

CONSTRUCTION
INDUSTRY
INSTITUTE

BAR CODE APPLICATIONS IN CONSTRUCTION

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A Report To
The Construction Industry Institute
The university of Texas at Austin

Under the Guidance of
Task Force 85-8
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and
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Committee

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EXECUTIVE SUMMARY

The construction industry lags behind the automotive, defense, health care, grocery, retail sales, and other industries in the widespread utilization of bar code technology. Essentially all vendors supplying materials for automotive assembly utilize bar codes in compliance with industry wide standards. Similarly, the Department of Defense has developed cost effective bar code procedures for a wide range of material inventory, receiving, issue, and audit applications. Bar coding has produced substantial cost savings in other industries, primarily as a result of reduced time for computer data entry, and improved data accuracy.

Bar code applications are, however, currently being developed by both owners and engineering contractors for applications relating to quantity takeoff, field material control, warehouse inventory and maintenance, tool and consumable material issue, timekeeping and cost engineering, purchasing and accounting, scheduling, document control, and office operations. Specific applications in these areas are discussed in this report.

Bar code hardware is relatively inexpensive, and applications are easily integrated into existing accounting and project control computer systems. Despite limited experience with bar code applications, CII owners and engineering contractors are projecting cost saving benefits similar to

those documented in other industries. In general, the costs associated with bar code implementation can be recovered within a six month period of time.

To fully realize the cost saving potential of bar code applications, the construction industry needs to develop a broad base of experience with bar code technology, and then, establish uniform standards similar to those currently in force in other industries. During the coming year, Auburn and Texas A&M Universities are continuing research in the areas of implementation guidelines and standards development.

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I. INTRODUCTION

The construction industry lags behind the automotive, defense, health care, retail sales, manufacturing, and other industries in the widespread utilization of bar code technology. The automotive and defense industries have developed uniform standards and education programs, and achieved successful industry wide vendor compliance through their respective industry action groups. Substantial cost saving benefits have been documented by the automotive and defense industries for a wide range of material, equipment, and document control applications. These applications very much parallel potential applications that could be developed for the construction industry.

Two major industries closely related to the construction industry have developed guidelines for the use of bar codes in product packaging, product coding, and distribution. The electrical industry, through a joint effort of the National Electrical Manufacturers Association, the National Electrical Manufacturers Representatives Association, and the National Association of Electrical Distributors, has developed and issued uniform guidelines for the use of bar codes by manufacturers, distributors and their representatives. The various trade associations of the heating, refrigeration, air conditioning and plumbing industries, through the efforts of the Industry Bar Code Alliance, have developed material control

numbering systems and related bar code application guidelines.

Industry action groups representing some 17 different industries, including those cited above, are jointly exploring bar code related issues as part of the Federation of Automated Coded Technologies (FACT). Decisions made by related industry action groups and umbrella organizations such as FACT will directly impact the ways in which bar codes can be used by the construction industry in the immediate future. Unfortunately, no industry action group has been created by the construction industry, and no formal liaison has been established with the action groups of other industries.

Realizing the tremendous potential for cost savings that is associated with bar code technology, and the need to examine the status of bar code application experience in other industries, the Construction Industry Institute (CII) funded the research effort described herein to explore the potential applications and the resulting cost saving benefits of bar code utilization in the construction industry. This report summarizes the status of bar code utilization in other industries, examines current applications developed by CII member firms, and presents representative cost and benefit data. Hopefully, this report will serve to educate CII members with respect to bar code technology, stimulate their in house bar code application development efforts, and promote the concept of a construction industry action group.

II. CII BAR CODE RESEARCH

Research objectives

The CII funded research described herein was conducted by the authors to address the following objectives:

- determine the status of bar code utilization in other industries;
- determine the status of bar code utilization in the construction industry;
- evaluate the resulting costs and benefits associated with bar code utilization;
- formulate guidelines for widespread construction industry implementation, and recommend industry wide standards that may be needed to achieve implementation

Research methodology

To address the objectives stated above, a comprehensive literature survey was conducted to document the status of bar code implementation in other industries. The major publications pertaining to the current state of the art in bar coding technology and applications are listed in Appendix I of this report.

A Bar Code Advisory Committee was created within CII for the purpose of guiding the research effort and identifying specific bar code applications that have been developed by CII member firms. The 63 member firms of CII were contacted and requested to forward to the project researchers information pertaining to bar code applications that have been implemented, or that were being contemplated, within their organizations.

During the course of the research, the authors performed a number of site visits to CII member firms (engineering contractors) who have actually applied bar code technology to their construction projects. Case study descriptions of these applications were drafted by the authors, forwarded to the CII firms for their review and approval, and then returned to the authors for use in the preparation of this report. A number of other CII member firms forwarded internal memoranda describing proposed applications, and other data, for use in this report.

Site visits to manufacturing and warehousing facilities unrelated to construction were also conducted. Copies of reports, standards, and educational materials developed and distributed by industry action groups and the Automated Identification Manufacturers (bar code hardware manufacturers and vendors) were also solicited.

III. AUTOMATIC IDENTIFICATION TECHNOLOGY

Definition

Automatic identification is the process of labeling and identifying and controlling items, materials, and equipment by any one of a number of separate but related technologies. The goal of automatic identification is to provide more accurate, detailed, and timely information about operations! Presently the various technologies that are used for automatic identification are: bar codes, optical character recognition (OCR), radio frequency (RF), magnetic stripe, and voice recognition. Brief explanations of each are presented below.

Bar codes

A bar code can be defined as a self contained message with information encoded in the widths of bars and spaces in a printed pattern (Harmon and Adams 1984). Bar codes permit rapid error free data entry into virtually any type of computer system. Assuming the typical bar code consists of 12 data characters, a bar code can be scanned by a hand held wand at least twice as fast as the data can be entered from a keyboard by a skilled data processor. Whereas keyboard data entry generally results in one error for every few hundred keystrokes, industrial bar code scanning is accurate to the order of only one error for several million characters entered (Allias 1985).

The term "symbology" refers to the structural

characteristics of the bar code symbol. In recent years various symbologies (UPC, Code 39, 2 of 5, and others), with their respective advantages and disadvantages, have been proposed and adopted by various industries. At present, the Code 39 symbology (also known as Code 3 of 9) symbology, which permits the coding of both numeric and alphabetic data, has evolved as the standard in the automotive, defense, manufacturing, and construction industries. The Uniform Product Code (UPC) symbology is widely used in the retail grocery and garment industries. This is a numeric code that consists of ten characters, the first five of which denote the manufacturer or supplier company, the last five of which denote a unique product for that manufacturer or supplier.

To enhance quality and promote consistency throughout their industries, the automotive, health, fabric, retail grocery and defense industries have developed symbology standards. These standards define requirements for bar code printing (print dimensions and tolerances, print density, reflectivity), readability requirements, shipping label layout, label data content, and label size. Some industries have also set standards pertaining to "data identifiers", which are symbols inserted into the bar code to tell the computer what type of information follows the symbol. For example, if the letter "P" is used as a data identifier within the overall symbol, the number following the data identifier is a part number.

All symbologies follow basically the same structure. An area before and after the symbol, called the quiet zone is

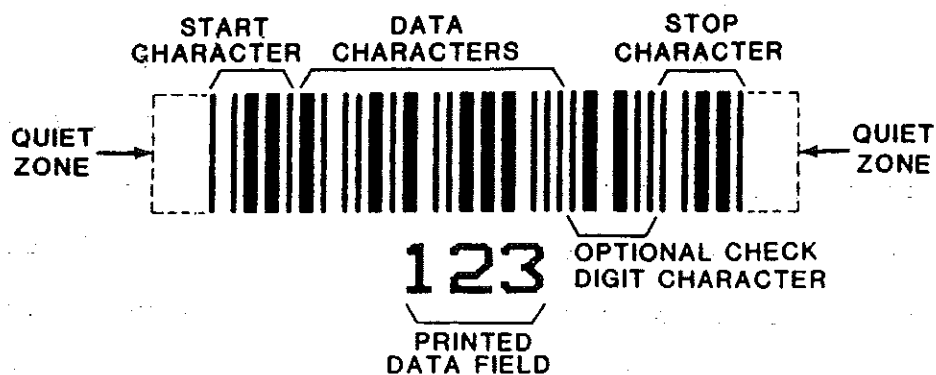
required. Immediately succeeding and preceding the quiet zones are the start and stop symbols. Between these two symbols are the data characters comprising the code. A typical bar code format, and the unique patterns that comprise the bar coded characters, are shown in Figure 1.

The basic element of the bar code is referred to as the 'X' dimension. This is the width of the narrow and wide bars and spaces. Some codes have the width of the wide bars in multiples of the narrow ones, while some other codes have as many as four different bar widths.

Bar codes are classified as either discrete or continuous. A discrete code is one where the determining dimension is the bar width. Spaces separating the bars are referred to as the intercharacter gap. Most industrial codes, including the popular Code 39, are discrete. For continuous codes, the determining dimension starts with the leading edge of a bar and ends with the space following the bar. There is no intercharacter gap in a continuous code. A continuous code may, therefore, be slightly more difficult to scan and print. The UPC symbology is a continuous code.

Optical character recognition

Optical character recognition (OCR) is the machine scanning of printed characters for the purpose of data processing. The forerunner to OCR was the optical mark reader (OMR) which is used in processing standardized tests. Generally, the characters to be read must be represented in a certain font type. However, some machines today have the ability to read



CHAR	PATTERN	BARS	SPACES	CHAR	PATTERN	BARS	SPACES
1		10001	0100	M		11000	0001
2		01001	0100	N		00101	0001
3		11000	0100	O		10100	0001
4		00101	0100	P		01100	0001
5		10100	0100	Q		00011	0001
6		01100	0100	R		10010	0001
7		00011	0100	S		01010	0001
8		10010	0100	T		00110	0001
9		01010	0100	U		10001	0001
0		00110	0100	V		01001	1000
A		10001	0010	W		11000	1000
B		01001	0010	X		00101	1000
C		11000	0010	Y		10100	1000
D		00101	0010	Z		01100	1000
E		10100	0010	-		00011	1000
F		01100	0010	*		10010	1000
G		00011	0010	SPACE		01010	1000
H		10010	0010	START/STOP		00110	1000
I		01010	0010	\$		00000	1111
J		00110	0010	/		00010	1101
K		10001	0001	+		00000	1011
L		01001	0001	%		00000	0111

Figure 1. Typical Bar Code Symbology

several different font types. OCR is being used in mail sorters to recognize zip codes, in retail department stores and in the banking industry to sort checks.

OCR use in retail department stores may, however, be declining. The primary reason for this is the poor scan rates of the hand held scanners. It is not uncommon to observe department store clerks using OCR hardware to scan a merchandise tag several times before finally entering the information by hand. This is one of the reasons why Sears is switching to bar codes.

Page readers are the latest product in OCR technology. Page readers are now available with page read rates that exceed one page per minute.

Radio frequency

Radio frequency (RF) is rapidly gaining acceptance in the automatic identification industry. RF has primary applications in areas where environmental constraints prohibit the use of other automatic identification technologies.

RF technology involves three system components: tags, scanners and readers. An RF tag is a printed circuit board that contains an antenna for receiving and transmitting data, and a chip for storing information. Parameters describing the tagged item and its status can be stored within the tag chip circuitry. The amount of information stored depends on tag memory. RF tags are considered to be either active or passive. Passive tags emit their information when activated by a signal from the scanner. Active tags have their own power

supply, usually a very small battery, which allows the tag to emit its signal once it has been activated. Active tags can also receive and store transmitted data, which is useful for tracking items that undergo a continuing change in production or shipping status.

An RF scanner is a device that is used to activate the tags. When the scanner's emitted signal is received by an active tag antenna, the tag is activated for receiving and/or transmitting information. Transmitted information is received by the scanner's receiving antenna and passed on to a reader. The reader decodes the signal and processes it for further use either by a computer or process control system.

RF applications are diverse and becoming more common. RF is being used to track railroad cars with tags placed below the cars and scanners placed between the tracks. RF is also being used by the trucking industry to monitor trucks at terminal facilities and by a number of other industries to identify and track valuable cargo shipments.

Magnetic stripe

Magnetic stripe technology utilizes a plastic card that has a strip of magnetic tape that contains encoded information. Data are encoded on the magnetic tape by varying the polarity of a magnetic field as it is passed across the stripe. Magnetic stripe cards are being used in credit cards, automatic teller machine (ATM) cards, ID cards, telephone cards, airline tickets, retail merchandise tickets, and in value decrementing systems such as those used on transit ticket vending machines.

Essentially the same data can be coded using either bar code or magnetic stripe technology. A greater data density can be achieved using magnetic stripe, thus making it well suited to plastic card and fare ticket applications. More sophisticated and expensive hardware devices are required to code and read magnetic stripe encoded data however, and, magnetic stripe data is sensitive to dirt, abrasions, and external magnetic fields.

Voice recognition

Voice recognition is one of the newest of the automatic identification technologies. In this technology the spoken word is processed to generate commands to a process control system. In most applications the spoken word or phrase is compared with words stored in a voice data base. Words stored in this data base are those of the speaker's voice pattern, allowing the system to function regardless of variations in user's voice accent.

Voice systems have proven effective for such applications as airline baggage handling. For example, United Airlines has installed a system at one of its terminal baggage handling operations. As luggage items pass along a conveyor a worker issues destination commands verbally. The command activates the baggage handling system to direct the item to the proper gate. This has allowed workers to process 30 items per minute compared to 12 items per minute with a manual system.

Other material handling activities using voice systems include incoming inspection, inventory control, mail and

package metering, barcode label generation, tool crib checkout and check in, and stock location assignment. Voice systems have also been used as part of quality inspection process in the steel, chemical, and paper industries.

IV. BAR CODE SYSTEMS COMPONENTS

Systems

The effective utilization of bar code technology requires properly selected devices to read and process bar coded information, and devices to print bar coded labels, tags, and documents. In general, these devices are inexpensive, easy to operate, and compatible with the user's existing data processing system.

Bar code system hardware peripherals can be linked to a host computer that is dedicated to one specific data processing or process control operation, or, more commonly, to a host computer that is performing other traditional data processing functions as well. The type and size of host computer used depends on the application, the number of scanning stations, the amount of data to be processed and tracked, and the importance of on line data availability to the user. For example if the application requires communications between multiple users, a networked microcomputer or minicomputer system will be required.

Printers

Printing bar codes for industrial applications is ideally accomplished using printers designed specifically for that purpose. Using special printers will help ensure bar code specification conformance. Bar codes are usually produced either off-site by a commercial printing process, or on-site by

the user with his own bar code printer. Each method is appropriate for different situations.

Commercial printing is the ideal technique when the same data or symbol is produced at a high volume or when the bar code is to be placed on a unusual or durable surface. A good example of this is grocery item packages carrying the UPC symbol. Companies that are just starting to use bar codes may find it economical to use commercial printers as well. Other advantages include expertise, quality and graphics capabilities associated with commercial printing. Commercial printing processes include lithographic, flexographic, gravure, and photographic to name a few.

On-site printing is more typical in most manufacturing and industrial applications. This is because of the random, non-sequential order of the data to be printed. Serial numbers, storage locations, and purchase order numbers are examples of bar coded information that is random in nature. Only on-site printing can satisfy such diverse requirements. With this method the bar code is either printed on a label and the label is affixed to the item or the code is printed directly onto the container or item.

The most common types of on-site printers used are impact, thermal, toner, and ink jet. Impact printers are either formed character or font, or dot matrix printers. Formed character printers are similar to typewriters in that characters are formed by using either a type ball, daisy wheel, or drum impacting a ribbon. Dot matrix printers use a shuttle print

head comprised of a series of pins arranged in an array. The characters are comprised of a pattern of dots and are formed by striking a ribbon with the pins. A narrow bar code bar is formed by overlapping a series of dots. A wide bar is formed from a series of narrow bars. Print quality is a concern with this method because of the way characters are formed.

Thermal printing is another economical way to produce bar codes. In this method, heat is used to form the images. The print head is comprised of a series of pins, much like that of dot matrix printers. To form characters individual pins are heated and applied to a heat sensitive paper stock. The paper reacts to the heat and characters are burned into the paper. One disadvantage of thermal printing is the tendency for the labels, which are on heat sensitive paper, to deteriorate if left exposed to a warm environment. On the other hand, thermal printers are quiet and require little maintenance since they contain few working parts.

Electrostatic printing is another popular printing method. This method uses toner to form the images much like the process used in copying machines. Laser and electrographical are the two processes used in this method. In the laser process a laser is used to charge the character pattern on a photoconductive drum. As the drum is passed by the toner it becomes attached to the charged areas on the drum. Next the paper or labeling medium is charged and passed by the drum. As it passes the drum the toner is attracted to the paper. The paper is then heated to permanently attach the toner and form

the characters. In the electrographical process the drum is charged by using a writing head instead of a laser. Both of these methods are capable of rapidly producing high quality, variable sized bar codes.

Ink jet printing is perhaps the most versatile method for producing bar codes. Since it is a non-impact method, bar codes can be printed on various surfaces such as bottles and cans. Ink jets are used to project tiny drops of ink onto a medium. The characters are formed by charging the ink drops and deflecting them into the correct pattern on the printing medium. The primary advantage of ink jet printing is printing speed and versatility of printed medium.

Table 1 compares the printing capabilities for the various types of printers. All of the printers in this table will print codes that conform to general bar code specifications.

However, no printer can guarantee 100% conformance. Therefore, in some applications each code printed may need to be verified.

Verifiers

Although not specifically required for all bar code applications, verifiers are useful devices that bridge the gap between printers and scanners. The purpose of a verifier is to insure that the code quality produced by a printer is decodeable by a scanner. Basically this involves decoding the symbol and measuring all the key features of the code (format, readability, print contrast, bar and space dimensions) to insure standard conformance.

Verifiers can either be off-line or on-line. On-line

Table 1 - Bar Code Printer Specifications

	Impact	Dot Matrix	Thermal	Laser	Ink Jet
Codes	One	Many	Many	Many	Many
Min. "X"	.0044"	.010-.021"	.005-.013"	.003-.004"	.01-.02"
Ratio	Fixed	Variable	Variable	Variable	Variable
Orientation	Picket	Picket Ladder	Picket Ladder	Picket Ladder	Picket Ladder
Size(Width)	3/4-3"	2-16"	2-8.5"	8.5"	-
Speed	2"/sec.	<1"/sec.	1-3"/sec.	1.5-3"/sec.	-
Dispense Label	Yes	No	Yes	No	No
Cost	\$4-5K	\$.5-9K	\$2-9K	\$1.8-50K	\$3-20K

Table terminology:

Codes - Refers to how many symbologies can be printed.

Min. "X" - The smallest width for the narrow bars and spaces.

Ratio - Width ratio of the wide bars to the narrow bars.

Orientation - Format that the code is represented in. Picket(fence) is a horizontal code. Scanning occurs in a horizontal direction. (Step) Ladder refers to a vertical code. Scanning occurs in a vertical direction.

Size - Bar size.

Dispense label- Can the printer affix bar coded labels?

verifiers are built in to the printer and check each code after it has been printed. These printers are often referred to as self verification printers. If the symbol is not readable the printer will print it until it is decodeable. It will do this up to a certain number of times and will shut down when this number is exceeded. The cost for these verifiers is in the neighborhood of \$10,000. Off-line verifiers are self-contained units. They will scan a code, determine if it meets the standard, and then give a printout of values for certain symbol features such as code density, print contrast and bar/space dimensions. Application and practicality play a big part in determining which one is appropriate.

Scanners

Scanners are used to read and decode bar coded information. The scanning process is initiated by passing either a light emitting diode or laser light source across the bar code symbol. As the light is passed over the code a bar will absorb the signal and a space will reflect it. This produces a reflected signal pattern which is conditioned and converted into an electrical analog signal. The analog signal is then analyzed and converted into machine recognizable characters. This is accomplished by using a decode algorithm located on a microprocessor. The algorithm will take the analog signal and measure the pulse widths which are then converted into ASCII characters. The algorithm must be capable of coping with a variety of imperfections such as symbol distortions, bar/space width errors, and signal spot acceleration effects.