Evaluation of Field Inspection Devices for Use with the PAVER Pavement Management System

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When properly implemented, the PAVER pavement management system has been found to be an extremely valuable management tool. The most important requirement the system imposes on users is the periodic update of the inspection data. Without up-to-date condition information, meaningful analyses cannot be performed. If accurate condition information is available, an effective maintenance and rehabilitation plan that will lead to significant avoided cost can be developed using PAVER. Although the cost of inspection is small compared with the avoided cost, it is a legitimate concern for many users. Some of the more practical and readily available devices that can be used for field data collection are identified and evaluated. A device from each of the following categories was selected: (a) paper and pencil, (b) portable computer, (c) bar code reader, (d) hand-held computer, and (e) voice recognition system. Each discussion describes the device, explains how it is used, and provides its advantages, disadvantages, and costs.

PAVER is a pavement management system (PMS) developed by the U.S. Army Construction Engineering Research Laboratory (CERL) for use by both military and civilian organizations. PAVER can be used to manage roads, streets, parking lots, and airfield pavements. The system capabilities include storing inventory and inspection data, determining pavement condition, predicting future pavement condition, comparing costs of maintenance and repair (M&R), and budget planning. PAVER is designed to optimize the use of funds allocated for pavement M&R.

Two versions of the system, Micro PAVER and Mainframe PAVER, are available for operation on a microcomputer or mainframe computer, respectively. Since its introduction in 1980, PAVER has been gaining widespread acceptance throughout military and civilian agencies.

PAVER uses the pavement condition index (PCI) condition survey and rating procedure developed at CERL. PCI is an objective, repeatable rating system for identifying the present condition of the pavement. PCI is calculated on the basis of the results of a visual condition survey in which distress type, severity, and quantity are identified. PCI provides a consistent measure of a pavement's structural integrity and operational condition.

When properly implemented and used, PAVER has been found to be an extremely valuable management tool. The most important requirement the system imposes on the user is the periodic update of the inspection data. Without the up-to-date condition information, meaningful analyses cannot be performed. If accurate condition information is available, an effective M&R plan that will lead to significant avoided cost can be developed using PAVER. Although the cost of inspection is small compared with the avoided cost, the cost of inspection is a legitimate concern for many users.

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The results of field inspections are commonly recorded on inspection forms, then manually entered into one of the PAVER computer programs for analysis. This method (the paper and pencil method) is reliable, yet time consuming. Recent advances in microcomputer technology make possible many alternate methods for the inspection data acquisition. Devices such as portable computers, bar code readers, hand-held computers, voice recognition systems, optical mark readers, and programmable calculators offer the potential to reduce the time required to collect and transfer field data to the PAVER program while maintaining data integrity, thus reducing the costs associated with pavement inspections.

OBJECTIVE

The objective is to provide an evaluation of available technologies that could be used for PAVER data collection. This information will aid the PAVER users in selecting a method for collecting field data.

APPROACH

A literature survey was conducted to select the candidate devices. Two criteria, device potential and cost, were used. The following list indicates the categories of the devices being considered for evaluation:

1. Paper and pencil,
2. Portable computer,
3. Bar code reader,
4. Hand-held computer, and
5. Voice recognition system.

There is some degree of variability within each of the categories. Some of the devices are markedly different from other devices in the same category. These differences, where applicable, are discussed in the next section. One device was selected from each category for evaluation.

Each of the selected devices was programmed with the intent of exploiting its respective strength. The software pro-

grams developed for the devices are not identical; however, the final product from each device (excluding the paper and pencil method), is a standard ASCII data file. Once the device was programmed, it was evaluated by several inspectors in actual field inspections.

The inspectors gathered distress data in the field and performed the steps required to transfer the data to the Micro PAVER computer program. Each inspector then completed a questionnaire that documented the view of that particular device. The evaluation results are given in the next section.

The field inspection devices were evaluated on the basis of the following criteria:

1. Physical characteristics of weight and size,
2. Display size,
3. Training time,
4. Simple data entry in the field,
5. Simple data correction in the field,
6. Data transfer speed, and
7. Reliability of data and data transfer.

The focus of this evaluation was on the devices themselves and not the software. In some cases, the hardware limited the capabilities and user friendliness of the software that could be developed.

Except where noted, it was assumed that two inspectors will be working together to gather data.

PAPER-AND-PENCIL METHOD

Physical Characteristics

The paper-and-pencil method of inspection requires that the inspector record the distress data on 8½- × 11-in. inspection forms. The four types of inspection forms are as follows:

1. Asphalt concrete roads and parking lots,
2. Portland cement concrete roads and parking lots,
3. Asphalt concrete airfields, and
4. Portland cement concrete airfields.

In order to perform an inspection, an inspector needs the appropriate inspection form and a clipboard for use in the field.

Operating Conditions

The paper-and-pencil method of inspection is possible so long as the weather does not interfere with the recording of data.

Cost

The costs associated with this method include those needed to reproduce the inspection forms and a clipboard for each inspector.

Training

The paper-and-pencil method of inspection requires less than 15 min of training.

Field Inspection Methodology

The inspectors walk along the sample unit together with one inspector calling out the distress, severity, and quantity as the other inspector records the information on the appropriate form. One inspector is needed to determine and measure distresses; the other is needed to record the information on the appropriate inspection form. The inspector writes the distress, severity, and quantity on the inspection form while in the field. One form is used for each sample unit. The completed inspection forms are then taken back to the office for data reduction.

Data Transfer

The data collected in the field need to be entered into the Micro PAVER computer program. Entry can be done in one of two ways. The first is to enter the data directly into the data base using the Micro PAVER computer program, which can be done using the INSPECTION DATA option from within Micro PAVER. This option requires that all the common distress and severity combinations be manually summed before being entered into the computer program. The second option is to create a standard ASCII input file. A word processor or a spreadsheet can be used to create an ASCII file. This file can then be read by Micro PAVER using the INSPECTION DATA (BATCH) option from within Micro PAVER. This option does not require that all common distress and severity combinations be summed before data input.

Advantages

The paper-and-pencil method of inspection is inexpensive and requires little training.

Surveys of inspectors have indicated that this method is very good in helping the inspector keep track of what distresses have and have not been recorded.

This method also allows the inspector to record preliminary information, such as inspector name, date, branch, section, sample unit, etc., before the actual field inspection. This would save some time in the field.

All the distresses for a given sample unit can be viewed at once thus making the editing process simple. The paper-and-pencil method also provides a permanent written record of the inspection results.

Disadvantages

The main disadvantages associated with the paper-and-pencil method are associated with data reduction and data transfer. If the user wants to enter the inspection data directly into the Micro PAVER data base, then hand calculations to reduce the data are required. The user sums the common distress and severity combinations for each sample unit. The total summed value for each sample unit is then manually keyed into Micro PAVER using the INSPECTION DATA option. For example, if an inspector recorded two occurrences of low-severity alligator cracking, the two quantities would have to

be manually added before being entered into Micro PAVER. This procedure can be time consuming and it increases the probability of errors in either the data reduction or the actual keying in of the data.

PORTABLE COMPUTER, TANDY TRS 80, MODEL 102

Physical Characteristics

The physical characteristics of the Tandy TRS 80, Model 102, are shown in Table 1.

Operating Conditions

The Tandy TRS 80, Model 102, should not be used in the rain or extreme temperatures.

Cost

The Tandy TRS 80, Model 102, sells for about $600.

Training

The Tandy computer requires less than 30 min of training.

Field Inspection Methodology

The inspectors walk along the sample unit together, with one inspector calling out the distress, severity, and quantity as the other inspector records the information using the Tandy computer. One inspector is needed to determine and measure distresses; the other is needed to record the information. The inspector is prompted by the computer to enter the appropriate information. All data are entered in the field.

Data Transfer

The Micro PAVER system includes a computer program written in BASIC that is used for data transfer from the Tandy computer to the personal computer (PC). This program uses the BASIC interpreter that is included with DOS. The Tandy computer also includes a program that is used to transfer data to the PC. These two programs work together to transfer the data. The data are transferred to the PC by an RS–232 cable. A file is created on the hard disk of the PC. After this file has been created, the Micro PAVER program is run and the INSPECTION DATA (BATCH) option is selected. This option reads the file on the hard disk that was created during the data transfer. Once read, the inspection data is stored in the Micro PAVER data base. Documentation for this procedure is provided in the Micro PAVER Users Guide.

Advantages

The Tandy TRS 80, Model 102, has a display large enough to exhibit four distresses at the same time. Having the distress displayed on the screen is considered an advantage because it helps the inspector keep track of which distresses have been entered.

The Tandy TRS 80, Model 102, computer has a full-sized keyboard.

Another advantage of using the Tandy TRS 80, Model 102, is realized in the transfer of data to the PC from the Tandy computer, which can be done electronically. The data are recorded in the field using the Tandy computer; computer programs provided with Micro PAVER and the Tandy computer make the data transfer quick and easy.

Once the data have been transferred to the PC, the INSPECTION DATA (BATCH) option is selected. When this option is used, the data do not need to be reduced. That is, the common distress and severity combinations do not need to be manually summed before being read into the Micro PAVER program.

The file created during the inspection can be printed and stored to provide a written record of the inspection.

TABLE 1 TANDY TRS 80 MODEL 102 PORTABLE COMPUTER

Microprocessor 8-bit 80C85 CMOS	**Display** 40 x 8 liquid crystal display, upper and lower case ASCII characters, 240 x 64 dot-matrix graphics
Clock Speed 2.4 Mhz	**Input/Output** Parallel printer interface, RS-232C serial interface, standard bar code reader interface
Memory 32K EPROM, 64K RAM	**Dimensions** 1½ x 12 x 8½" (H x W x D)
Keyboard Full-size 56-key QWERTY style with embedded 10 key datapad, plus 8 programmable function keys	**Weight** 3 lbs.
Certification FCC Class B	**Power Supply** Four "AA" alkaline batteries for operation. Internal rechargeable batteries for memory. Optional AC adapter.

Disadvantages

The primary disadvantage in using the Tandy TRS 80, Model 102, computer for field inspections is that the computer is rather cumbersome and heavy for field work over a period of time. For two inspectors working together, it is not a serious problem. One inspector uses the distress field guide and other equipment as the other inspector records the distress information with the computer. The inspector using the computer may find it difficult to handle the field book, tape measure, etc., and the computer all at once.

The Tandy computer has a maximum of 64K of RAM. Because the computer has limited memory, the software could not be developed to allow the user to view and edit an unlimited number of distresses. The maximum number of distresses that can be viewed or edited is four. Once those four distresses have been stored, they cannot be retrieved. This problem was not a major disadvantage.

MICRO WAND III BAR CODE READER

Physical Characteristics

The physical characteristics of the Micro Wand III are given in Table 2.

Operating Conditions

The Micro Wand III can be used in the temperature range of 32° to 113° F and a humidity range up to 95 percent noncondensing.

Cost

The Micro Wand III bar code reader with 128K RAM and 32K EPROM sells for $1,400. UDL 3.1 (development software) is $800 (a one-time cost), for a total of $2,200.

Training

The Micro Wand III requires less than 30 min of training.

Field Inspection Methodology

The inspectors walk along the sample unit together with one inspector calling out the distress, severity, and quantity; the other inspector records the information using the Micro Wand III. One inspector determines and measures distresses while the other records the information. The inspector recording the information has a sheet of paper with the bar codes printed on it. There is one bar code for each distress and a bar code for each severity. The program prompts the user to type in the date, branch, section, etc. This information is typed into the Micro Wand III using the keyboard on the bar code reader. The program then prompts the user to input the distress, severity, and quantity. The distress and severity are recorded by running the bar code reader over the appropriate codes and the quantity is recorded by typing in the appropriate number from the keyboard. All data are entered in the field.

Data Transfer

The inspection data are stored in the Micro Wand III. The data are transferred by running a computer program on the PC in conjunction with a program on the Micro Wand III. These two programs work together to transfer the data. The data are transferred to the PC by an RS–232 cable. A file created on the hard disk of the PC can be read into Micro PAVER by selecting the INSPECTION DATA (BATCH) option from within Micro PAVER. When this option is selected, the user does not have to manually sum common distress and severity combinations.

Advantages

The Micro Wand III is portable and lightweight and can be easily handled by one inspector (see Figure 1). Data transfer accomplished by file transfer between the Micro Wand III and the PC takes little time and helps ensure the integrity of the data.

Once the data have been transferred to the PC, the INSPECTION DATA (BATCH) option is selected. When this option is used, the data do not need to be reduced. That is, the common distress and severity combinations do not need

TABLE 2 MICRO WAND III BAR CODE READER

Microprocessor 68HC11	**Display** 16 x 2 liquid crystal display, upper and lower case ASCII characters
Clock Speed 1.23 Mhz	**Input/Output** RS-232C serial interface, optical interface, acoustic adapter
Memory 32K EPROM, 32K RAM (upgrade to 128K available)	**Dimensions** 1¼ x 1¾ x 7" (H x W x D)
Keyboard 35-key keyboard with embedded 10 key numeric pad, plus 4 programmable function keys	**Weight** 7 ounces.
Certification FCC Class B	**Power Supply** One 9 volt battery (NiCad, Alkaline, Lithium) and battery charger, Optional AC adapter

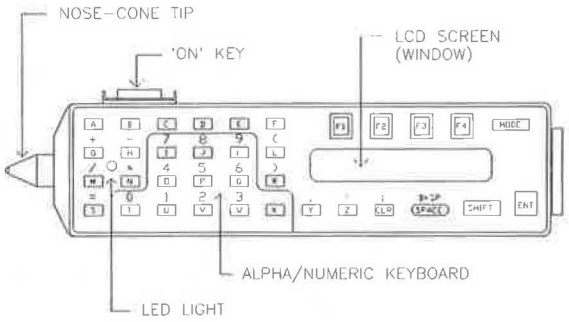

FIGURE 1 Micro Wand III bar code reader.

to be manually summed before being read into the Micro PAVER program.

The file created during the inspection can be printed and stored to provide a written record of the inspection.

Disadvantages

The foremost problem with the Micro Wand III concerns the display. The Micro Wand III has only two lines of 16 characters each. Because of the small display, only one distress can be seen and edited at a time. Inspectors using the Micro Wand III found this drawback to be significant. While collecting distress data, it is easy for an inspector to forget whether or not a certain distress was recorded. If the inspector cannot see previous entries, there is no way of knowing whether or not the distress was recorded. This uncertainty leads to errors and inaccurate PCI inspections.

NATIONAL DATACOMPUTER DC 3.0 HAND-HELD COMPUTER

Physical Characteristics

The physical characteristics of the DC 3.0 are given in Table 3.

Operating Conditions

The recommended temperature range for the DC 3.0 is −5° to 125° F.

Cost

The cost breakdown for the DC 3.0 is as follows:

RAM Memory (K)	*List Price ($)*
128	1,995
384	2,495
640	2,795
960	3,245

Training

The National DataComputer requires less than 30 min of training.

Field Inspection Methodology

The inspectors walk along the sample unit together, with one inspector calling out the distress, severity, and quantity as the other inspector records the information using the National DataComputer. One inspector determines and measures distresses; the other records the information. The inspector is prompted by the computer to enter the appropriate information. All data are entered in the field.

Because the National DataComputer can be held in one hand, it is possible for an inspector to inspect PCC pavement and record data. AC pavement requires two inspectors because a measuring device needs to be carried to measure the quantity of each distress. When inspecting AC pavement, it is too difficult for one inspector to carry all the necessary equipment.

Data Transfer

The inspection data are stored in the National DataComputer. The data are transferred by a computer program on the PC

TABLE 3 NATIONAL DATACOMPUTER DC 3.0 HAND-HELD COMPUTER

Microprocessor 80C88	**Input/Output** DB 25 serial port, DB 9 bar code port, 8 pin DIN serial printer port, RJ-11 and 300-1200 or 300-2400 baud internal (Hayes compatible) modem
Memory 128, 384, 640, or 960K RAM 32 or 64K EPROM	**Dimensions** 10 x 5 x 2½" (H x W x D)
Keyboard full sized numeric keys, downsized QWERTY keyboard	**Weight** 34 ounces.
Display 10 lines x 26 characters 80 x 160 full graphics capability Backlit and Supertwist	**Power Supply** 4AA (plus room for 4 spares) NiCad battery pack, cigarette lighter adapter

that works with a program on the National DataComputer. The data are transferred to the PC by an RS–232 cable. A file created on the hard disk of the PC can be read into Micro PAVER by selecting the INSPECTION DATA (BATCH) option from within Micro PAVER.

Advantages

The National DataComputer proved to work well for field inspections. The computer is relatively light and easily held in one hand. Its enlarged numeric keypad makes entry of numbers easy. The National DataComputer has a display large enough to exhibit five distresses at any one time. The user is not limited to viewing the last five distresses. The screen can scroll up and down to exhibit all the distresses that have been entered for that sample unit. Each line on the display contains the distress code, description, severity, and quantity. Having the distress description displayed on the screen is considered an advantage because it reduces the possibility of entering erroneous distress codes.

Because the National DataComputer has adequate memory and a relatively large display, it could be programmed to make error correction simple. The user moves the cursor to the line that needs to be edited and types in the changes.

Data transfer is accomplished by file transfer between the National DataComputer and the PC. This process takes little time and helps ensure the integrity of the data. The file created during the inspection can be printed and stored to provide a written record of the inspection.

Once the data have been transferred to the PC, the INSPECTION DATA (BATCH) option is selected. When this option is used, the data do not need to be reduced. That is, the common distress and severity combinations do not need to be manually summed before being read into the Micro PAVER program.

Disadvantages

Some inspectors found that the shift keys on the National DataComputer were a little awkward to use. The National DataComputer has the shift key located on the keypad next to all the other keys. Other hand-held computers have the shift key on the side of the unit near where the thumb would rest while holding the unit. Having the shift key next to the thumb on the side of the unit would make using the shift key a little easier. Although the National DataComputer does not have the shift keys located in the most convenient way, it is not a significant problem.

ASTROVOIS AUDIO VOICE RECOGNITION SYSTEM

Within voice recognition technology, there exist two distinct categories. The first category includes devices that record the human voice on tape. The tape is then played back to a computer that recognizes the words recorded on the tape. The second category includes devices that allow the user to have an interactive relationship with the device while in the field. That is, given the correct spoken command, the device will respond with synthesized words.

The device evaluated for this report is the type that requires the users to record their voices on a standard cassette tape and then play them back to the computer at a later time.

Physical Characteristics and Hardware Requirements

The AstroVOIS system requires an IBM or compatible computer with DOS 3.1 or higher and at least 10 MB of free hard-disk space. The computer should have at least 640K RAM and one free expansion slot for the TI speech hardware kit.

Cost

Item	*Cost ($)*
Sony Walkman Professional	230
Marantz PMD430 Cassette Recorder	450
Noise canceling microphone	200
Audio cables	25
AstroVOIS Audio Tape System	5,500
Total	6,405

The costs of the Marantz cassette recorder, audio cables, and AstroVOIS audio tape system are one-time costs. Each inspector would need the Sony Walkman Professional and the noise-canceling microphone.

Operating Conditions

The Sony Walkman Professional should not be used in high humidity or extreme temperatures.

Training

Each inspector needs to train the AstroVOIS system to recognize his or her voice.

This is done by connecting a headset to the Marantz tape recorder, which in turn is connected to the Texas Instruments speech board that is installed on the computer. Once the AstroVOIS program is executed, it prompts the inspector to say aloud the words that appear on the screen. While the inspector is verbally responding, the AstroVOIS system measures and stores characteristics of the inspector's voice. This procedure is repeated until the AstroVOIS system can correctly recognize all the words. The AstroVOIS system uses PAVER words to enroll an inspector. These words include sample unit, asphalt, concrete, alligator crack, and corner spall. Once the AstroVOIS system recognizes the inspector's verbal responses, a mock pavement inspection should be performed to ensure that the AstroVOIS system will recognize voices from a tape recording. Training time varied from 6 hr to 3 days. Pavement inspection using the AstroVOIS system is described in the following paragraphs.

Field Inspection Methodology

The AstroVOIS system recognizes words by comparing the spoken word against a list of possible alternatives. For this reason, the inspector needs to meticulously follow a script of possible words. For example, permissible responses following inspection date include branch. Likewise, permissible responses following sample unit include sample type.

Because the AstroVOIS system allows the user to have both hands free, one person is capable of conducting an inspection.

The inspector takes the Sony Walkman and headset and microphone to the field. Then, the inspector follows the script and records the distress data by speaking into the microphone that is connected to the Sony Walkman. The inspector records all the inspection information on the cassette tape. Error correction in the field is accomplished by rewinding the cassette and taping over the erroneous data.

Data Transfer

The inspection data are stored on the cassette tape on which the data were recorded while the inspector was in the field. In order to transfer the data to the PC, the cassette tape is placed in the Marantz tape recorder, which is connected to the Texas Instruments speech board on the computer, and played back to the computer. The AstroVOIS system then matches words on the cassette tape with the words from the inspector's enrollment. Once AstroVOIS has processed the cassette tape, a file is created on the hard disk of the PC. This file can be read into Micro PAVER by selecting the INSPECTION DATA (BATCH) option within Micro PAVER. When this option is selected, the user does not have to manually sum common distress and severity combinations. Once this has been done, the inspection data will be stored in the Micro PAVER data base.

Advantages

Normally, two inspectors are needed to inspect pavements but with the AstroVOIS system the user has both hands free; thus one person can inspect both AC and PCC pavements.

To provide a permanent record of the inspection the cassette tapes can be stored or transcribed.

The cassette can be processed while it is unattended thus allowing employees the freedom to attend to other tasks.

Data transfer is accomplished electronically between the AstroVOIS system and the PC. This process takes little time and helps ensure the integrity of the data.

Once the data have been transferred to the PC, the INSPECTION DATA (BATCH) option is selected. When this option is used, the data do not need to be reduced. That is, the common distress and severity combinations do not need to be manually summed before being read into the Micro PAVER program.

Disadvantages

The training procedure is time consuming and difficult for some people. One inspector was unable to train the AstroVOIS system to reliably recognize his voice.

The AstroVOIS system is somewhat sensitive to loud noises. If loud noises are recorded, the AstroVOIS system may have problems recognizing words recorded on the tape.

Another major disadvantage with the AstroVOIS system is data correction. In order to edit data, the user must rewind and play back the tape to the point where the change needs to be made. Once that point is found, the correct data are recorded over the old data. Several inspectors reported that this process was inconvenient.

In order to view the data, the tape must be rewound and played back. Inspectors reported that this was inconvenient and may have reduced the reliability of the data. If recorded distresses are not easily viewed, the inspector can easily forget to enter a distress or may enter a distress twice.

CONCLUSION

Current technology offers many alternate methods of data acquisition and transferral. A summary of the features of the devices tested is presented in Table 4 and Figure 2. Portable

TABLE 4 DEVICE SUMMARY

DEVICE	PHYSICAL CHARACTERISTICS			OPERATING CHARACTERISTICS					COST	
	weight	dimensions	display	manual calc. required[1]	training time	data entry[2]	data editing	data transfer	initial	per team[3]
Paper/Pencil	N/A	8½x11"	8½x11"	yes	< 15 min	5	5	manual	$ 10	$ 10
Tandy TRS 80	48 oz	1½x12x8½"	40x8 char	no	< 30 min	4	3	electronic	$ 600	$ 600
Micro Wand III	7 oz	1¼x1¾x7"	16x2 char	no	< 30 min	3	2	electronic	$ 2,200	$ 1,400
National Datacomputer	34 oz	10x5x2½"	10x26 char	no	< 30 min	4½	5	electronic	$ 2,495	$ 2,495
AstroVOIS	10 oz	5x3¼x1¼	no display	no	4 - 6 hours	3	1	electronic	$ 6,405	$ 430

[1] Data manually entered into Micro PAVER must be reduced. All common distress - severity combinations must be summed before being entered into Micro PAVER. If a data file is produced during the inspection, that file can be read directly into Micro PAVER and thus manual data reduction is not necessary.

[2] 5-excellent 4-good 3-fair 2-poor 1-unsatisfactory

[3] This cost represents the cost per inspection team after the initial cost.

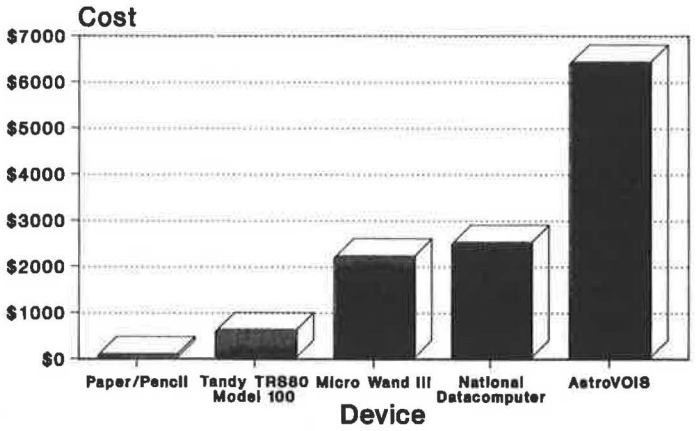

FIGURE 2 Start-up cost comparison.

computers, bar code readers, hand-held computers, and voice recognition systems all have the potential to help facilitate the acquisition and transferral of field data.

Portable and hand-held computers are relatively light, inexpensive, and easy to use. Depending on the software, collecting and editing data while in the field can be easy.

Bar code readers are generally much smaller and lighter than most portable and hand-held computers. The display on most bar code readers is small and makes field data collection and editing somewhat difficult.

Voice recognition systems are initially expensive and require more training than other devices. Editing data while in the field is difficult.

All the devices mentioned offer the user electronic data transfer that can significantly decrease the amount of time required to transfer field data to the PC.

FUTURE RESEARCH

Other technologies that have the potential to expedite field data collection are optical mark readers (OMRs), programmable calculators, and electronic notepads.

OMRs scan a preformatted form (see Figure 3). OMR forms can be developed exclusively for PAVER inspections. The information is recorded on the form by blackening an oval or rectangle with a pencil. The data are transferred to the PC by passing the form through the OMR. The OMR can be equipped with a multiple-sheet feeder that would allow multiple forms to be processed automatically. One advantage of using an OMR would be that field inspectors could record data using paper and pencil and still be able to transfer data to the PC quickly and accurately. A typical rate for a multiple-sheet feeder is 40 sheets per minute.

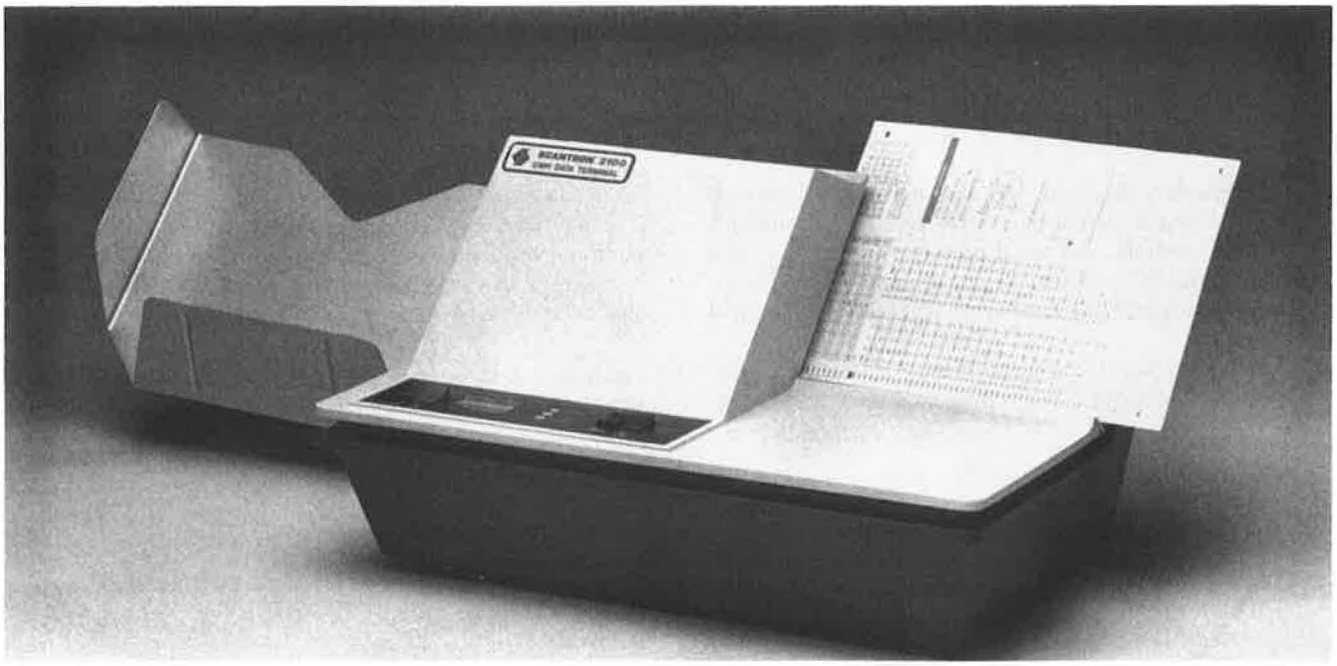

FIGURE 3 Scantron optical mark reader.

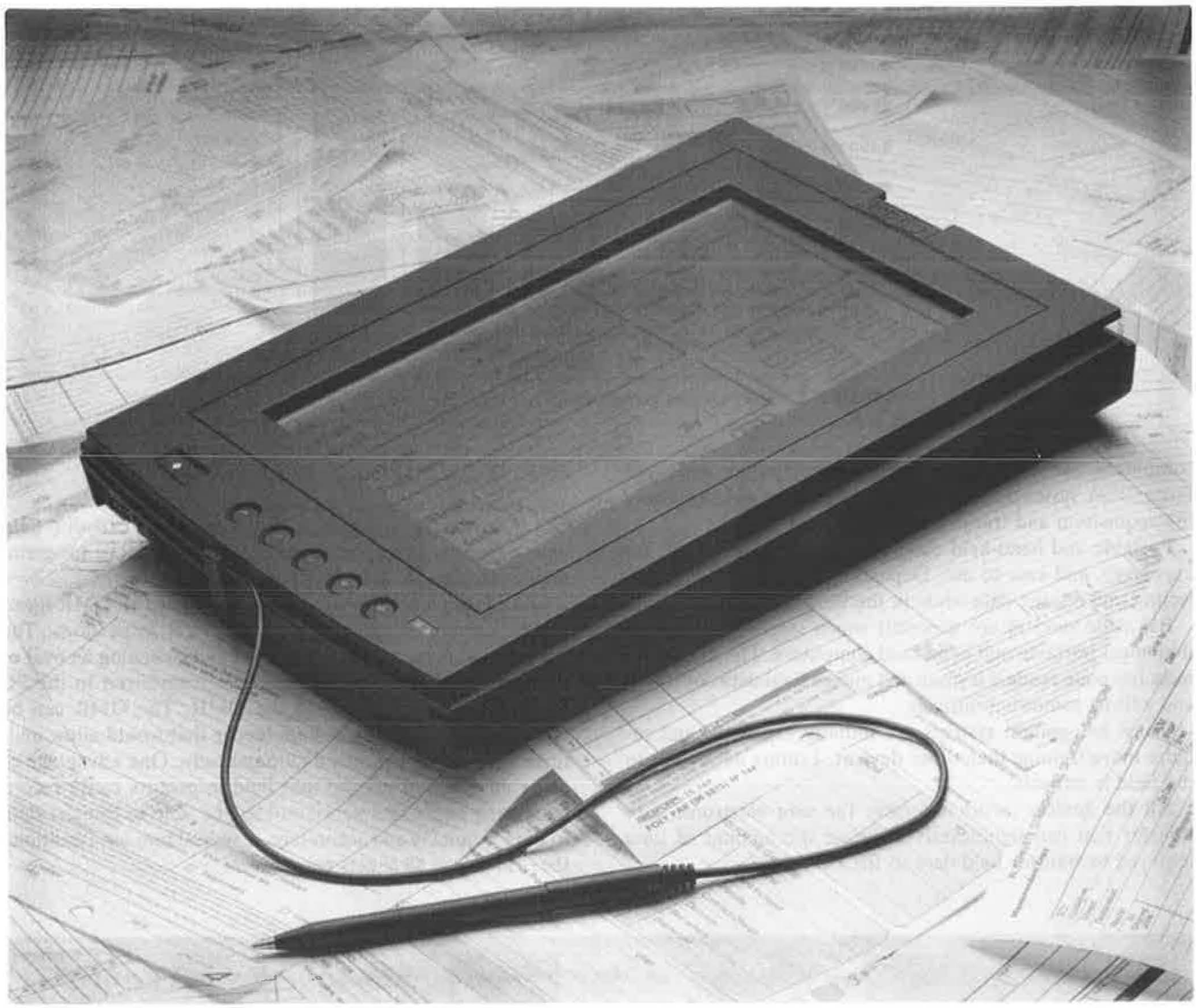

FIGURE 4 GridPAD pen-based portable computer.

Programmable calculators are fast becoming hand-held computers. Calculators now have up to 288K RAM, multiple line displays, printers, and serial ports for transferring data to and from the PC. Calculators are relatively inexpensive, small, and lightweight, and have many other uses besides field data collection.

Electronic notepads (see Figure 4) are computers that recognize written characters. The computer is the size of a clipboard and allows the user to handprint data and diagrams. The computer allows the user to create customized forms that could be used for PAVER data collection. One of the advantages of this type of computer is that the user inputs data just as if he or she were writing on a piece of paper.

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