Automating Construction Data Acquisition for the Florida Department of Transportation By Using Pen-Based Computers

RALPH D. ELLIS, JR.

The management and administration of construction contracts require the collection and analysis of a great deal of information as the project progresses. Much of this information is recorded and collected at the project site. Although the microcomputer is now used extensively as a construction management tool, the collection of field data remains essentially a paperwork process. The results are presented of a trial program undertaken by the Florida Department of Transportation that involved the use of pen-based computers for job-site data acquisition. Data entry with the pen-based computer is accomplished by writing on the screen with a tethered pen. Capabilities of this new technology are discussed. Results of the field trials are presented with recommendations for future implementation.

Effective management of construction requires a continuous collection of project information. Most of this information must be observed and recorded at the project site. For example, progress updates, pay estimates, inspection, and testing all require extensive field data collection. A state transportation agency's construction management success depends largely on the quality of the information obtained from the project site. Accurate and timely information is essential for sound management decisions.

Although the microcomputer is now widely used as a construction management tool, the recording of information at the job site remains essentially a handwritten paperwork function. Both owners and contractors make extensive use of preprinted forms to record daily project information. Field personnel may be required to commit much of their time to this paperwork. The field reports are normally submitted back to the office at intervals. At the office, the handwritten information might be retyped or keyed into a computer. Often the information remains in handwritten form and is simply stored in a project file. Obviously, the retrieval of this handwritten information at some future date can require a great deal of time.

Various direct data entry devices have emerged and have been tried with varying degrees of success in the construction industry. One of the most successful has been the bar code readers (*1*). Bar coding has proven to be particularly useful in material management applications (*2,3*). Other, still evolving systems such as the voice recognition systems have had limited application (*4*). These devices can recognize and respond to a limited preset vocabulary. However, direct data acquisition remains a goal that industry has not yet been able to achieve. Data collection procedures for the majority of today's construction projects are the same paperwork-intensive methods used for years.

The Florida Department of Transportation (FDOT) has one of the nation's largest construction programs. In the past few years, the construction budget has doubled. This year the dollar volume is expected to approach one billion. Managing this expanding construction program is extremely challenging.

In an effort to improve the efficiency of its construction management system, the FDOT continually examines emerging technology. The recently developed pen-based computer appeared to be ideally suited for job-site data collection. Consequently, the FDOT employed the University of Florida to develop and field test a pen-based computer data acquisition system for use on FDOT construction projects. This study has now been completed and the results are presented in this paper.

PEN-BASED COMPUTER TECHNOLOGY

Hardware

Pen-based computers utilize recent technological advances in computer screens, microchips, and software. The primary difference between the pen-based computer and a conventional notepad computer is the absence of a keyboard. The user interface is a tethered pen.

When the pen is touched to the screen, an electrical voltage is passed between the pen and the screen. The screen has a special coating that facilitates the electrical connection. Microprocessor hardware within the computer records the exact position of the pen point on the screen. Using advanced handwriting recognition software, the computer is able to interpret handwritten print. The character recognition algorithm functions by analyzing both the sequence and the location of the pen strokes. When the writer pauses, the pen strokes are instantly converted to digitized characters and the handwritten print is replaced on the screen with a standard text.

Department of Civil Engineering, University of Florida, Gainesville, Fla. 32611-3730.

These computers are about the size of a clipboard and weigh about 4 lb. Internally, the pen-based computer is comparable with a conventional microcomputer. Pen-based computers are available with the latest microprocessor chips. Configuration typically includes 1 to 4 megabytes of main memory. Memory storage is provided by removable random-access memory (RAM) storage disks. Access time for the RAM storage disk is much faster than that for even the fastest hard drive. In addition to the RAM storage devices, the latest models can now be obtained with a conventional hard disk drive. As with conventional laptop computers, power is supplied by an internal rechargeable battery pack or by direct connection to a power source.

Using an MS-DOS operating system allows the pen-based machines to run practically all IBM XT–compatible software. Spreadsheets, scheduling, estimating, and other traditional application programs can be performed. A graphic image of a standard keyboard can be called up on the lower portion of the screen. Touching the pen to the keyboard image acts exactly as a keystroke on a keyboard. However, the true power of the pen-based computer is realized by using specifically developed application software.

Software

Pen-based computers are a new technology; consequently, national software vendors have not yet emerged. Some application software is being custom developed for individual users by software consultants. Other organizations have elected to do the programming with in-house resources.

Programming is generally accomplished through a pen-based interface programming language. This interface software provides the handwriting recognition capabilities that translate printing into ASCII characters. The interface software also contains a specialized function library that facilitates the development of the input screens. The interface language requires a general programming language platform such as C or Clipper.

Programming design focuses on objects and events. In the pen-based environment, objects are the figures on the screen. For example, a check box is an object. An event is some occurrence caused directly or indirectly by the user. Examples of events include touching the pen to the screen or writing in a field. Essentially, the software is designed to look for an event and then make an appropriate response.

The basic product of the application software is the form or input screen template. A particular application may use a single form or may use multiple input screens linked interactively. The form serves as the input interface. Data are acquired from the user by means of several different types of input objects shown on the screen. These input mechanisms are

- Lists,
- Buttons,
- Radio buttons,
- Check boxes,
- Text fields, and
- Graphic fields.

The list provides the user with a group of choices. Selection is made by touching the screen. The list can contain many more choices than are shown on the screen. The user can scroll through an extensive data base of items and select the appropriate one. The list feature is perhaps the most useful of the data input devices.

Buttons, radio buttons, and check boxes are simply either on or off. They may be used to record a user choice or to activate a dynamic list. The buttons may also be used as a menu of choices for selecting different forms or applications.

The text field allows the input of printed text. Information printed in by the user is converted to ASCII text and recorded. A numeric keypad or a typing keyboard may be called up on the screen from a text field. The information can be entered as key strokes rather than as printing.

Graphic fields are used to record graphical information input by the user. The graphic image is digitized and recorded. One important use of this feature is for a signature block. Signatures can be recorded and stored as graphic images.

DEVELOPMENT OF PEN-BASED REPORTING SYSTEM

FDOT's Daily Report of Construction

Although many different forms are used in FDOT's construction management system, it was initially decided that only a single form would be converted to the pen-based system. The form selected was the Daily Report of Construction. This is a two-page form (single sheet, front and back) used by FDOT to record general information about construction project status. The contents of this report include the following general categories:

1. Project number, contractor, subcontractor identification, date;
2. Listing of the work activities performed on the report date;
3. Listing of the numbers and trade classification contractor personnel on the project;
4. Listing of the numbers and type of contractor equipment on the project;
5. Listing of the work quantity increases by contract pay item number;
6. Weather information including any delaying effects;
7. General comments; and
8. Signatures of the technician and the project engineer.

A daily report of construction is completed each day on every FDOT construction project. A separate report is done for the prime contractor and each subcontractor.

The daily reports are handwritten in the field by FDOT personnel. Normally, the reports are submitted to the resident construction office once a week where a weekly summary report is prepared. Each month a monthly pay estimate summary is prepared. The monthly pay estimate lists the work quantity performed on the project by pay item number. The original copies of the daily report of construction are held in the project construction file. Other than the work quantities

for pay estimates, no daily report information is extracted, retyped, or keyed into a computerized data base.

Retrieval of specific information requires physically reviewing the paper copies of the daily report of construction, which can be a time-consuming task. For example, gathering information relating to a contract claim may involve many person-hours of management time.

To facilitate the field personnel's use of the pen-based computer, the daily report of construction replicated on the pen-based computer was almost an exact copy of the original preprinted form. However, the length of the form required that it be divided into seven sequential computer screens.

Computer Hardware

The pen-based computer selected for this study was the GRIDPAD model 1900 by GRID Systems Corporation. When this study began in 1991, GRID had been manufacturing pen-based computers for several years. In fact, GRID was the only viable source for the required hardware. Since that time, several computer manufacturers have now developed pen-based computers.

The GRIDPAD is approximately the same size and weight as a conventional notebook computer. Power is provided by a rechargeable battery pack. Input to the computer is by writing on the screen with a tethered pen. Data storage is provided by two removable RAM cords available in 512-kilobyte or 1-megabyte capacity.

The computers appeared to be quite durable and suitable for field use. However, the screen, which is glass, can be broken if struck by a hard object. Figure 1 shows a GRIDPAD pen-based computer.

Software

Software development was performed using the Clipper data base language and Pad Base pen-based development tools by R2Z, Inc.

Building the on-screen forms with the Pad Base tool kit is fairly straightforward. However, writing the underlying Clipper code involved considerably more work. The daily report of construction actually consisted of 278 data fields, which required more than 3,000 lines of Clipper code to support the application.

Software development for the daily report of construction application required approximately 500 programming hours. Much of this time can be attributed to learning a new development language. Subsequent applications are expected to require far less programming effort.

An office resident data base management utility was also developed in Dbase IV. This application was designed to receive the report information from the pen-based computers and to provide reporting and file storage functions.

Pen-Based Reporting System

The FDOT's daily report of construction form was converted to a pen-based computer application requiring seven screens. When the computer is turned on, the initial pen-based reporting system (PRS) screen appears. Menu selections include

1. Work on a new report;
2. View/edit a previous report; and
3. Quit.

A pop-up scrollable list gives all projects currently in the computer memory. The user selects the appropriate job by touching the pen to the project number on the list. Standard project information is then pasted to the header portion of the daily report form on the screen. Menu selections are made by touching the pen to the appropriate on-screen button. Figure 2 illustrates the PRS opening screen.

Data are entered on the form either by touching the pen to a check box or by printing the information in a text field. Because of space constraints, not all the PRS screens have been included here. However, Figures 3 and 4 show the general layout and are representative of the complete application.

One of the more convenient features of the PRS is a memory resident listing of all contract pay items for each project. When updating pay item quantities, the inspector can pop up a scrollable listing of all pay items. By touching the pen to an item, that item can be pasted to the form. Because the signature blocks are programmed as graphic fields, the inspector's signature is saved exactly as signed in a graphic file.

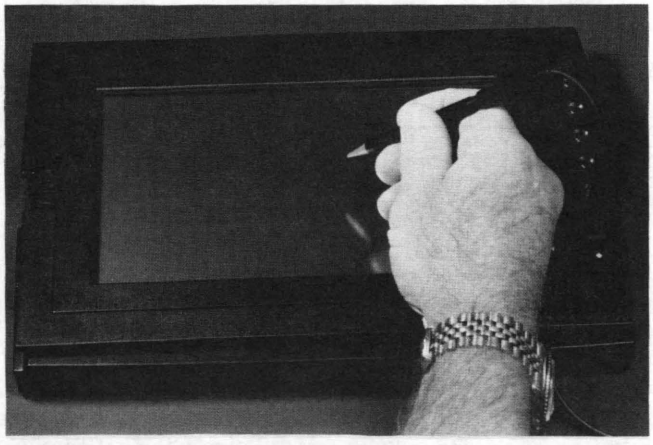

FIGURE 1 GRIDPAD pen-based computer.

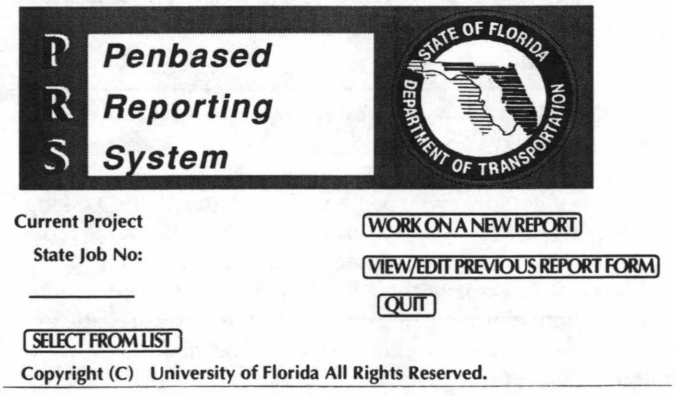

FIGURE 2 Opening screen of the pen-based reporting system.

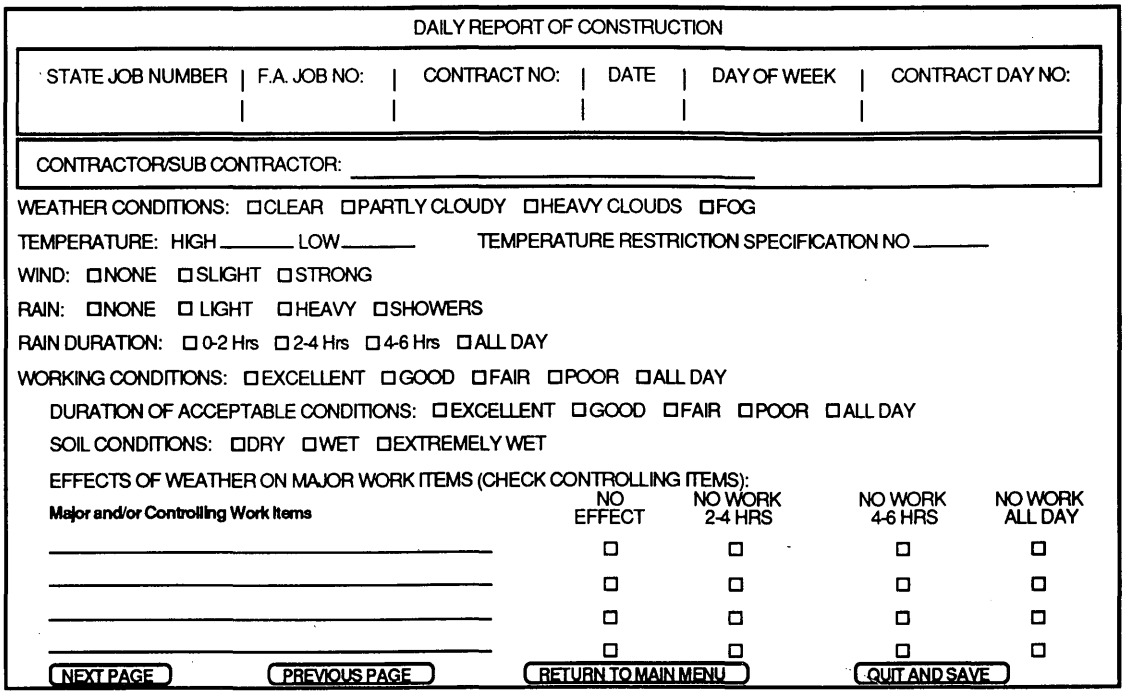

FIGURE 3 Weather information screen.

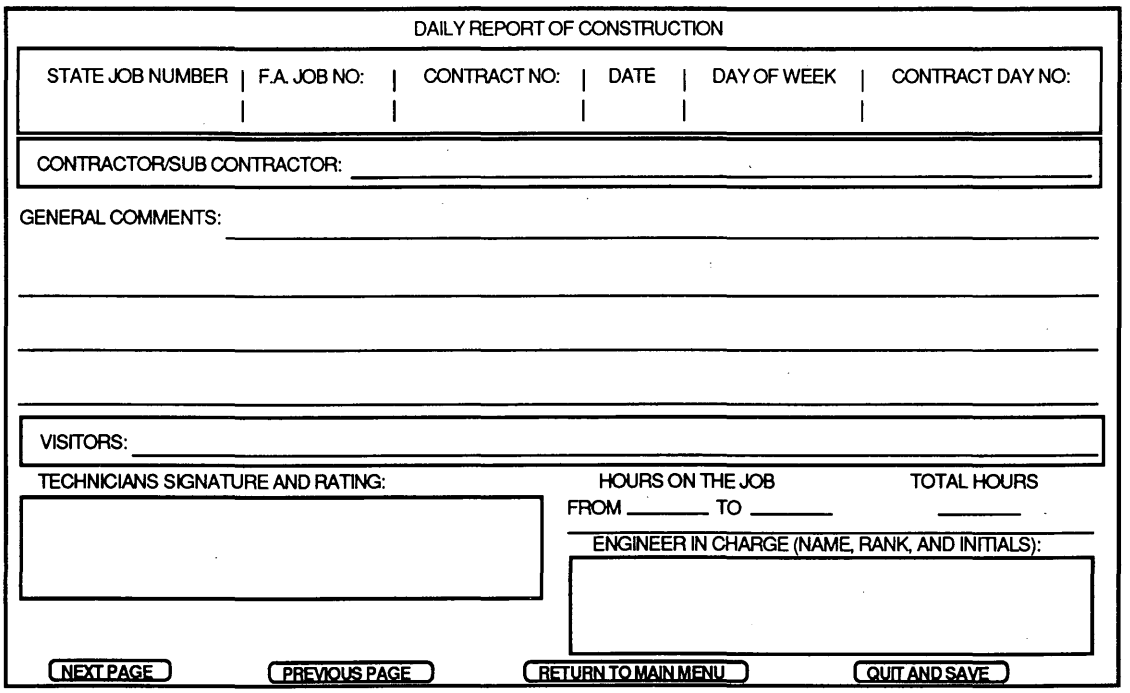

FIGURE 4 General comments and signature screen.

Transfer of data from the pen-based computer to the desktop microcomputer is made by direct connection between serial parts. LapLink software is used to transfer data.

Figure 5 shows how the PRS functions within the FDOT construction management system. Initial project data are transferred by direct connection from the mainframe computer at the central office to the desktop personal computer (PC) in the resident's office. This initial project information is then transferred to the pen-based computer from the office PC. At weekly intervals the daily report data are uploaded from the pen-based computer to the office PC. Printed copies of the daily reports as well as weekly and monthly summaries can be produced from the Dbase utility in the office PC. The monthly pay estimate is generated and transferred to the central office by the office PC. Keyword or conditional queries to the data files can be made using the Dbase utility.

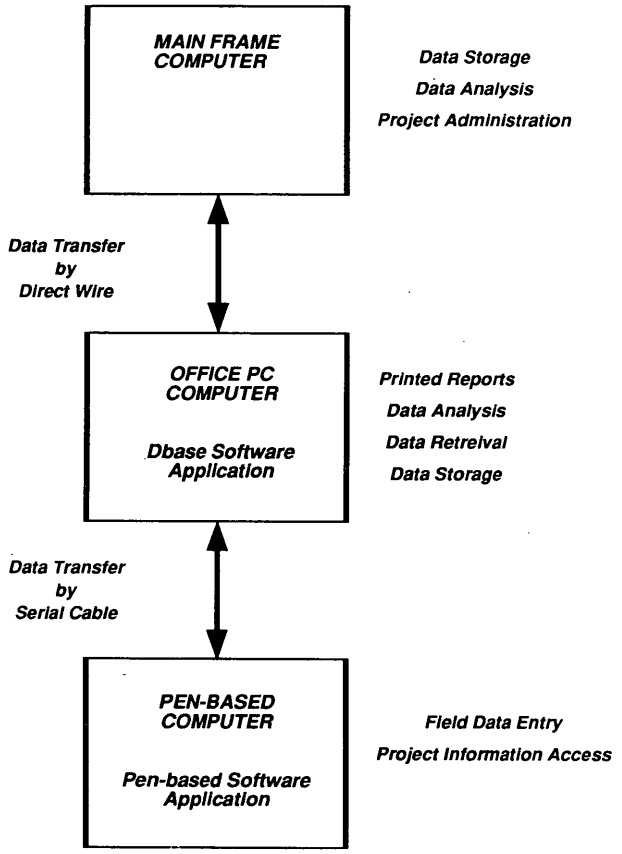

FIGURE 5 FDOT automated project site data acquisition system.

FIELD TESTING

After bench testing and initial debugging, the application was field tested concurrently on six projects for 2 months. The projects selected were typical of the FDOT construction program. One bridge construction project was included. The others were roadway projects.

The PRS was used in parallel with the traditional preprinted daily report of construction. The paper forms were filled out first and then the data were entered on the pen-based computer. This arrangement ensured that the project information would not be at risk. Field users of the system were given a half-day orientation seminar on the pen-based computers and the PRS software.

Computers were assigned to the field users after the orientation seminar. Users were asked to practice with the pen-based machines for 1 week before actually beginning work on the daily reports. Also, a handwriting tutorial by GRID Systems, Inc., was installed on each of the computers. Each user was encouraged to work through the tutorial.

Throughout the field testing, debugging and enhancement of the software continued. Problems were eliminated when reported to the researchers by the field users. At the conclusion of the testing, users were interviewed to obtain their opinions and input into the study.

RESULTS OF THE STUDY

PRS functioned successfully. Field inspectors were able to use the pen-based computers to record FDOT's daily report of construction. Reports were transferred to the office PC. Printed copies of the daily reports and weekly and monthly summaries were produced by the Dbase utility. No hardware failures occurred.

Most new systems are met with a certain amount of organizational resistance. However, FDOT field users were committed to giving the pen-based computer a fair trial. Some problems were discovered during the field testing. These lessons learned should prove valuable when developing organization implementation plans.

Aside from software debugging, the following were the most significant problems:

1. The handwriting recognition feature of the computers requires that some letters be formed in a certain way. Some of the field users experienced difficulty in having the computer correctly interpret their writing. As might be imagined, the frustration level of the user at the job site can rise considerably.
2. More space needed to be allocated to the text fields.
3. Users were required to complete the report on the printed form and then enter the data on the computer. Therefore, they were burdened with twice the work.
4. Primarily because of problems with the handwriting recognition, most of the users believed that the pen-based computer required more time than manual completion of the form.
5. The pen-based computers used did not have back-lit screens. Therefore, night use was not possible.

The following are some of the direct benefits of the pen-based system:

1. The need to key in or retype handwritten reports is eliminated.
2. Field data are managed by a computerized information management system.
3. The field user is given direct access to project information stored in the pen-based computer.
4. With enhanced pen-based forms, the field user's recording time can be reduced.

CONCLUSIONS AND RECOMMENDATIONS

Automating the recording and analysis of construction site data will improve project management efficiency. Pen-based computer technology provides a tool for eliminating job site paperwork. The walking user at the job site can now directly access the microcomputer. Pen-based technology is evolving very quickly. Hardware capabilities are expanding rapidly. Software development will undoubtedly follow.

This study has resulted in the following specific recommendations:

1. Pen-based forms should be designed so as to minimize the need for the user to input data by writing. The use of check boxes and scrollable lists can eliminate much of the

printing. The daily report of construction was replicated as is. An enhanced pen-based version would be preferable.

2. Users should be given adequate practice time with the pen-based computer before trying an actual application. Field testing in this study indicated that handwriting recognition success improved significantly after 1 to 2 weeks of practice.

3. The specific categories of information included on job-site forms should be reviewed before conversion to a pen-based system. Basic information management concepts should be applied when evaluating the report designs and content.

4. The full potential of a pen-based reporting system is only possible when integrated with an organizational computerized management information system.

5. Enhanced or "smart" forms can be developed that not only collect data but also provide information and analysis to the field user.

REFERENCES

1. L. C. Bell and B. G. McCullouch. Bar Code Applications in Construction. ASCE *Journal of Construction Engineering and Management*, Vol. 114, No. 2, 1988, pp. 263–278.
2. E. J. Lundberg and Y. J. Beliveau. Automated Lay-Down Yard Control System-ALYC. *ASCE Journal of Construction Engineering and Management*, Vol. 115, No. 4, 1989, pp. 535–544.
3. W. J. Rasford and M. J. Herbert. Bar Coding in Construction Engineering. ASCE *Journal of Construction Engineering and Management*, Vol. 116, No. 2, 1990, pp. 261–280.
4. W. A. Hyman et al. *NCHRP Report 334: Improvements in Data Acquisition Technology for Maintenance Management Systems*. TRB, National Research Council, Washington, D.C., 1990.

Publication of this paper sponsored by Committee on Computer Technology.