in the southern U.S. Their data show that the cost of logging increased 40 percent in a 10-year period (1995 to 2005) while the price received for logging services declined by 10 percent. Contractor operations must continuously find more efficient operational models to survive.

One approach is to use new technology to improve efficiency and reduce costs. While production efficiency through mechanization has been thoroughly exploited, relatively little development effort has focused on improving efficiency through better management control of operations. The majority of forest operations contractors in the United States are relatively small, independent business units organized as sole-proprieter enterprises. Their "management information systems" (MIS) typically consist of monthly billings, production reports, and direct observation of daily operations. A constant challenge of the small business is to track this data in a manner that allows the business owner to manage work flow and cost recovery.

Cambium Forstbetriebe has developed a more sophisticated MIS for logging using technologies of radio-frequency identification (RFID), global positioning (GPS), enterprise resource planning (ERP) and global system for mobile communications (GSM). The Cambium Log Tracking System (LTS)[1] manages information about cut logs through the forest operation from felling to customer delivery. A passive RFID tag inserted in the butt of a log provides a unique object identifier. Forest workers with readers at each processing step record various attributes of the log such as location, grade, ownership, etc. This information is communicated to the ERP system where appropriate reports are generated and shared back to inform subsequent processing operations. For example, the report of skidded logs can be used to generate a loading request for truck transport. Cambium handles approximately 70,000 m^3 of sawlogs per year. The LTS produces savings through reduction in lost logs (currently 10 to 15 percent of total volume) and improved efficiency in managing reporting and accountability (Kasturi, 2005).

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[1] Mention of trade names is solely for the information of the reader and does not constitute endorsement by the US Department of Agriculture.

Review of the Technology

RFID Applications

RFID technology has been in development since the 1940's (GAO 2005). The basic system consists of a tag, a reader, and a database. The simplest tags, or transponders, are passive devices that simply store a unique identification number or other data. More complex tags can be interactive, receiving data or actively transmitting information. RFID technology is most commonly applied to track the movement of goods in supply chain management systems. Applications include: consumer goods, groceries, highway toll systems, libraries, automotive manufacturing, security access and many others (Poirier and McCollum 2006). An international coding system maintained by the Electronic Product Code (EPC) network facilitates global application of unique RFID identifiers. At least 13 federal agencies of the US Government utilize RFID (GAO 2005) in their operations.

In its most basic form, RFID is an alternative form of item identification similar to bar coding. However RFID has some important features, including:

1) the ability to read multiple tags simultaneously,
2) line of sight is not needed minimizing alignment issues,
3) longer read distances are possible than with optical technologies,
4) tags can be read through dirt or protective materials,
5) potential to encode more data (bits) than optical codes,
6) and potential to modify the data on the tag.

These characteristics only describe the capabilities of the RF reading technology. It is important to keep in mind that the RFID application also includes data transmission and manipulation components. For example, a manufacturing application may use RFID to read tags on a pallet of parts. However the tag information needs to be checked against a database to determine what the pallet actually contains. Then the information on quantity, location, time, etc. will be used to update the company's inventory records. The simplest RFID application may only identify items against a database, while more integrated applications could include inventory control, automated billing, asset security, or other functions.

Logistics in Forest Operations

Forest operations generally involve processing and movement of trees and parts of trees from stump to a wood-using facility like a sawmill or pulpmill. The operation is highly variable depending on forest conditions, product options, ownership and regional differences. For example, a tree can be felled and processed directly at the stump into precisely dimensioned logs meeting the requirements of the end-user (in this case, a sawmill). Alternatively, a tree can be felled and skidded (pulled) out of the woods as a single piece for subsequent processing at roadside.

As a tree moves through the process, merchandizing decisions are made that separate parts of the tree. High-quality logs may be destined for a sawmill while lower-quality parts of the tree may go to a pulpmill or for energy use. As the tree is cut and sorted, inventory develops at different stages. The whole forest operation involves the management and coordination of felling, skidding, processing, sorting, loading and trucking activities.

Logistics management in forest operations tracks the movement of materials and resources. Uusitalo (2005) provides a review of state-of-the-art wood procurement systems for cut-to-length operations in Nordic countries. Individual trees can be precisely processed for optimal value recovery. Individual logs, manufactured to specific product requirements are sorted and marked in the woods. Information about the wood-in-process is available to all parties. The potential of this type of logistics application is to improve recovery and reduce costs using real-time information about the wood and product flow. Carlsson and Ronnqvist (2005) describe operational applications at different scales for wood supply management in Sweden. In their opinion, the greatest potential for improving efficiency and reducing cost is better integration through the wood supply chain.

The Cambium LTS described above is a successful example of an RFID-enabled logistics system for managing the work flow of individual high-value logs. Most forest operations in the US, however, track production units that are individual truckloads. The objective of this project was to evaluate the performance of RFID-enabled transportation management with a simplified MIS for asset tracking and activity reporting. Results of the test were reviewed to assess potential application of this technology to small and mid-sized forest products contractors.

Case Study of Container Tracking System

Current System

The business enterprise in this study collects biomass and transports material to wood-using customers. Biomass may be in the form of loose slash, thinnings, chips, sawdust, or other mill residues such as slabs. Using a roll-off container system (Atkins et al 2007), appropriate containers are dropped at biomass generating locations. When the containers are filled, the truck returns, picks up the containers and transports the material to the right customer. Currently the contractor's equipment includes 17 bins and bunks, a pup trailer, and a hooklift truck. He works with multiple biomass producers and multiple biomass markets across a wide geographic area, principally in western Montana and neighboring states.

Billable activity can occur on both ends of the work cycle. Biomass producers may be billed a disposal cost based on some measure of volume removed such as loads, cubic yards, or tons. Disposal costs for a biomass producer may even include some variable cost items such as a mobilization fee, a mileage charge, or a tipping fee. At the other end of the operation, the wood consumer is billed for the material delivered. This could include consideration for the volume and type of material, quality, and distance hauled. For any specific project, the contractor must consider the value of the end product, his operating costs to handle the material, and the market value of biomass disposal to the original producer. Between the values generated at each end of the operation, the contractor must be able to recover costs and generate profit.

The contractor currently uses a paper-based system to track work through the process. Each biomass container is assigned a unique number. The truck driver has a notebook with data forms to record information about date, time and location of container activities. When a load is picked up the form data includes information about the type of material in the load, source of biomass, delivery point and the size of the load (tons or yards). Periodically the truck driver will physically deliver the accumulated data forms to the contractor's office. There the information is reviewed by the bookkeeper who generates hardcopy invoices to submit to customers.

Several problems were noted with this system. First, it is difficult to keep track of the physical location of each container as they shuffle among projects and customers. The last location of a bin may only be recorded on a slip of paper. This can be particularly challenging when drop points are not identifiable sites (like factories) but rather nameless landings in the woods. A second problem is the time lag of production information between the truck notebook and the business office. Forms may accumulate in the cab for days or weeks before they are registered as work completed in the office. This can delay billing and increase working capital costs.

The Container Tracking System

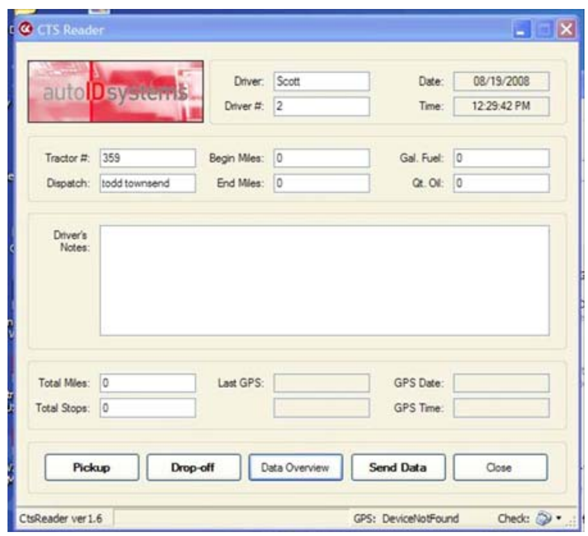
Working with the contractor, Cambium designed a prototype system that would fit the biomass container application. Existing paper data forms were reviewed to establish the data needed for the business. The physical configuration of bins and the rolloff truck were examined to determine operating requirements like sensing distance, power supply and mounting orientation. In order to help integrate the RFID application into existing processes, the entire work cycle was studied. This revealed potential issues like reading bin tags during the pup trailer loading process.

The prototype Container Tracking System (CTS) is based on ultra-high frequency (UHF) tags operating at 869 MHz. Each bin and container were identified with Sokymat EM4222 inline tags mounted on the front structure (Fig 1). These are Class 1 passive read-only devices with a unique EPC Gen2 64-bit identifier. The tags were isolated from the steel with a ¼"plastic dielectric spacer to reduce interference.

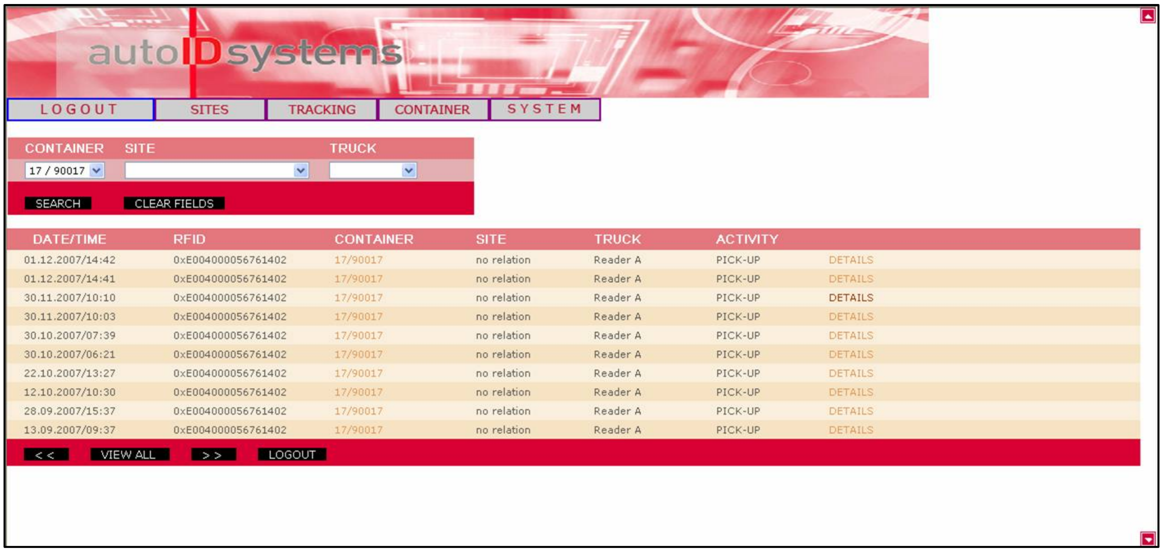
A Sirit Infinity 510 multi-protocol reader with two circular polarizing antennas (Poynting Patch-A0025) transmits and receives tag information. The transmit/receive antenna was mounted inside the rear window of the truck (Fig 2) while the second antenna, mounted under the passenger seat, was used to detect the ambient RF environment for active noise cancellation. In open air testing this configuration had a read range of 2-3 m.

The in-truck system operated on a laptop PC (HP 6515b) running Windows XP. A USB GPS receiver (GlobalSat BU-353) was connected to the laptop to provide position information. The BU-353 is Wide Area Augmentation System (WAAS)-enabled to provide 5 m location accuracy. The laptop included a mobile broadband card for internet connectivity, a navigation application (DeLorme StreetAtlas USA) and the mobile CTS application called CTS Reader. The laptop was placed in a rugged aluminum case that rested on the passenger seat. All of the RFID components in the truck were powered from a DC inverter running off vehicle power.

CTS Reader is a single-screen data-entry tool (Fig 3). When the truck driver executes a work event (pickup or dropoff), he opens the application and fills in the data fields. The bin identifier is recorded by the RFID components while the physical location is determined by the GPS unit. Free entry fields allow the driver to add information about mileage, fuel use, and general notes about the event. Data is stored in a data file queue in the laptop, marked as "to be sent." CTS Reader includes an option to manually enter a container ID if the RFID tag is unreadable (damaged or blocked, for example). Whenever the driver is ready to upload data, the broadband connection is established and the "Send Data" button initiates a data upload via Sonic XML Server to a remote secure system. The datafile is marked as sent and the queue is emptied.



A second CTS application with the master database and additional query functions resides on the secure server. Using the website and a password, company personnel can access the main database application. The prototype application allows data queries by site, driver, or container. The site function lets users assign a name (ie, "Mill XYZ") to a specific geographic position. When an event occurs within the range of the defined site it is identified with that location. Searching the database for all events at a site would generate a report of all pickups and dropoffs for a given customer. Selecting the container form allows a user to view the last recorded location including a map function using Google Earth.



The web-based application eliminates the need for physically transferring data forms from the truck to the company office. If the driver uploads events as they occur the system can operate in real time—with immediate notification of collection or delivery of products. Automatic data recording for time, date, position and bin eliminates potential errors associated with hand-coded forms. Once the data is entered by the driver it is electronically available for company use in billing or management.

Results

The CTS was originally implemented in the spring of 2007 on 17 containers. The system was modified over the summer to address some basic problems with functionality of different components. When the system had been well-shaken out it was run for over 200 work events at multiple locations around western Montana. The containers were dropped and picked up at mills, woods landings and woodyards. Subjective information about the performance of the system was collected during several interviews with the driver and contractor over the course of the study. During the operational period the weather ranged from 2° to 75°F and included rain and snow.

Operationally, the CTS functioned as designed. The GPS unit was able to locate positions in remote areas of Montana. The broadband connection was functional in many locations and the driver would generally be able to find cellular service at some point in a given day. Data uploads to the remote server were easily executed. The RFID tags survived a wide range of environmental conditions (summer-winter) exposed on the containers for the seven-month test. While the RFID reader was generally able to acquire the tags, there were some events where it was unable to read the ID. This was not a consistent problem and may have been due to ice on the window over the antenna or ice on the tag. In open air testing it was also noted that there were differences in read range among the tags. Several times, when a tag did not read, the operator cycled the roll-off system in an attempt to re-acquire the tag. When this happened it added significant time to the pickup and drop-off activity.

Functionally, the laptop imposed some limitations on usability. A key problem was positioning and viewing the display. An intial configuration of the system on a different laptop had marginal outdoor viewability. The HP 6515b has a 14.1" LCD display with 1280 x 800 resolution. The "BrightView" polarization film has higher contrast ratio and less blurring than traditional anti-glare screens (300:1 contrast ratio with 200 nits typical brightness). Even this display was difficult to read under some cab lighting conditions, particularly with dust on the LCD. The consumer laptop was also not appropriate given other environmental conditions in the truck. Rated operating temperatures from 32° to 95°F can be easily exceeded. Other parameters such as shock, moisture, and dust likely exceed design requirements although these were not quantified in this study.

A second usability issue that surfaced with the laptop configuration was the bootup time. A cold boot takes approximately 90 seconds to be at the data entry screen in CTS Reader. If the GPS has difficulty acquiring its signal the boot time may be even longer. Although the computer can be in standby mode (with a very quick 5 second wakeup cycle), any data in open applications is not saved to disk in this state. This issue is easily addressed by configuring the power options to put the computer in standby when the display is closed and exiting the CTS application before closing the computer.

Cabling and connections were another prototype problem. The connection between the laptop and the RFID reader, for example, went through three cables. A USB to serial interface cable was connected to a 9 to 25-pin serial cable that then connected to a serial key adapter that was plugged into the reader. Power for the laptop computer came from vehicle DC through an AC inverter, then through the computer's power transformer to turn the AC back into DC. Each of the connections in power and signal cabling introduced problems when things got bumped or jostled. Obviously these issues would be addressed in any production system.

The enterprise application on the remote server was less successfully utilized. At the outset of the system design one of the key issues was the ability to locate containers. The system provided that functionality including a map. However, during the period of the test, this was never an issue. The containers were always accounted for and it wasn't necessary to use the feature provided in software. The database of container events was used to extract information for billings. However the actual billing process (entering bill information on customer invoices, submitting bills to customers, etc) remained the same as it was prior to the CTS system. In effect, the only obvious benefit of the server application was to provide electronic delivery of the information from the truck driver to the office.

Because this was a prototype system it is difficult to determine costs. The RFID reader with antennas costs approximately $3000. Each UHF tag costs approximately $4.50. The laptop computer with GPS capability cost about $800. Power inverter, cabling and miscellaneous equipment adds another $200 for a total hardware cost of the system of

$4000 plus tags. If the laptop were upgraded to a more ruggedized unit the total hardware costs would be $5000 to $6000. The critical unknown is the cost of the software and support. The laptop application, server database, and website maintenance were developed as custom programs and the market price of such a system is not available. It would likely involve some up-front purchase as well as monthly support or licensing costs.

The payback for a Container Tracking System could accrue from several different potential savings that include:

1) Reduced billing cycle (Days of Sales Outstanding--DSO) through faster invoicing,
2) Reduced administrative costs (handling reports, invoices, tracking bins)
3) More efficient truck scheduling to increase ratio of loaded miles to total miles

An analysis of the financial impact of billing cycles was developed that included variables of bin volume, daily bin turnover, pickup and delivery values, and number of bins in the system. These variables all affect the daily sales volume. Assume the RFID system enables the contractor to reduce average DSO from 30 to 10 days. At a sales volume of $4000 per day the system would generate annual savings of about $6,427. The savings increase proportionately with sales volume. For example, doubling the number of bins doubles the savings. A contractor with 40 bins, with an average rotation of 2 days and a total cycle value of $40 per ton could accrue annual savings of $12,855 through faster billing.

Reduced administrative costs are harder to quantify. We were unable to establish how much time the contractor currently spends tracking customers, loads, and billing. It is highly variable and outlier events (like the misplaced bin or invoice errors) may require hours of admin effort. It seems reasonable to assume, for the contractor operation in this project, that a savings of several hours per week could easily be achieved. If this is charged at labor rates ($25 per hour) the annual savings would be on the order of $2500. Like the billing interest costs, administrative savings are directly related to the volume of billable work.

Trucking efficiency can be improved by better management of bin dropoff and collection trips. For example, coordinating drop off of empty bins on a trip to collect loaded bins would be more efficient than simply delivering empties and returning unloaded. For smaller operations, logistics management is usually an expert-based function of a dispatcher. As work volume increases, routing and scheduling alternatives become more numerous and complex and can easily defy human optimization. The RFID system could affect trucking efficiency in several ways. First, better information about bin locations and scheduled events could help a human dispatcher make better decisions. As work volume increases, a routing algorithm could be included in the application to provide optimized solutions (McDonald et al 2001). Recent applications suggest that a 5 to 10 percent increase in loaded miles can be achieved through better scheduling in forest products transport. Again, these savings would be proportional to total work volume.

For a single truck system like the contractor in this study the annual cost savings may be on the order of $10,000 to 15,000.

Conclusions and Recommendations

While this prototype system proved to be functional in the forestry transportation application, clearly some improvements would be needed for actual use. A key issue would be the best choice of the computer platform for the truck—the laptop imposed some limitations and was really underutilized in this application. For example, the CTS Reader and associated programs don't need the memory, hard drive capacity or CD/DVD features of a laptop. A simpler dedicated device might be more robust and usable (viewability, boot times, mounting in the cab, etc.). Cabling and power connections could also be improved and simplified.

The value of the RFID component itself is based on whether it is more reliable or faster than an alternative such as writing down a bin number on a paper form. In this test, the system was reliable in recording bin identification. In addition it also accurately and instantly recorded location, date and time. Arguably these functions are more reliable via RFID than with an operator recording information on a form. The primary concern with the time required involved operator interaction with the computer itself (booting, loading applications) not with the RFID data form or input requirements. The system also enabled instant transmission of data to the company.

As pointed out by Poirier (2006), the real value of RFID comes from action based on the identifying information. RFID is merely a technology that enables automatic collection and entry of identification data. The enterprise application that uses the identifying information can create value by automating tasks and by reducing lead times for activities such as billing. To realize this kind of benefit however requires a fully integrated system. In this prototype test, for example, the RFID information was recorded and transmitted to the database where the company office could access it. However, to create a bill, the bookkeeper had to manually transfer the information to a separate billing process. A truly integrated EIS would have a one-button process for billing that combined event data (delivery quantity, dates) with customer data (negotiated rates, billing address, etc) to generate and submit timely statements.

An integrated enterprise application could also provide better information to manage work. For example, in the current paper-and-pencil recordkeeping system, it would be difficult and time-consuming to develop a report on the average amount of time that a bin is sitting waiting to be filled. An integrated enterprise application could be designed to provide such measures as part of a management "dashboard" (Alexander 2007). This information might be used to identify jobs that have low bin utilization.

The question of the value of such a system is difficult to quantify. Some benefits are direct and measurable. For example, timely billing can reduce working capital requirements. Faster data entry can reduce bookkeeping time. Quickly locating a misplaced load by using GPS coordinates saves labor costs in hunting down the missing container. All of these savings are a direct function of the volume of work (bin transfers). Smaller work volume would have lower total savings. The simple analysis in this project suggests that the greatest potential savings are likely in improved trucking efficiency and reduced billing cycles. A small contractor may be able to realize an annual savings of $25,000 to $30,000 from the three sources noted above using an RFID-enabled system.

The greatest potential value is more likely found in creating new products or values through better data management. For example, instead of a single flat billing rate for the use of a container, the RFID system might enable an hourly or daily rate structure that would attract new customers. The system might be able to provide estimated delivery times, or an optimal route scheduling routine, or an online tool to set a pickup time. To develop the right set of work activities and value drivers requires a careful review of the business. With that starting point, an integrated enterprise application could be developed.

In this demonstration project the full potential of RFID was not realized because of the lack of a robust enterprise application that matched the work needs of the particular contractor and the low volume of bin activity. The features incorporated in the server application for the test provided examples of possible use but did not effectively integrate with the existing business work processes. However, with an appropriate enterprise management system mid-sized contractors would likely be able to realize operational savings with such technology.

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