

A computer-based time study system for timber harvesting operations

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Abstract

A computer-based time study system was developed for timber harvesting operations. Object-oriented techniques were used to model and design the system. The front-end of the time study system resides on the MS Windows CE and the back-end is supported by MS Access. The system consists of three major components: a handheld system, data transfer interface, and data storage. The design module on the handheld is used to design harvesting functions and variables for different types of machines, sites, and stands. The data collection module also resides in the handheld system and is used to collect time, motion, and other data for harvesting machines in the woods. The interface module of data transfer is used to transfer field data from handheld to the main data storage on a desktop PC. This module resides on a desktop PC and allows the user to manipulate and export the data collected in the field. Results from field tests indicate that this system can provide accurate and reliable time study data of logging operations.

Time study is "a set of procedures for determining the amount of time required, under certain standard conditions of measurement, for tasks involving some human, machine, or combined activity" (Mundel and Danner 1994). Throughout the years, time studies have been conducted in different ways. Early in the 20th century, stopwatches and paper were used to measure and record times (Howard 1989). This method usually required two people working together. One operated the stopwatch and recorded the times and the other took measurements about the site and volume of timber being removed from the forest. This method is probably the most common method used in logging production.

However, such traditional time studies can be very tedious, expensive, and error prone (Olsen and Kellogg 1983) and

are being replaced by computer-based time study methods (Howard and Gasson 1991). Another method that has been introduced to time studies is the video camera. It captures exactly what is happening on video, while the time measurement is recorded. Information about the site or volume of timber is still needed, so extra time and resources are required to collect these data.

In recent years, new techniques have been introduced into computer-based time studies of forest operations. A DOS-based handheld time study system

was developed with the advantages of the ability to modify the time design "on the fly" and the economy of keystrokes (Howard and Gasson 1991). Designing, editing, and preparation of the time study had to be done on the base computer and the edited data were saved in a plain text file with this system. The design driver had to be downloaded to a handheld prior to use. Using the built-in clock in the computer, the observer used the program to collect times while entering the site and volume information.

An automated time study of felling and skidding was developed by McDonald and others (McDonald and Rummer 2000, McDonald 1999). It used Global Positioning Systems (GPS) for tracking machine movements and switches for monitoring machine functions. The system was successful in providing gross time study data, but less so in providing detailed elemental times. Their results also indicated that the sequencing of tree cuts with felling cycles was subject to errors.

Some generic data collectors have been developed for industrial engineering management, such as DataMyte (www.datamyte.com) and DigiForm (www.digi-form.com). DataMyte could

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collect data in demanding factory environments and provide solutions for enterprise-wide quality control systems while DigiForm is a procurement information management system. Computer-Integrated Time Study (CITS) has been developed by C-Four to assist industrial engineering time study (www.c-four.com). CITS is capable of collecting, organizing, and presenting time studies of a general industrial engineering process. More computer knowledge, however, is required for the user to operate and customize the program for the logging industry. Apparently, an accurate, user-friendly, and portable time study tool for timber harvesting operations is needed.

Objectives

The objectives of this study were to:

1. Develop a handheld time study system with MS Windows-based graphical user interface (GUI) for timber harvesting operations.
2. Adapt a relational database as the backend for time and factor data storage in the system.
3. Build an interface module for time and factor data communication between desktop PC and handheld PC (HPC) using ActiveX Data Object (ADO).
4. Evaluate the performance of the handheld time study system with field tests.

System structure

This time study system consists of three major parts: the handheld system, a GUI on the desktop PC, and a data storage component (**Fig. 1**). The handheld system is used to edit species, design harvesting functions and variables, and collect site, elemental time, and variable data. The GUI component on the desktop provides the interfaces and functions needed to transfer data between the handheld and the desktop PC, and to manipulate and export the data for later analyses. The data storage component is a typical relational database containing tables of the time study data.

The handheld system was written with Microsoft VB CE, which runs under a Microsoft Windows CE environment. It contains two modules: design and collect (**Fig. 2**). Framework design was essential to promote full exploration of the advantages of computer-based

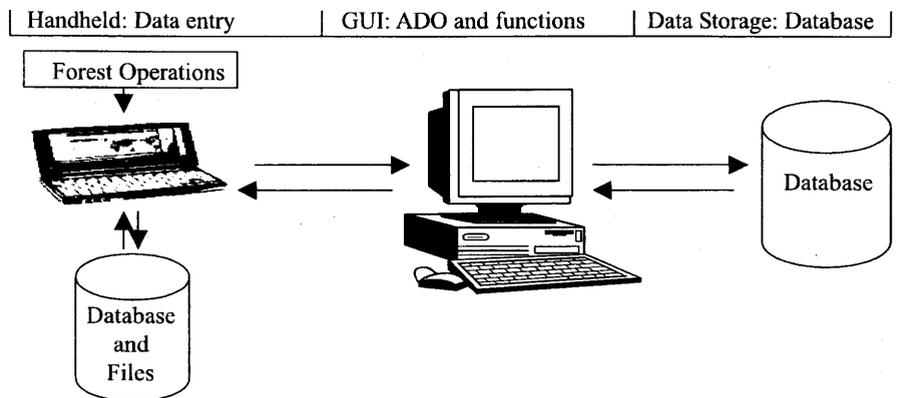


Figure 1. — Architecture of the time study system.

time studies over traditional manual methods and had to conform to well-established design principles established in previous efforts (Howard and Gasson 1991, Gibson and Rodenberg 1975). The design module in this system includes functions that allow the design work to be done on either the PC or the handheld. It provides the user with the option to enter or edit tree species to be used in the study site.

Harvesting functions refer to the procedures or steps involved in the work cycle of a harvesting machine. For example, chainsaw felling may require four steps: walk to tree, acquire, fell, and delimb/top. The system allows the users to define functions for a specific machine. Harvesting variables are the factors that affect harvesting operations and elemental times. For example, diameter at breast height (DBH), height of the tree, and distance between harvested trees are the variables for chainsaw felling in addition to site effects. Once the time study design is completed, the collect module can be invoked and will retrieve the information entered in the design module. Supporting help files using html-based architecture are also provided for this handheld time study system.

The data transfer interface module was written with MS VB V6.0 under a Microsoft Windows 98 or NT environment. ADO CE application programming interface (API) was employed to conduct data transfer via a dynamic link library (DLL) – `adofiltr.dll` (Roof 1998). This DLL contains two func-

tions, `DesktopToDevice()` and `DeviceToDesktop()`, which are used to transfer data or copy tables. It runs on the desktop PC, not the handheld. The desktop initiates and controls the transfer process. The key requirement for this transfer process is to have the same table schemas on both desktop and handheld. The ADO CE data transfer feature has a solid set of tools for transferring data. While the manual method for copying tables does not offer the control needed by most applications, the programmatic method does. This feature allows the transfer of complete tables between devices rather than requiring the synchronization of individual records.

A relational database model was used for holding harvesting functions, variables, and time study data in the handheld system, which was implemented based on the entity-relationship (ER) model (**Fig. 3**). The relational database model presents the data as a collection of tables. Instead of modeling the relationships in the data according to the way that it is physically stored, the structure is defined by establishing relationships between data entities. An entity represents a data table in the ER model and has attributes (fields) that are the descriptive properties of the entity. Primary key refers to one or more fields that make a record unique in a data table. The field or fields used to link to a primary key in another data table are known as foreign keys and a foreign key is any field(s) used in a relationship.

Basically there are six data entities in the model: *harvesting functions*, *variables*, *site*, *species*, *time track*, and *felling/skidding/forwarding/yarding*. Each entity has its own attributes. For example, the *harvesting functions* entity has function ID and name, and machine type attributes. Entities are related using relationships such as “has,” “contains,” and “associates” in the model. A derived attribute *Elapsed_time* was used in the *time track* entity, which is derived from *Start_time* and *End_time* attributes. Attributes belonging to a key are underlined for an entity set. Cycle number, machine type, function start time, end time, elapsed time, and associated harvesting variables are automatically recorded. Harvesting functions, variable data, and species are stored in separate data tables in the design module, which are identified by their primary keys and

harvesting machine types. In the collect module, harvesting functions and variables can be queried and retrieved for a specific machine type on which another data table is created for storing functions, variables, and elemental times. Species information is also retrieved for data entry. The site data table contains general information such as site number, name, location, slope, and weather conditions about the logging site. Site number is used as a foreign key to associate site information with other data tables created in collect module.

The *time track* entity is used to track the start and end times of each element in a work cycle. It can also be used as a backup data table for felling, skidding/forwarding, or yarding data entities. The *felling/skidding/forwarding/yarding* entity is designed to store time study data of felling, skidding, for-

warding, or yarding depending on the type of logging operation being studied. Data schemas of the main data storage on the desktop PC are the same as those used in the handheld system in order to facilitate the data transfer.

System implementation

Design module

Three functions were implemented in this module for designing and editing species, harvesting functions, and variables (Figs. 4a, 4b, and 4c). Data were edited and saved into the database in the design phase and are then retrieved for uses in the data collection phase. The system also allows the user to navigate the database for a species, function, and variable. While navigating to a specific data record in the list, the user can edit or delete the current record.

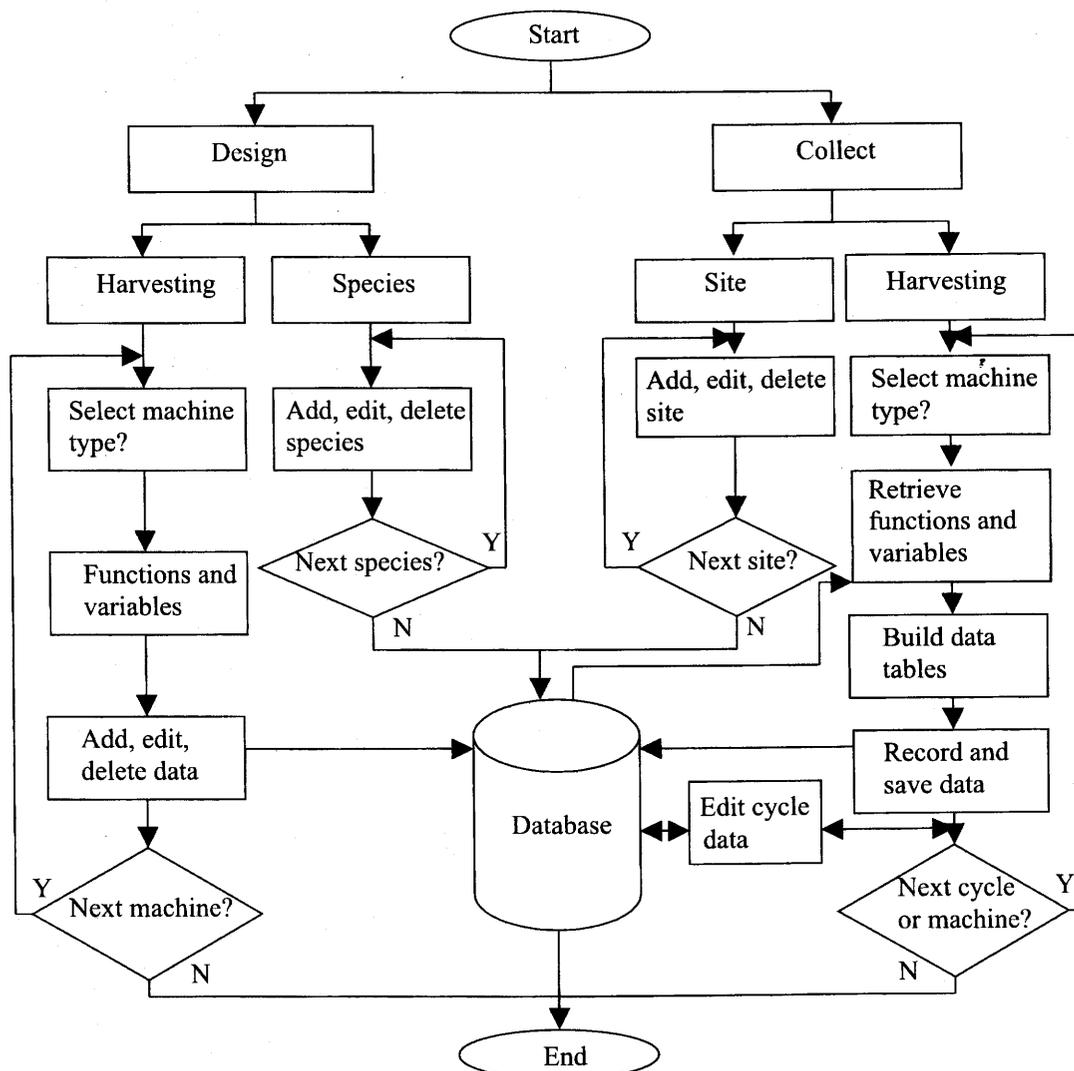


Figure 2. — Flowchart of the handheld-based time study system.

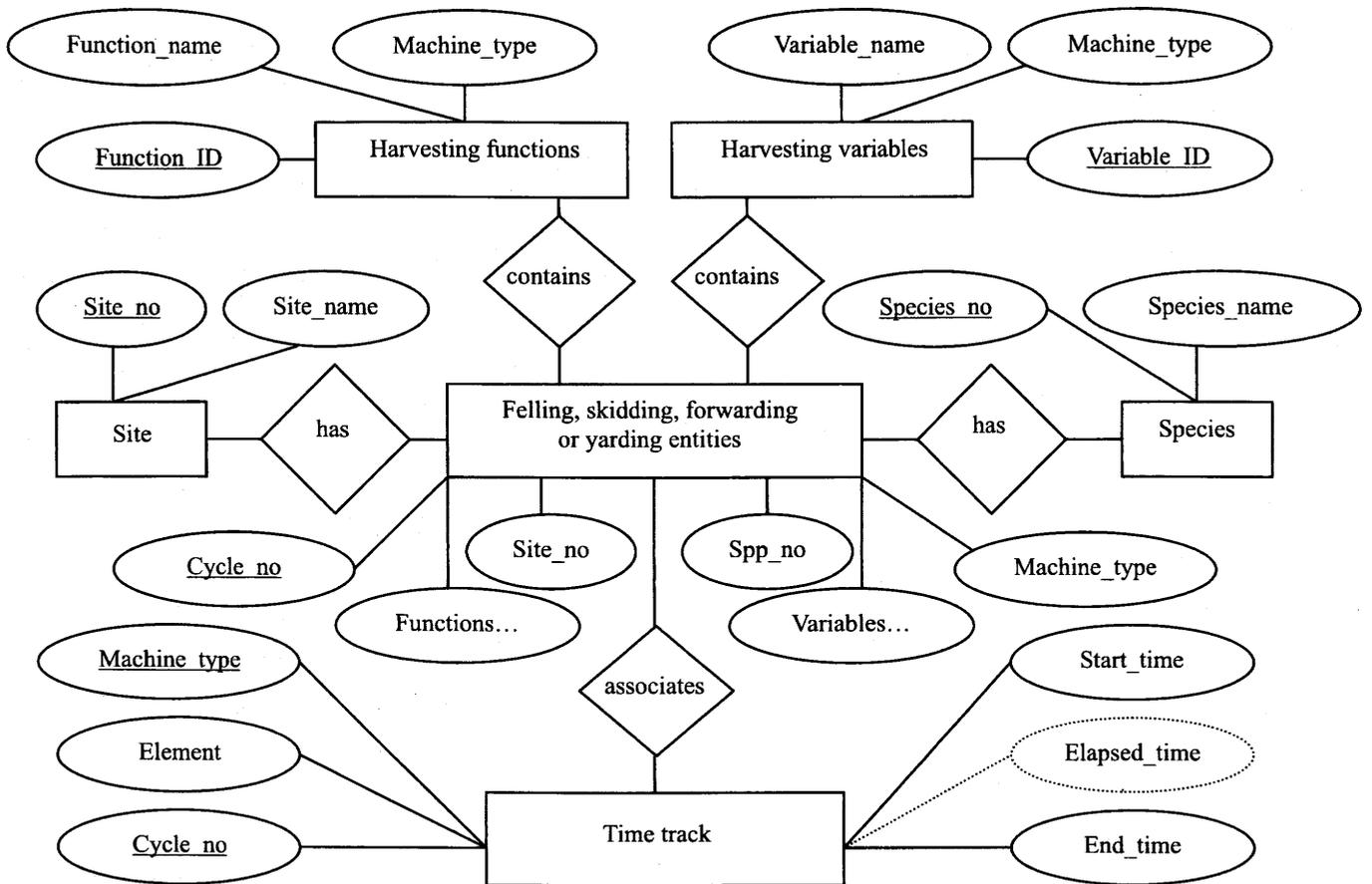


Figure 3. — ER data model of the handheld time study system.

Harvesting functions and variables were implemented to allow the user to design and edit their names and associate them with machine types. Data fields, including function/variable ID, function/variable name, and harvesting type, are used in such a data table.

Collect module

There are three required fields: site name, site slope, and study date to collect data for a site (Fig. 4d). The user is required to fill out these three data fields for this site. The site number will automatically be increased and recorded when a new site is added. The *Site No.* will be retrieved later when the user starts to collect time study data and will be saved together with these data as a foreign key in the database.

Collecting elemental times and variable data is the ultimate objective of time studies. When invoking the collect module to collect harvesting elemental

times and variable data, all the useful information entered under the design module can be retrieved and employed (Fig. 4e).

Elemental times and variables are saved in a database table whose data structure is created based on the parameters entered in the design module. The handheld system can check the data table status to determine whether the table was created or if the existing table's data structure is consistent with the current data. If the table does not exist or its structure is not consistent, a new table can be created.

In order to associate the site information with the time study data, a site number in the *Site No.* combo box must be selected. To record elemental time for a function, the user needs to select the function from the *Function* list box by simply clicking this function. Hit *Start* when this function starts and hit the *Re-*

cord Time button once the function ends. Repeat the above procedures for any other functions in the list. If the user is not sure what function the logger is going to perform next, the program allows the user to click the *Start* button first, then select the correct function when it is identified, and finally click *Record Time* when the function is completed. The system also allows the user to record a function multiple times in sequence and the elapsed time for this function is then accumulated accordingly. To record a value for a variable, the user needs to select the variable in the *Variable* list box using the same procedures outlined for selecting a function. Then, the user can simply type a value in the text box beside the *Record Value* button and click this button. The value for the selected variable is recorded. Repeat the procedures for other harvesting variables. A brief comment can also be recorded in the system; it is

especially useful to record a comment for a cycle or the delay reason in that cycle.

Another option is also provided to enter the variable's value. If the handheld does not have a keyboard or the user does not like to use the keyboard on the handheld, she/he can use the *Species* combo box to select a species by clicking the species required if the variable is tree species. If the variable is numeric, the user can click the *Get Number* button and a data input form will be invoked. Then, the user simply clicks number buttons and the *Enter* button to get the required number.

Once the recording is completed for the current tree or current work cycle, the user would click the *Next Tree* or *Next Cycle* button to save the current

tree/work cycle data to the database. Elemental time is recorded in seconds and can be converted to minutes when the user exports the data for analysis. Units for harvesting variables can be defined by the user.

An editing function for the data in a cycle is provided in the data collection module. The system is implemented to allow the user to go back to any previous work cycle being recorded, then edit the elemental times and variables or fill out the missed data in the cycle. Since it requires connecting to the same data object from two different processes at the same time, the system would not allow the performance of two or more data manipulation events concurrently, but rather sequentially, in order to avoid mutating table errors.

This functionality is especially useful for the time study of chainsaw felling. For example, the sawyer may harvest one tree and complete all the functions before walking to the next tree to be harvested. In some cases, however, the sawyer might acquire and fell a tree, then walk to another tree and acquire and fell it, and then go back to the first tree to delimb and top it. To edit the cycle data, the user first needs to navigate to a cycle using the < or > buttons and then use the following procedures: 1) select the function or variable from the list boxes; 2) modify their values in *Time* and *Value* boxes; and 3) click *Edit* button to update the cycle data (Fig. 4e). The user can also use the *Start* and *End* buttons in the *Edit Cycle* frame box to record the

(a)

(b)

(c)

(d)

(e)

Figure 4. — Main forms in the handheld-based time study system.

elapsed time for the selected function instead of entering a value in the *Time* box.

Transfer data

A data transfer module was implemented on the desktop PC, which provides three basic functions: 1) transfer data from HPC to PC; 2) update main data storage; and 3) empty data tables copied on the HPC. For the sake of data security, this module was designed to run the events sequentially. First, the data tables on the HPC are copied to a temporary database on the PC. Then, the tables in the temporary database are appended to the related tables in the main database. Finally, the system empties the data tables on the handheld in preparation for the next time study. Meanwhile, the user can decide whether or not the event should be activated in each step.

Field application

The handheld time study system was tested in typical central Appalachian logging operations in West Virginia in August 2001. The logging system examined during the time study was chainsaw felling and cable skidder skidding. A partial cut was performed in the hardwood stand. The major species in the stand are yellow-poplar, white ash, American beech, and red maple with average DBH of about 12 inches. Average site slope is about 20 percent and the temperature on the testing days was about 80°F. A video camera was used to identify the time lag and elapsed time difference of the handheld system for chainsaw felling while two cameras were used to record the continuous activities of the cable skidder. Motorola

walkie-talkie radios were used for communication between the person on the landing and the person in the woods for skidding operations. The following items were examined to evaluate the performance of the handheld system: 1) battery condition; 2) screen viewing condition; 3) time lags of start time and end time for each element; and 4) difference of elapsed time.

Time lag of start or end time was measured by subtracting the start/end time recorded with a video camera from the start/end time recorded by the handheld for each element. Difference of elapsed time for an element was the absolute result of subtracting elapsed times recorded with the video camera and the handheld. Before the field tests, the internal clocks of handheld and video camera were set to exactly the same time.

The main battery of HP Jornada provides power to the system while performing the time study in the field. Under normal operating conditions, the fully charged battery could provide power for up to 7 hours. During our tests, the handheld was used for about 5 hours a day and about 60 percent of its power was used. There is a backup battery in HP Jornada that is used to protect the data when the main battery runs out of power. However, the backup battery does not provide enough power to operate the program.

The handheld computer was easy to operate but at times it was hard to tell what the feller was doing because of the understory. We noticed that viewing the HPC screen in direct sunlight was diffi-

cult. Once appropriate contrast and brightness were adjusted and direct sunshine was avoided, the HPC worked very well. The stylus was used in much the same way the user would use a mouse to navigate and select objects on screen. The user could also use a fingertip to tap the touch screen, but the stylus would provide the greatest accuracy.

A total of 32 work cycles were recorded for chainsaw felling while 21 cycles were examined for the cable skidder (Table 1). Time elements evaluated were Walk to tree, Acquire, Fell, Delimb/top, and Delay for chainsaw felling; and Travel empty, Choke, Travel loaded, Unchoke, and Delay for the cable skidder.

Average start time lags were between 0.06 and 0.11 minutes, while average end time lags ranged from 0.07 to 0.14 minutes among elements for chainsaw felling. Time lags were due largely to the delays for identifying the start or end of an element. However, there was one case where the handheld started to record the start time 0.11 minutes earlier than the time recorded with the video camera for the felling element in our field tests. Difference of elapsed time is the point of most concern for examining the performance of the time study program. If the start time lag is equal to the end time lag, there will be no difference between elapsed times recorded by the video camera and handheld. In the field study, the difference of elapsed time only varied between 0.03 and 0.09 minutes for the time elements in chainsaw felling. Skidding test results also showed that the average start time lags ranged between 0.07 and 0.13 minutes and aver-

Table 1. — Statistics of field performance of handheld-based time study system.

Harvesting	Element	Start time lag				End time lag				Difference of elapsed time			
		Mean	SD ^a	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
----- (min.) -----													
Chainsaw felling	Walk to tree	0.09	0.08	0.02	0.33	0.08	0.07	0.02	0.27	0.05	0.06	0.00	0.20
	Acquire	0.07	0.05	0.02	0.23	0.07	0.05	0.02	0.20	0.03	0.03	0.00	0.15
	Fell	0.06	0.06	-0.11	0.21	0.08	0.07	0.02	0.33	0.05	0.07	0.00	0.30
	Delimb/top	0.11	0.07	0.03	0.37	0.14	0.11	0.03	0.47	0.06	0.09	0.00	0.37
	Delay	0.11	0.10	0.05	0.27	0.07	0.03	0.03	0.12	0.05	0.07	0.02	0.15
Cable skidder skidding	Travel empty	0.11	0.08	0.03	0.33	0.13	0.10	0.03	0.43	0.04	0.07	0.00	0.33
	Choke	0.13	0.10	0.03	0.42	0.12	0.08	0.03	0.38	0.04	0.04	0.00	0.15
	Travel loaded	0.16	0.08	0.05	0.42	0.17	0.09	0.10	0.40	0.07	0.09	0.00	0.37
	Unchoke	0.08	0.05	0.03	0.20	0.09	0.06	0.03	0.25	0.03	0.04	0.00	0.17
	Delay	0.07	0.01	0.07	0.08	0.08	0.08	0.02	0.07	0.01	0.01	0.00	0.02

^a SD = standard deviation.

age end time lags were from 0.08 to 0.17 minutes for the elements of cable skidding. The difference of elapsed time was only between 0.01 and 0.07 minutes.

Discussion

Many improvements have been made since time study was first introduced. From stopwatches to video cameras and now to handheld computers, changes have continued to be made for the better. The Windows CE-based handheld time study system developed in this study provides a user-friendly interface and more flexible functionalities to collect time study data of forest operations. The system can design the species, harvesting functions, and variables in either the office or in the woods. Touch screen or numeric data entry on handheld computers also provides an efficient means of data collection. No specific computer knowledge is required to operate this time study system. With the integration of the data transfer interface, this system can improve time study work greatly and make the task easier, more efficient, and more accurate.

Although the system is intentionally designed for elemental time studies, it can be used for gross and work sampling time studies. Furthermore, it can also be used for all types of logging machines. The system can be used to perform time studies for two or more different types of machines. In order to collect the data for the same types of logging machines, one handheld unit has to be used for each machine.

A statistical analysis module should be added to the system. This will allow the user to analyze the data and provide

some basic statistics such as sample size and error of the time studies.

HP Jornada is the development prototype of this time study system. However, this system is compatible and can be run on any handheld computer such as Juniper Allegro, Palm and Pocket PCs with Windows CE or H/PC 2000 operating systems.

Using walkie-talkie radios to communicate between the person on the landing and the person in the woods worked well. However, it could distract the user to some extent. Another technique that can be potentially used for such communication is wireless networking, which uses a Windows CE-based personal digital assistant (PDA) to manage two or more handheld units through a wireless link. When one person on the landing starts to record the elemental times for functions in a skidding or forwarding cycle, the other person in the woods will be notified and can record the times and other variables for the subsequent functions in the same work cycle.

The system was successfully used in the field tests and provided accurate and satisfactory data. The difference of elapsed times recorded with the video camera and handheld was less than 0.1 minutes for the elements of felling and skidding. Time lags were noticed in the field tests when the user hit the *Start* and *Record Time* buttons for recording the elemental times. This was mainly caused by delays in identifying the start or end of the time element. In our tests of partial cuts, sometimes it was difficult to identify the start and end of an element for chainsaw felling. Such time lags can

be reduced if the start and end of an element can easily be identified and if the view of the handheld user is not blocked. Under extreme weather conditions, the system should work if it is loaded into another type of field handheld PC such as Juniper Allegro. If the study must take place in winter, some extra fully charged main batteries should be taken with the HPC in order to keep it working for several hours. Extensive applications of this system will be conducted in a research project at West Virginia University.

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