BAR CODE-DRIVEN EQUIPMENT AND MATERIALS TRACKING FOR CONSTRUCTION
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ABSTRACT: The utilization of bar code–based materials management systems has helped the Department of Defense, as well as entire industries, to save hundreds of millions of dollars through improved productivity, timeliness, and data accuracy. Can this technology be used in construction? Many authors have proposed a variety of potential applications. This paper presents the design and development of a pilot yard control system that utilizes the bar-coding concept. It demonstrates how the system was designed to fit the stated objectives. Also presented is software for the integration and verification of bar-code data. Finally, a brief discussion emphasizes the importance of selecting the proper labels and adhesives for the expected environments of the bar codes within the construction environment.

INTRODUCTION

1982 brought a major boost to bar-code technology as the U.S. Department of Defense started to require all suppliers to ship their goods with attached bar-code labels. Since then, both the grocery and auto industries have stepped up their efforts requiring bar-code labels on every item moved between plants and organizations.

What are bar codes and what are their effects? Burke (1984) states: “Bar codes are messages where information is encoded using widths of wide or narrow bars and spaces (i.e., unique wide or narrow combinations of black and white bars). They provide a means of creating labels which can be read by instruments.” Bar codes have proven to be money savers due to their ability to support automatic data collection concepts. After the grocery industry reached the point where the number of labeled items proved the practicality of the system, savings of more than 1-1/2% of the gross profit resulted. This is considered extremely high because of the very low profit margin in this industry. Baker (1983) gives other examples of resulted improvements: “(a) Decreased work in process investment has been reported to be up to 65%, (b) reduced raw material parts and finished goods inventory are running as high as 50%, (c) less paper processing. In some plants this is running as much as 90%, (d) increased output from existing capacity is running as much as 35%.” These successes have been related to the use of the bar-coding technology. The results lay in improved equipment and material tracking, employment of the just-in-time material delivery, higher responsiveness to customers, less waiting time, and the utilization of multi-purpose robots (Baker 1983).

This paper describes the result of a research and development effort to introduce a prototype system for tracking construction equipment and material. The goal was to improve the accountability for the individual items and to improve the accuracy and timeliness of the tracking information. The effort was broken down into two separate tasks: (1) Developing and imple-
menting an automated tracking system; and (2) testing the survivability of bar-code labels and adhesives in the construction environment. The following primarily presents the results of the first task and briefly describes the conclusion of the second task. For a detailed description of the principles of bar codes, the reader is referred to other published articles (Bell et al. 1985; Stukhart 1988).

PRINCIPLES OF YARD CONTROL SYSTEMS

Construction yard management is closely related to site operations. Some of the main functions of a yard include: (1) Making equipment and materials available when required; (2) ensuring that the delivered equipment and materials satisfy the project requirements; and (3) sustaining the operation of the equipment and the flow of materials during the entire construction process. While the manufacturing industry separates the function of materials management from the machinery management, the construction management industry generally does not separate them. The two major resources, equipment and material, are handled by the yard management. For example the cranes, concrete buggies, electric hammers, and steel beams are shipped from the same yard using the same ordering system and delivery trucks. The yard manager is responsible for the inventory of a sufficient amount of scaffolding material as well as for securing the repair of cranes and trucks. However, equipment and materials are not solely shipped from the yard. Other flow paths include direct delivery from a material supplier to the site, from one site to another site, from one site to the supplier for refills (e.g., gas bottles), and back to the site. Since all these paths have to be controlled, the management of a construction yard is complex, but critical for maintaining uninterrupted construction operations. Detailed information about position and states of equipment and materials is a main requirement for accomplishing these goals.

The accounting for equipment and nonconsumable materials is another function of the tracking system. Because its objective is to properly account and charge each ongoing project for the use of every piece of equipment, tool, or nonconsumable material on a daily basis, timely information about the location of every item is mandatory. Necessary repairs and lost parts have to be charged to the individual projects as well.

Traditionally, the necessary work to support all the required management functions is done manually. Only recently have computers been introduced, primarily as data storage devices. As expressed by the yard manager of the investigated company, there is a great need for improving the state of the art. Three key elements of the yard control system need enhancements. First, the accountability for individual items needs to be increased (e.g., for gas bottles). Second, the tracking information should be available to the yard as well as the site managers, and third, further reduction of paperwork and errors during data entry are mandatory.

A research team from the University of Maryland was invited to investigate how the use of bar-coding technology could help to reach those three goals. It was decided to first analyze in detail the present system before designing and developing a prototype system that could be tested in the real world. The following sections will describe the traditional concept before the structure of an improved concept is introduced.
DESCRIPTION OF CURRENT SYSTEM

The George Hyman Construction Company, for which this work was done, is a large general construction company. It has offices in Los Angeles, Miami, Philadelphia, New York, Washington, D.C., and Boston, with 20–40 active construction projects at any time. In support of these projects, the company owns and operates approximately 3,000 individual pieces of equipment and tools ranging from simple drills to construction cranes. The yard management is also responsible for renting, leasing, or buying equipment and non-consumable material such as scaffolding or steel beams. Today's information regarding the transfer, the date, and the quantity of the transferred equipment or material is collected by hand and then manually entered into a personal computer (PC). This information is then used for updating project costs resulting from equipment usage. The update may occur weekly or biweekly depending on when the data is entered into the computer and processed. The following sections discuss the sequence of steps that occur, starting from the initial request for a piece of equipment or material until the transfer is entered into the computer. Fig. 1 presents a graphic model of this process.

The five elements of the yard control system are connected through the flow of information and physical items. These five elements include: (1) The project; (2) the yard office; (3) the delivery truck; (4) the PC-based yard computer; and (5) a main frame computer in the central office. In order to understand the behavior of the system, a detailed understanding of the ordering and delivery system is necessary.

Ordering (Step 1)

Typically, a construction job site supervisor contacts the yard office and makes a request specifying the delivery time and the desired type and quantity of the equipment and/or materials. This request is normally written down on a small piece of paper, and then it is posted on a board at the yard office.

Preparation of Shipment (Step 2)

The day before the equipment is to be delivered, the appropriate delivery items are consolidated onto a work ticket and availability is confirmed. On the morning that the delivery is scheduled, the labor foreman is given the work tickets to distribute to the appropriate truck drivers responsible for the deliveries. The truck drivers load their trucks with the specified items and write down on the work ticket the specific identification numbers of each piece of equipment, tool, or material.

Preparation of Transfer Ticket (Steps 3 and 4)

With all the equipment and materials loaded, the truck driver returns to the yard office where a formal transfer ticket is prepared. The transfer ticket is the document that states the specific pieces of equipment and materials that are delivered to the job sites. In other words, every time a transfer takes place a transfer ticket has to be issued. The truck driver is handed two copies of the transfer ticket.

Site Delivery (Steps 5, 6, and 7)

The equipment and material is transported to the project site where one copy of the transfer ticket has to be signed after it has been updated to reflect
the actual shipment. If items are rejected, or simply ordered by mistake, the transfer ticket has to be changed accordingly.

Information Processing (Steps 8 and 9)

The transfer tickets are collected at the yard office. At some point, a batch of tickets is processed. At this time each ticket item is priced, which means that an appropriate standard “usage cost” is applied. From time to time (e.g., end of the week) the data from all the tickets is entered into the yard’s computer. After the data is edited and corrected it is uploaded to the mainframe where error checking occurs. Any errors in the batch must be corrected before the data is finally used to update the equipment data base and the project cost accounts.

The described method provides many opportunities to introduce modern approaches in data collection and information processing. One such example
is the use of the bar-code technology to improve the quality and the timeliness of information.

**COMPUTERIZED YARD CONTROL SYSTEM USING BAR CODES**

The George Hyman Construction Company had decided to develop a pilot yard control system that utilizes bar-code technology. In order to avoid any disruptive impact of the prototype system to the ongoing operation it was decided not to change the existing information routing path. Nevertheless, a bar code-based system as an automatic identification system to improve the accuracy and timeliness of the produced information should be developed and tested. Based on these goals a basic concept model was developed that is presented in Fig. 2.

The following presents a narrative description of the modified delivery sequence modeled in Fig. 2, which is designed to take full advantage of the computer and the bar-code technology.

**Ordering (Steps 1 and 2)**

The sequence starts with a need at one of the project sites. As a result, the construction job site supervisor places an order with the yard office by phone. The request is entered immediately into the PC through the use of the keyboard.

**Retrieval of Ordered Items (Steps 3, 4, and 5)**

On the morning that the order is to be delivered to the project site, the appropriate work tickets are printed and distributed to the truck drivers for the preparation of the shipment. As the equipment is loaded, the bar code on each material or equipment item is read with the automatic reader and the data stored in a portable data entry terminal (PDET). At the yard office the PDET is connected to an IBM PS/2 PC via an RS-232 communication cable and the bar-code data is uploaded into the PC and stored in a data file.

**Order Verification (Steps 6 and 7)**

The uploaded data represents the individually identified items ready to be shipped. At this step the order is checked to be sure that those items match the work ticket. The system searches the data bases to see if the loaded items identified with a bar code are, in fact, representatives of ordered equipment or material types (e.g., is bar code xyz a concrete buggy of type k?). In addition, the system verifies that all the requested goods have been loaded on the truck.

**Delivery (Steps 8 and 9)**

After it is properly verified the truck driver delivers the order to the site and has the job site supervisor sign the transfer ticket to acknowledge receipt of the items. If items are no longer appropriate, corrections can be made on the transfer ticket. The transfer tickets, which are already in the PC data base, are then returned to the yard and are updated with any changes, and then uploaded to the company's mainframe computer.

**Returns (Step 10)**

Since the return of equipment and materials to the yard is less formal (i.e., no work tickets are needed), the transfer tickets must be generated based on
FIG. 2. Graphic Model of Proposed Computerized/Bar Code Yard Control System

the bar codes read with the bar code reader as the items are returned to the yard. The same holds true for deliveries from one site to another. The location of the actual bar code entry is irrelevant as long as the origin and the destination of each (or a series of) material and equipment item can be properly identified. The following chapter will present the developed system in more detail.

**DESIGN OF YARD CONTROL SYSTEM**

For the design of the overall system, three interrelated subsystems were defined: (1) Data capture and information processing; (2) data bases; and (3)
data verification and updating. The design of these three subsystems will be discussed individually in the following sections.

It needs to be stated at this point that the labeling of each piece of equipment and material will be crucial for the success of the system. The labels should be attached once the item enters the system (e.g., through purchase) and last until the item is eliminated from the system. In the case of an accidental loss of the label, it should immediately be replaced to provide continuity. As will be discussed later, a backup label might be of help in such a situation.

**DATA CAPTURE AND INFORMATION PROCESSING**

Automatic data capture is needed for steps 4, 5, and 10, while information processing is closely related to step 7 described in the previous chapter.

The bar-code technology allows the capturing of data, which can be processed into information. For example, realizing that a certain equipment code (data) is following a project code (data), the system is able to infer that the identified equipment is being shipped to the project. Therefore, a well-organized framework, which is able to use not only the data itself but also its position within a data stream, could help in the processing of information at no extra "cost." For this purpose, a three-tiered hierarchical structure was developed (see Fig. 3). The structure mirrors the three distinctive hardware levels reaching from the simple data storage device to the sophisticated mainframe computer.

The proposed approach copies the traditional control system by merely automating the input of data concerning the actual deliveries to the different

![Diagram of the Hierarchical Structure of Yard Control System](https://example.com/diagram.png)

**FIG. 3. Hierarchical Structure of Yard Control System**
FIG. 4. Bar Board with Origin and Destination Codes

<table>
<thead>
<tr>
<th>Name of Location</th>
<th>Origin Code</th>
<th>Destination Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yard</td>
<td><img src="image" alt="Origin Code" /></td>
<td><img src="image" alt="Destination Code" /></td>
</tr>
<tr>
<td>J.H. Garage</td>
<td><img src="image" alt="Origin Code" /></td>
<td><img src="image" alt="Destination Code" /></td>
</tr>
<tr>
<td>Tech. Center</td>
<td><img src="image" alt="Origin Code" /></td>
<td><img src="image" alt="Destination Code" /></td>
</tr>
</tbody>
</table>

projects. Data that is collected at the yard or at the different sites is uploaded from a portable data storage device attached to a bar-code reader (wand or laser scanner). Additional basic data, such as the cost code for each item, is stored in the yard data base. Information regarding the shipment of items from one location to another, together with the date of the shipment, is uploaded to the IBM System 38 mainframe computer for the updating of the central yard data base. As a result of automating data collection and data transfer, reports and on-line inquiries of the main data base are very accurate and near real time. This means that information about the movement of each and every piece of equipment or material item should be available not more than one day after it occurred.

Each equipment or material transfer can be described with four basic data sets: (1) Destination of delivery; (2) origin of delivery; (3) item specification; and (4) date. Only the third data set is produced by the bar code attached to the individual item. In order to create a truly automated data collection system it is necessary to also include the automatic capture of data related to the destination and the origin of delivery. The date is inferred from the time of entry or uploading provided by the internal clock of the computer.

One method for collecting data about the destination of shipments, which is also bar code-based, is the use of a bar board. The idea is to hold standard information, such as the code of a project, represented by a bar code on a board. In effect, this concept is used to code all the ongoing projects. Bar-code labels identifying each project or yard as a destination, as well as the origin of a shipment, are placed next to each project, thus allowing automatic data entry. Fig. 4 presents an example from the developed bar board. It is good practice to attach the bar board to the bar code reader so it will always be available when needed. The main purpose of having two codes for each location is to make it possible to distinguish between a destination and an origin of a shipment.

In order to facilitate computer searches, identifiers incorporated in the codes are used to distinguish between delivery locations and items of delivery. In the example presented in Fig. 5, the codes that start with an alphanumeric CI code indicate a location.

Fig. 5 shows an example of a stream of bar codes that is uploaded from the hand-held computer into the PC. If the rule states that every data stream for a new shipment has to start with two codes for origin and destination,
FIG. 5. Example of Bar Code Stream Uploaded from Bar Code Reader

<table>
<thead>
<tr>
<th>Record No.</th>
<th>Barcodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CI0277</td>
</tr>
<tr>
<td>2</td>
<td>CI0271</td>
</tr>
<tr>
<td>3</td>
<td>000333</td>
</tr>
<tr>
<td>4</td>
<td>000255</td>
</tr>
<tr>
<td>5</td>
<td>001123</td>
</tr>
<tr>
<td>6</td>
<td>001200</td>
</tr>
</tbody>
</table>

A simple algorithm can be utilized to analyze the data stream. The algorithm can be based on two simple rules: (1) Codes that begin with a CI always have to come in pairs (origin and destination); and (2) all numeric codes between two pairs of CI codes represent equipment or material items related by the head pair. With these two basic code identifying rules a very simple, but flexible, structure for data capturing develops.

The following section describes the second important element of the overall system, the data base. The need for total integration and data verification procedures provided many challenges for the design of this subsystem.

**Data-Base Management**

For the necessary integration of hardware and software between the different hierarchical levels of the yard control system presented in Fig. 3, interfaces for uploading had to be developed. In addition, structures for several databases had to be established and integrated into an overall data-base management system. Data files for data management had to be developed. Fig. 6 presents a schematic overview of the overall system.

The data-base management system written in dBASE III+ comprises three main data files for equipment/materials, projects, and work and transfer tickets and an interim data file for storing bar codes during uploading from the PDET. Several linked programs provide the user with direct access to these different data files for searching and updating. A separate program was written in QuickBASIC, to upload data stored in the PDET to the yard office PCs.

Each of the data files has its own record structure. Fig. 7 shows the structure for the equipment/material data file. The two other main data bases hold data about each ongoing project (e.g., address) and the different work and transfer tickets (e.g., individual items delivered).

The equipment/material data record holds eight data fields, one numeric and seven character fields. The field ATJOB holds the latest destination of
that particular item identified with the ID_NUMBER and DESCRIPTION. BARCODE1 and BARCODE2 store the bar codes of two labels attached to each equipment or material unit. This backup system was developed based on the field testing of labels, which concluded that in order to reduce the

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Width</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ID_NUMBER</td>
<td>Numeric</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>2 DESCRIPT</td>
<td>Character</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>3 ATJOB</td>
<td>Character</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>4 TRANSDATE</td>
<td>Character</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>5 BARCODE1</td>
<td>Character</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>6 BARCODE2</td>
<td>Character</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>7 GROUP</td>
<td>Character</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8 SERIES</td>
<td>Character</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

FIG. 7. Record Structure for Equipment/Material Data File
probability that a code could not be scanned due to loss or destruction of a label, a second label would be attached at a secure location on the unit. Therefore, BARCODE1 is considered to be the prime while BARCODE2 is the backup code. The labels have to be attached to the individual equipment and material and its code entered manually into the data base once. Lost labels can be replaced with a new code, which will require an update of the Equipment/Material data file.

This proposed flexible concept of storing the bar codes with the equipment/material item has several advantages. For example, after the destruction of a bar-code label, a new label has to be attached to the item. Because the data base allows updating of the bar codes, a new code can be assigned to the piece of equipment or material. This flexibility is a key economical advantage since it is not necessary to reorder labels with the same number, which is very expensive due to the small size of the order. The capability for updating the bar codes in the data base allows the next label to be assigned from the stack of preordered codes.

The GROUP and SERIES fields store company specific codes identifying the group and the series the unit belongs to. These two fields allow the use of the company’s present identification system, which is based on a group and a series code for every item. It needs to be mentioned that this data file is kept small with only the necessary data. The detailed information about each unit is kept in the main data base on the IBM System 38 mainframe computer (see Fig. 3). Also, for the purpose of efficient searching, indexed files are automatically handled and updated. Fig. 8 shows four such files and their keys.

Each of the keys is used for different search procedures. BARCODE1, for example, is used for identifying the proper equipment or material record after a bar code is read from the stream of uploaded codes. If no code can be identified, BARCODE2 becomes the key and the search is repeated.

Data Verification and Updating

Automatic data collection has to include automatic verification and updating of data files. For that purpose, an algorithm was developed that is able to analyze the data stream as it is uploaded from the bar-code reader.

Fig. 9 presents a flow chart of an algorithm that is able to interpret a bar code after it is identified as being the code of an equipment or material unit. The name of the data-base field that holds all the uploaded bar codes is NEWCODE. TICKDATA holds the data about all the issued tickets, and
FIG. 9. Flowchart of Data Verification Algorithm

TICKETS handles the ticket numbering system to allow for the automatic issue of ticket identifiers.

EQMABAR1.NDX is the name of the data file holding all the information relating to the equipment and material items indexed by the prime bar code BARCODE1. It is selected first for a search through the field BARCODE1. If no matching bar code can be found EQMABAR2.NDX is searched using field BARCODE2. If this search also fails, a message is given to the user alerting him to the fact that for the code stored in NEWCODE no bar code exists in the EQ.MAT data file.

If, however, a proper match is found, then the bar code is meaningful and the identified item is compared to the work tickets stored in TICKDATA, which holds all the requested equipment or material types identified with a
group and series number code as well as the shipment destination matching
the destination related to the bar code reading the back of equipment (e.g.,
Project Tech Center). This search fulfills two purposes; it checks whether
the loaded item type: (1) Was actually requested (e.g., a concrete bucket);
and (2) is the item of the correct capacity (e.g., a 2.5-cu yd concrete bucket).
In the case of a proper match between a ticket item and the identified equip­
ment/material item, which also includes the proper destination, the ticket
file is updated by copying the bar code of the item into a field of TICK-
DATA. When the field is no longer empty, then this unit has been loaded
on the truck and is ready to be delivered. If no work ticket can be identified
that matches the job destination with the group and the series number of the
identified item, a check is made to determine if there exists a work ticket
that has the destination and origin declaration as the item represented by the
bar code. If YES, then a wrong item was loaded because it was not listed
on the work ticket and should be removed from the truck. If NO, a new
transfer ticket needs to be started and the equipment/material item appended
to the list of ticket items stored in the data file TICKDATA. This situation
occurs when material is returned to the yard without prior entry of a work
ticket.

The final results of this procedure are messages about mismatches and a
printout of a transfer ticket for each delivery. The overall concept is designed
based on rapid data communication from one computer to another and a fast
data verification process that takes place while the truck driver is waiting.

After final editing, which should only include deletions of items not ac­
cepted by the job site and returned to the yard, the ticket information is ready
to be uploaded into the IBM System 38 mainframe computer for final pro­
cessing. The updated detailed information on the location and state of each
every unit of equipment/material is now available for queries by man­
agement or for proper cost accounting.

As stated at the beginning of this paper, the data collection and infor­
mation processing system is only one element that has to be designed to fit
the objective of an efficient and effective control system. The second very
important issue is the selection of labels and adhesives that ensure the sur­
vival of the codes in the construction environment. The following section
provides a brief summary of a search effort to identify the critical factors
and proposes recommended procedures for design and development of the
labels.

**Selection of Labels and Adhesives**

Readable bar code labels are the essential components of bar code tech­
nology. Of course, there are alternate approaches to automated data collec­
tion, such as entry of the codes by hand, but they eliminate the main ad­
vantage—error reduction. One simple remedy that helps to reduce the
probability of losing a readable code is the use of a backup label attached
at a secure place. However, this does not guarantee that both labels will
survive an environmental exposure that neither is fit to endure.

The bar-code industry provides many different label types (e.g., aluminum
labels) developed for different conditions, such as excessive humidity, heat,
or physical abuse. Bar codes can also be made cheaply out of nondurable
paper using laser printers. Separate from the question of which label to use

393
is the problem of adhesive selection. While the label has to ensure the readability of the code the adhesive must be responsible for keeping the label at its intended location. Labels and adhesives can be selected in many different combinations.

**Labels for Construction Site**

The general conclusion of an intensive laboratory and field test was that the amount of exposure to heat and physical impact are the key factors when deciding on labels for the traditional construction environment. If only moderate heat (below 100° F) and no major physical impact can be expected, some of the less expensive plastic labels are sufficient. Should the environment be more "demanding," thin aluminum labels, which are 10 times more expensive than plastic labels, should be used. The study also showed that due to the lack of experiences with labels on construction equipment and material, labels need to be pretested before they are used in large numbers. The critical nature of label survivability will make this a very worthwhile effort for the overall success of the system.

**Adhesives for Construction Site**

Parallel to the testing of labels, the performance of many adhesives has been investigated. Generally, several pressure-sensitive adhesives performed satisfactorily. The fact that they are already applied to the back of the label was found very important. The ease with which the labels can be administered has a major effect on the amount of effort (and frustration) needed to mount them. For example, two component adhesives are very cumbersome because they require time until they harden. If the surface is not totally flat, then the labels need to be pressed down for a period of time, thus slowing down the labeling effort. Again, the wide variety of available adhesives and their differences in performance, which was measured in shear strength after exposure to different conditions, warrants an effort to match the proper adhesive to the expected conditions during the life of a label.

In conclusion, the study found that there are labels and adhesives presently available that satisfy the requirements of a normal construction site. It is, however, wise to have backup labels on every control item in order to avoid interruptions of the automated data collection process.

**Conclusions**

Reports discussing the implementation of bar-code technology in other industries show how productivity has improved through the reduction of idle times of resources, which resulted in true cost savings. The construction industry, with its chronic productivity problem and high percentage of resource idleness, could be a prime candidate for the use of bar coding. This paper presented the results of an effort to design and develop a control system that utilizes the advantages of automated data collection through the use of laser scanners and light pens. It demonstrated how present systems can be adapted, how hardware and software can be integrated, and what the important factors in label technology are.

A word of caution is offered. The described study has reinforced the knowledge experiences in other industries have taught—that great care should be taken in designing and implementing bar-code technology. Every ele-
ment, such as hardware or labels, should be tuned to fit the construction environment. The writer is convinced that the success stories from other industries can be repeated in construction if enough care is given to properly use the technology. The George Hyman Construction Company is presently taking steps to fully implement the system with state-of-the-art hardware.

**ACKNOWLEDGMENT**

The research effort was sponsored by The George Hyman Construction Co., Bethesda, Maryland. The continuing support and direct involvement of Alan J. Petrasek, project executive; Jim Forsythe, yard manager; and John M. Knowles, assistant yard manager, are greatly appreciated. The knowledgeable input by W. W. Harris III from W. W. Harris and Associates, Millersville, Maryland, which was based on years of experience working with bar codes, was invaluable. The work of my former graduate students Nooshin Amirpour and Paul E. Christensen is also acknowledged.

**APPENDIX. REFERENCES**


