2D Bar-Code Applications in Construction

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Abstract: Two-dimensional (2D) bar codes provide a greater capacity for encoding data than regular or linear symbology. With recent developments in 2D hardware, this symbology can now be employed in industrial applications. This paper discusses this technology and its applicability in the construction environment. A comparison with one-dimensional bar codes is made, and advantages and disadvantages are discussed. An explanation of how data are encoded and scanned along with the hardware and software requirements is included. Finally, several construction applications are proposed to illustrate how this technology could be applied in the construction industry.

INTRODUCTION

Bar codes are slowly gaining acceptance and finding applications in the construction industry. Bar codes provide the advantages of relatively error-free data entry and much faster data-entry times. Therefore, applications in material takeoff, field material control, warehouse inventory, tool and consumable material issue, timekeeping and cost engineering, purchasing and accounting, scheduling, document control, and office operations have been proposed by Bell and McCullouch (1988). Additionally, Abudayyeh and Rasdorf (1992) proposed a design for an automated solution to construction information management systems that incorporate the use of bar codes. One of the major obstacles preventing broad acceptance in the construction industry is the lack of industry standards (Stukhart and Pearce 1989). Even with this major obstacle, construction companies are utilizing bar codes in various ways.

A new bar-code symbology that has two-dimensional (2D) characteristics has been developed. The primary reason for the development of the technology is "the need to put simple information on small items and the increasing demand to put more information into bar-code labels has made some linear bar codes obsolete for some applications" ("AIM" 1990). This paper describes how this symbology can be utilized in the construction environment.

TWO-DIMENSIONAL SYMBOLOGY

A two-dimensional (2D) symbology consists of several rows of stacked one-dimensional (1D) bar-code data. Each row may be separated by a horizontal bar as in Code 49 (see Fig. 1), or no separator between adjacent rows such as PDF417 (see Fig. 2). In other words, it is a multirow bar-code symbology. A one-dimensional symbology contains data only in one dimension, say the x-dimension. A two-dimensional symbology contains data in both the x- and y-dimensions. A two-dimensional symbology can contain more characters than a one-dimensional symbol of the same size.

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FIG. 1. Example of Code 49 Symbol

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FIG. 2. PDF417 Symbol with Human-Readable Information and Parameters

Fig. 1 is an example of a Code 49 two-dimensional symbol. Code 49 can contain two to eight rows, depending on data density. Every row has a start and stop character at the end of the row, and is separated by a separator bar. The bottom row contains a check character, and the number of rows encoded in the symbol.

A one-dimensional bar code is primarily used as an identifier tag on an object; a two-dimensional symbology can contain a file of information about an object. This is the major advantage of a two-dimensional symbology.

Currently, there are many two-dimensional symbologies, or stacked bar codes. For example, Codablock, Code 16K, Code 49, Code 1, and PDF417. Most of them are public-domain property. They differ by capacity, size, accuracy, and self-correcting capability. An example of a PDF417 label is shown in Fig. 2, including the human-readable label.

PDF417 is a matrix symbology that allows a maximum 1,481 bytes of ASCII characters in each symbol. The characters encoded in PDF417 can be ASCII, alphanumeric, mixed, numeric, or user-defined. The user-defined characters can be specified according to an application. Thus, PDF417 symbology provides more character types than other two-dimensional symbologies.

Two-dimensional symbologies offer advantages for bar-code applications in construction and other industries because of their reliability, efficiency, and higher code-word density. On a construction site, the label should be very durable due to the harsh environment. A common label problem is distortion, which can cause misreads or no reads. If the label is stained or distorted, the dimension of bars and spaces is changed, then data can be misread or no data decoded when the label is scanned. Fig. 3 shows examples of two label problems.

With a matrix 2D symbology, data affected by label damage can be recovered through a data-recovery algorithm. These algorithms are sophisticated to the degree that data recovery is possible with a damaged label. This is an extremely valuable capability over one-dimensional symbology.

Another advantage of the two-dimensional symbology is real-time data processing. As mentioned previously, a two-dimensional symbology embodies entire information in the symbol itself. Fig. 4 shows a one-dimen-

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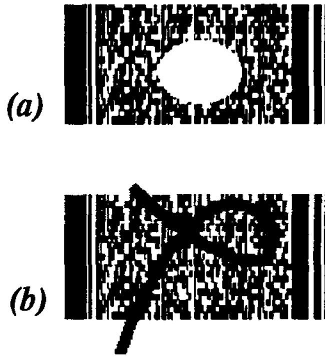

FIG. 3. Examples of Torn and Distorted Symbols

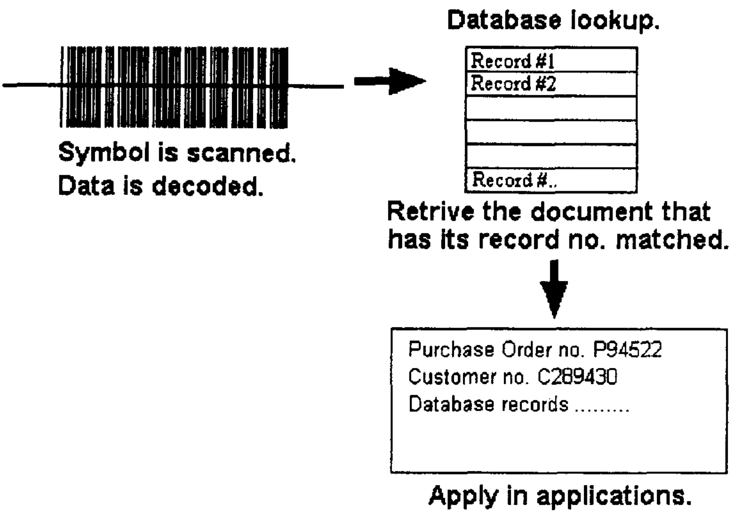

FIG. 4. One-Dimensional Symbology Application Scheme

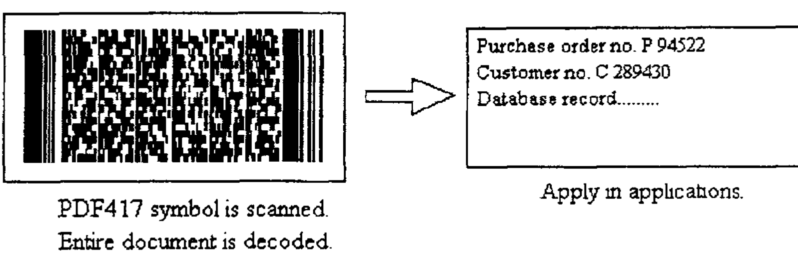

FIG. 5. Two-Dimensional Symbology Application Scheme

sional application scheme versus a two-dimensional application scheme in Fig. 5.

The application scheme of one-dimensional symbology shown here is constrained due to its capacity and capability in encoding and decoding information. When a one-dimensional symbology is used this way, a database lookup table is required.

For a two-dimensional symbology application, database lookup is not required since the 2D symbol contains all necessary information. With a portable data terminal and a scanner, all necessary information is obtained in real time without a host computer. One-dimensional symbology applications require a host computer in order to obtain this information.

HARDWARE AND SOFTWARE OF 2D SYMBOLOGY

Hardware and software for two-dimensional symbologies currently are symbology-specific, meaning that each symbology requires unique hardware and software to encode and decode. This is very different from one-dimensional symbology and is currently a major disadvantage.

For example, hardware for the PDF417 symbology includes a scanner with interface cable, an interface controller, a decoder box, and special printers capable of producing 2D symbols. For example, a PostScript printer. (Fig. 6 shows two-dimensional components.)

Software Requirements

To produce and print symbols, software is required, and is typically symbology-specific. Currently, the software for a symbology is purchased through the hardware supplier.

Encoding Data

To explain how data are encoded, a typical construction purchase order is used. Purchase-order information is usually recorded in database records. Each record contains information in fields. Each field (for example, purchase-order (PO) number, item number, description, etc.) is separated by a comma and a quotation mark. The comma is used to separate each field or category in the database file—it serves as a delimiter. Therefore, the database software can distinguish each field when decoded by recognizing the comma and placing a value in an appropriate field. The following database record in text-file format can be encoded to 2D symbology: "P 123456","ABC Company","273 First St.","Lafayette","IN","47905",". . ."

This text-file format is accepted by most database software. The database software will recognize each field separated by a comma (comma delimited). Therefore, for example, the P 123456 will be placed in the PO field, the ABC Company will be put to an address field, and so on. Therefore,

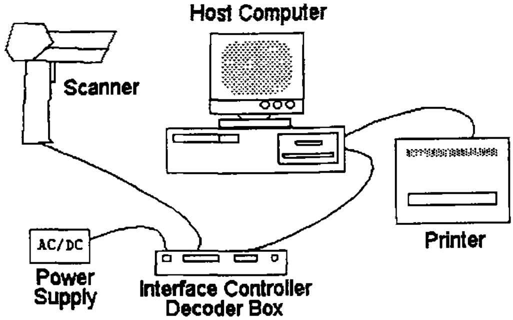

FIG. 6. Two-Dimensional Components

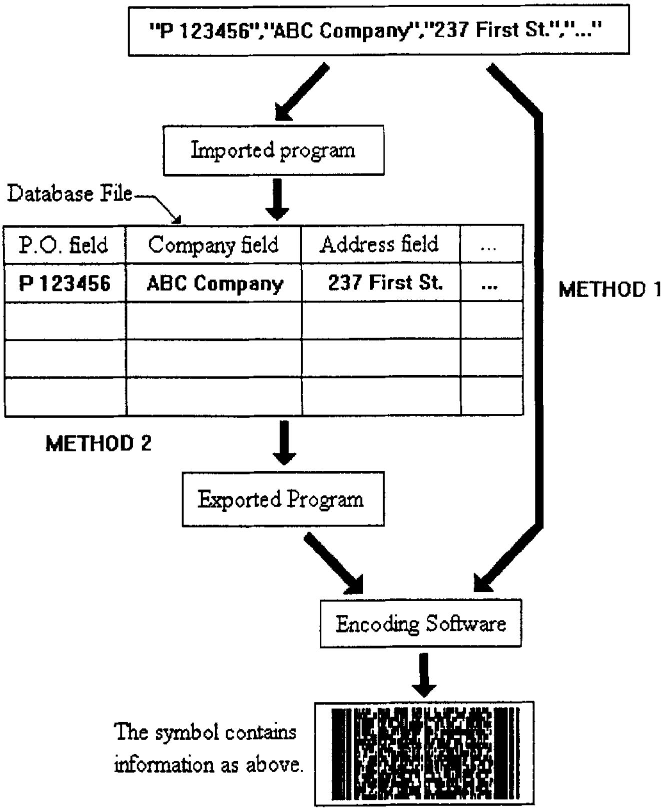

FIG. 7. Encoding Schemes

database records can be either created from the text file or conventional keyboard entries.

There are two ways to direct the encoded data. Fig. 7 illustrates both methods. These two are

1. The data are encoded and sent directly to the printer. The data are then stored in a label. No encoded file remains.
2. The data are encoded and stored in a PostScript (*.PS) file. The file can be transmitted to the printer when necessary.

Neither method has advantages over the other and no special hardware or software is required.

Decoding Data

Currently two methods can be used to decode 2D symbols: One is with a 1D scanner; the other is with a 2D scanner.

If a two-dimensional scanner is not available, a conventional handheld laser scanner can be employed to decode the symbol. To scan data, the scanner beam is walked up and down the symbol. The projection of the laser beam is shown in Fig. 8.

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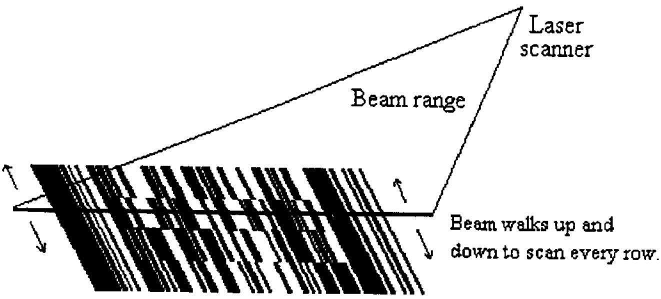

FIG. 8. Projection of Laser Beam on Symbol

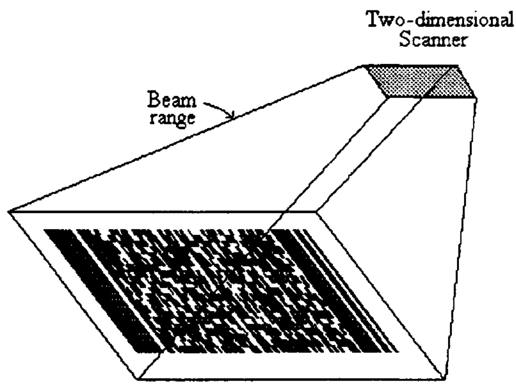

FIG. 9. Projection of Two-Dimensional Scanner Projection over Symbol

Using a one-dimensional laser scanner is rather cumbersome and awkward for scanning 2D codes. Therefore, 2D scanners are being developed that produce a rectangular-box laser-beam pattern that can cover an entire symbol. The label can be easily scanned and decoded. Fig. 9 shows the projection of the rectangular-box beam.

TWO-DIMENSIONAL SYMBOLOGY APPLICATIONS

The two-dimensional symbology, with its ability to encode more information than one-dimensional symbology, can provide new data-management opportunities for contractors and owners. The following describes some of these potential applications.

Identification Card

Figs. 10 and 11 are examples of identification cards that employ one- and two-dimensional symbols, respectively. These identification badges, using either one- or two-dimensional symbology, are adjustable depending on their usage and design.

Comparing Figs. 10 and 12, the one-dimensional symbology occupies more space than the two-dimensional symbology. Even though in Fig. 10 the one-dimensional symbol contains only the identification number of the card holder, the symbol in Fig. 11 contains an identification number, name, department, etc., in a smaller area. With two-dimensional symbology, more

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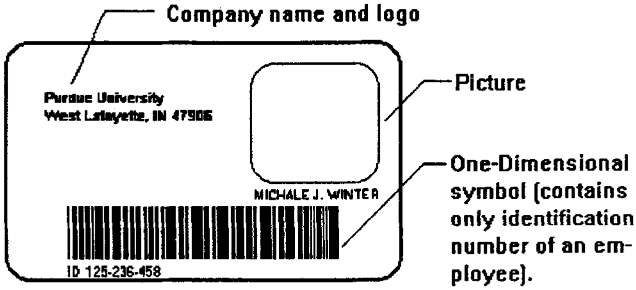

FIG. 10. Identification Card with One-Dimensional Symbology

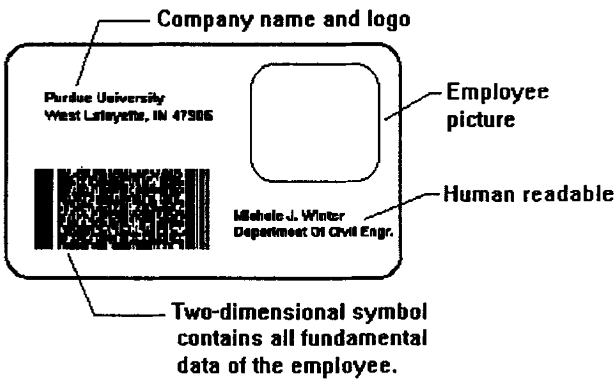

FIG. 11. Identification Card with Two-Dimensional Symbology

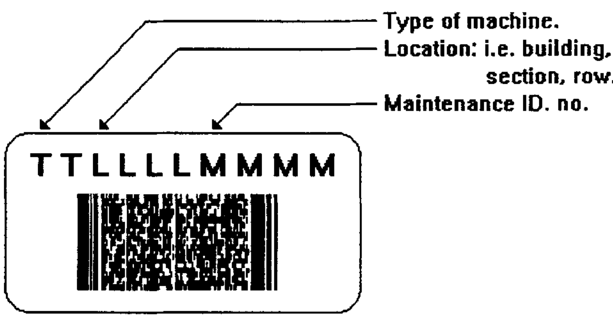

FIG. 12. Example of Maintenance Label, Using Two-Dimensional Symbology

information can be encoded, including human-readable information, as shown in Fig. 11. Data can be obtained in real time by scanning the badge. More information about the employee can be obtained for use in timekeeping, productivity, safety incidences, and security applications.

Maintenance Management

The construction environment requires the keeping of many records. One example is equipment maintenance records. Recording maintenance history is time-consuming but necessary. The maintenance information that is recorded should include last maintained date, next service date, which parts

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in a machine were repaired or replaced, and who performed the maintenance. In traditional maintenance management, paper forms record maintenance information and files are kept on each piece of equipment.

A two-dimensional bar-code technology is very suitable for this purpose. A two-dimensional symbol can contain the maintenance records—last maintenance date, who did it, next maintenance date, and which parts were repaired or replaced. The symbol can be attached to the machine for accessibility. Once scanned, the data is brought into the portable scanner, where a maintenance history can be viewed. Equipment maintenance information can be updated and a new label generated and placed on the machine for future access. Fig. 12 shows an equipment maintenance label.

Shipping Processing

Distributing materials just in time (JIT) is a very important process in construction and other industries. The construction process can be interrupted because of insufficient or wrong materials, which can be caused by shipping the wrong items or less quantity than specified in the purchase order.

In the automotive industry, a standard shipping label has been adopted and developed called the Automotive Industry Action Group (AIAG) label. This label has also been adopted by other industries. Fig. 13 shows an example of an AIAG label modified for the construction industry. The label contains one-dimensional bar-code fields and a two-dimensional symbol encoding all information displayed.

As illustrated in Fig. 13, the AIAG label comprises four main components

1. Part number (P): the number of the material shipped
2. Quantity (Q): quantity of the material
3. Vendor serial number (V): supplier serial number

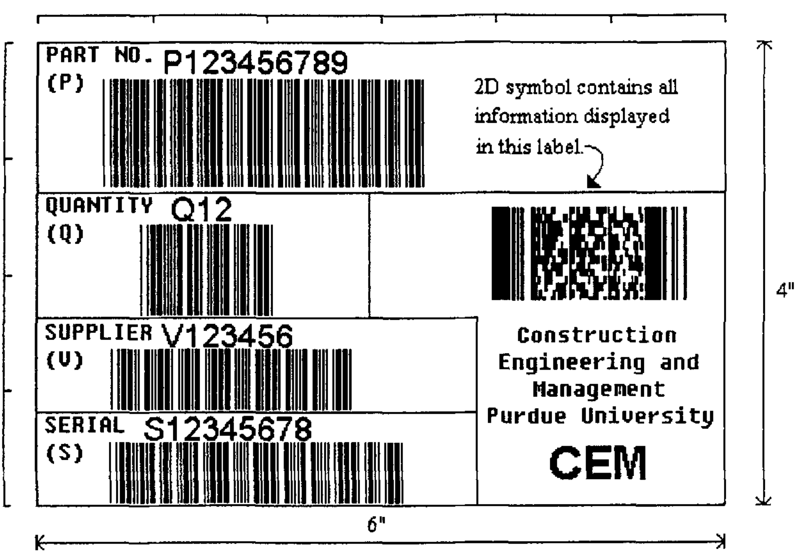

FIG. 13. Example of AIAG Label, Adapted for Construction Industry, Using Both Linear Symbology and Two-Dimensional Symbology

4. Serial number (S): the label serial number (this number can be used as a reference to its database record)

The standard AIAG uses one-dimensional symbology. The two-dimensional symbol in the label can contain all information displayed on the label, or more if necessary. The part number, quantity, supplier serial number, label serial number, company address, and destination address can be encoded into one symbol.

The label in Fig. 13 can be adapted to another label that utilizes two-dimensional symbols. The size of the label can be dramatically decreased, and only one scan is required. The label in Fig. 13 requires at least four scans to obtain the information. A two-dimensional label for shipping and handling may look like the label illustrated in Fig. 14 (scale is provided for the comparison of the sizes of labels).

As seen in Fig. 14, the label size has been reduced approximately 60%. The information contained is the same as in Fig. 13. The human-readable information is still included in case the symbol is distorted and scanning becomes impossible. Both labels in Fig. 13 and Fig. 14 have advantages and disadvantages. Fig. 13 has both symbologies so the label data can be scanned with a conventional scanner on either the two- or one-dimensional labels. Fig. 14 would require the contractor and/or vendor to have a two-dimensional scanner.

Process Equipment Repair

Construction companies that provide not only construction services but also maintenance services for the complete facility could utilize a 2D sym-

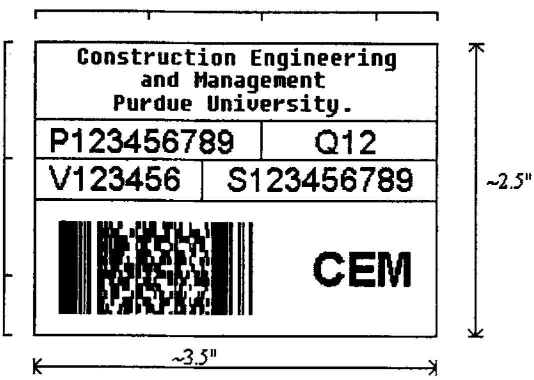

FIG. 14. Example of Shipping Label

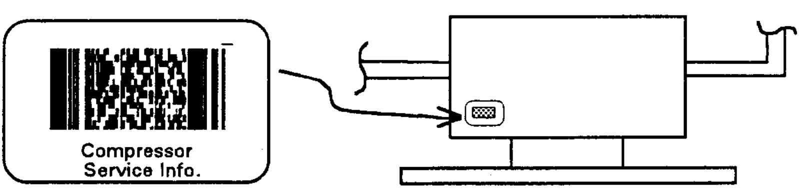

FIG. 15. Two-Dimensional Symbology that Contains Compressor Service Information

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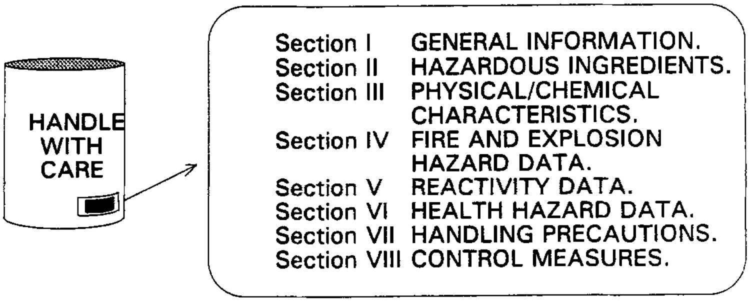

FIG. 16. Hazardous-Material Safety Data

bology to provide instructions for maintenance crews. The label could be affixed to an engineered equipment item and it would provide instructions on repair operations. Fig. 15 shows a label that could be affixed to a compressor for this purpose.

Material Safety Data Sheet

For hazardous materials, the Occupational Safety and Health Administration (OSHA) requires the keeping of material data sheets. Each material is to have a data sheet on record. The sheet contains information on hazardous ingredients, physical/chemical characteristics, fire- and explosion-hazard data, reactivity data, health-hazard data, handling precautions, and control measures. This is a lot of information to track and have accessible in case of an accident. With a 2D label this information could be encoded and placed on the container of the hazardous material. Thereby making it accessible and available at the point where timely information may be crucial for health considerations. Fig. 16 shows a container of hazardous material with a 2D label containing safety data.

The following section explains how to transfer scanned 2D data into a database file.

SCANNING AND STORING 2D SYMBOLOGY DATA INTO DATABASE FILES

Loading scanned data into a database file is not as straightforward as the loading of one-dimensional symbology data. Scanned data comprise fields in a data file. A carriage return is encoded at the end of the last field in a record. The scanned data are appended into a database field and record one at a time.

To explain the process, a field purchase order is used. Generally, the format of a purchase order is flexible depending on its usage. However, the format should include necessary categories such as purchase-order number, destination address, items ordered and their details, and so on. Fig. 17 shows a purchase-order form that is used in this application. The main categories in the purchase order are the fields in the database file. These are purchase-order number, contract number, sequence number, attention to, destination address, phone number, date, date required, ship via, order by, item number, quantity, description, and price.

A purchase order has two main parts: (1) The top part is a purchase-order number and general information; and (2) the bottom part is item information, such as number, quantity, and unit price.

Field Purchase Order

Construction Engineering and Management
Purdue University
West Lafayette, IN 47907
(317) 494-2240

This number must appear on all invoices, shipping memos, bills of lading & packages.
Purchase Order number ________

Ship to: ______________________ Attn. to: ______________________
Address: ______________________ City: ______________________
State and Zip Code: ______________________ Tel: (___) ______________________

Date	Date Required	Ship Via	Order By

Item No	Qty Ord	Qty Rec'd	Description	Unit Price	Extended Price	Acct No

FIG. 17. Example of Field Purchase Order

Date ( ) Page_PAGE

CUSTOMER ADDRESS AND P.O. NUMBER

P.O. NO.: p_number ATTN. TO: attn_to

CONT. NO.: cont_no ADDRESS: address city

SEQ. NO.: seq_no sta, zip PHONE: phone

FIG. 18. Empty Report from *shipp.dbs* Database File

Date( ) Page_PAGE

ITEM AND ITS DESCRIPTION IN PURCHASE ORDER

P.O. NO.	ITEM NO.	QTY	QTY REC'D	DESCRIPTION	UNIT PRICE	EXTN'D PRICE	ACCT. NO.
p_number	item_no	qty	qty_r	descrp	unit_prc	extend_prc	acct_no
						extend_prc	
						=========	

FIG. 19. Empty Report from *item.dbs* Database File

```
"P 502933"," "," ","Matt Wilson","98 Helmut St.,","San Jose","CA","92596",
"236-925-9562","10/29/92","11/15/92","UPS","Mailed in" [Enter]
"P 502933","I 962153","100","100","Sand paper",".5",".5","AC 361542" [Enter]
"P 502933","I 226895","5","5","Rebar # ... (Ton)","1000","5000","AC 361758" [Enter]
"P 502933","I 145826","10","10","Spade","20","200","AC 361253" [Enter]
```

FIG. 20. Example of Exported Text File from Database File

These two main parts are grouped into two database files. The reason is to not limit the number of PO line items. Therefore, one database is for storing general PO information and another for the line item fields. Two database files are created and combined into one database file. Fig. 18 shows the fields for the database storing general PO information and Fig. 19 for line item information.

The second database file has one common field (purchase-order number) with the first database file. This purchase-order field is used to link the two database files. After the two database files are constructed, a third database file is constructed by combining the two together.

RETRIEVING SCANNED DATA INTO DATABASE

Data scanned will most likely be organized in a text-file format. Fig. 20 shows PO data in a text-file format. The data are arranged in four records that are terminated by *[Enter]* (a carriage return).

The first record represents the top portion of the purchase order. The other three records are the three line items in the PO. Each field is separated by a comma (,).

A data-import program is written to read information from a text file. Once the information is stored in the text file, the information can be retrieved using the data-import program.

The concepts behind the database import program are:

1. Separate each field by using a comma [the quotation mark (") is optional].
2. Separate all records using *[Enter]*.
3. Read the first record and append it to a database file.
4. Read the rest of the records and append them to a second database file.
5. Combine the two database files to create a third database file. This database file will be used in the database software manager.

DOWNSTREAM IMPACT

For the construction user, two-dimensional symbologies can provide additional capabilities and opportunities over one-dimensional symbologies. Because a large amount of data can be encoded, the data can be placed at the source, where it is easier to locate. This accessibility provides quicker data retrieval, which benefits the user because the information is just a scan away. This would eliminate having to scan an identifier label and go through a database lookup-and-retrieval process.

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A significant downstream effect is the elimination of multiple data entry and handling. With data encoded, the need to key it in is eliminated and every activity associated with data handling is automated. This increases the through flow speed of data and reduces the chance of entering erroneous values. So with this 2D technology the user can create in these proposal applications an automated data-management system.

CONCLUSION

The two-dimensional symbology has a very high potential to replace traditional one-dimensional symbology in some applications that require more encoded data and a high level of error correction. However, there are linear symbology applications that cannot be effectively represented by two-dimensional codes. The writers envision a combination of the two symbologies for construction applications. And with the development of 2D scanners, both technologies can be scanned and decoded with one hardware device, allowing the utilization of both technologies in construction-data management.

For example, a symbol can represent an invoice or a purchase order. Scanning the symbol is an efficient way to enter this information into the data-processing system. Data are entered more reliably with less effort and time.

Two-dimensional symbology can be employed in other applications such as asset tracking, maintenance management, and employee identification card. The example for the material shipping process was given in this paper.

Some current construction-data-management processes can benefit from 2D utilization. However, current 2D hardware is limited; but when it becomes available, construction-operation applications should be pursued and developed.

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