TITLE: Introduction to Automated Identification Systems—With a Focus on Bar Coding

KEY WORDS: Automation; bar coding; civil engineering; construction; identification systems; information tracking, resource identification, standards; technology assessment

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A discussion of available automated identification technologies is presented. An introduction to bar coding technology is included, along with an analysis of presently used languages and labels. A generic bar coding system architecture and an actual implementation of this architecture suitable for use in a construction environment is presented. Construction engineering applications of bar coding technology are presented and discussed.

CE ABSTRACT: Introduction to Automated Identification Systems—With a Focus on Bar Coding, by William J. Rasdorf and Mark J. Herbert. Automated identification systems are presented and described, emphasizing bar coding technology. A generic bar coding system architecture and an implementation of this architecture for use in a construction application is presented. Construction engineering applications of bar coding technology are enumerated and discussed.

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Introduction to Automated Identification Systems- With a Focus on Bar Coding

William J. Rasdorf¹ and Mark J. Herbert²

Abstract

Automated inventory control has been used for many years in such industries as manufacturing, automotive, and retail grocery. These industries have recognized technologies such as Bar Coding, Magnetic-Stripe, Optical Character Recognition, and Radio Frequency as viable solutions to the information and production control problems they encounter. One of these technologies, namely bar coding, is slowly being implemented in certain civil engineering applications. As the use of bar coding grows, it will be important for civil engineers to gain a solid understanding of this identification technology and its potential applications. This paper provides an introduction to automated identification systems emphasizing bar coding technology.

A discussion of available automated identification technologies is presented. An introduction to bar coding technology is included, along with an analysis of presently used languages and labels. A generic bar coding system architecture and an actual implementation of this architecture suitable for use in a construction environment is presented. Construction engineering applications of bar coding technology are presented and discussed.

1 Introduction

Keeping track of information flow in the design/construction process is a vital task that is directly related to the timely completion of a building project. Accurate and timely information on the status of project resources and activities is needed to allow managers to most effectively evaluate the overall project status and to make the best possible decisions about scheduling.

Much attention has been focused on improving the construction "process," i.e., the methods and equipment used. While this is clearly an important focus, the concepts of adequate resources and their timely availability are not to be neglected. Without timely resource availability, activities cannot be performed regardless of how proficient the process. Key issues, therefore, are inventory control and materials management, both of which are difficult using the present methods of large scale hand counting and paper record keeping.

To help collect data rapidly, automated identification system technologies are being introduced, both in initial data collection and in support of the ongoing process of information updating. Automated identification systems are important in the design/construction process because they

¹Associate Professor, Departments of Civil Engineering and Computer Science, North Carolina State University, Box 7908, Raleigh, NC 27695.

²Civil Engineer, Davidson and Jones, Inc., Raleigh, NC 27609 (formerly a Research Assistant, Department of Civil Engineering, North Carolina State University).

use project databases which are continually updated to help manage projects in a timely and cost efficient manner. Today's projects have a multitude of databases such as 2D, 3D, commodity, material, payroll, cost, and schedule databases. These databases can be readily maintained, both in the design and field office, using automated identification systems and thus facilitating better project management.

The authors would like to emphasize that automation extends beyond the boundaries of mechanical activities, processes, and assemblies. This paper maintains that automation in data acquisition is also appropriate, and indeed, is one of essential focus areas that will help promote the future advancement of the design/construction industries and enhance their international competitiveness.

This paper reviews some of the technologies that can be used to support varying degrees of data acquisition automation and discusses their suitability in a construction environment. A more detailed look at bar coding technology, which is used increasingly in construction industry applications, is included.

2 Automated Identification (ID) Technologies

This section introduces automated identification technologies that are presently used in inventory control applications. First, it presents an overview of the various criteria that are used to rate ID system performance. Next, data acquisition technologies, including Bar Coding, Optical Character Recognition (OCR), Magnetic-Stripe (MS), and Radio Frequency (RF), are compared and contrasted in terms of their system performance in a construction environment.

2.1 Automated ID System Criteria

The main reason for implementing an automated ID system is to increase data acquisition performance. The performance referred to here can be measured in many ways. Two of the more common measures are read rates and substitution errors, i.e., speed and accuracy. These and other performance criteria that relate to a data acquisition system are discussed in the following paragraphs. Additional detail can be found in reference [Burke84] where a full range of comparative criteria are given, including the following: wand, scan, and card read rates; print rates, quality, and contrast ratio; character set size and composition; character limitations and cipher densities; depth of field; document print speed; reading speed and directionality; erasability, recodability, and visibility of data; destruction, reconstruction, contamination, and deterioration of data; data redundancy and error rates; and reading device limitations.

An ID system's ability to accurately read data can be quantitatively measured using read rates. A first read rate is expressed as a percent that measures of the number of correct reads per one hundred input device scan attempts. As expected, automated data entry systems provide read rates that are much higher than that of manual data entry. Depending on the task, a typical keyboard entry person would enter one or two wrong characters every hundred keystrokes. This would give a read rate of about 0.98. In comparison, bar code data entry systems generally allow about one wrong character in a million or more scanned characters, giving a read rate of 0.999999 or better. This is a substantial improvement over manual data input, especially when large amounts of data are entered.

In addition to read rates, another aspect of performance is the substitution error rate. Substitution errors are errors that occur when an ID system misinterprets data, such as a character. In automated systems, this type of error is usually caused by printing defects on the label. It may also be due to label distortion and degradation caused by conditions of use or location. Depending on the system and the decoding algorithm used, substitution errors can vary widely. In general, the data in Table 1 can be used as a guide for error rates [Allias84,Burke84].

From the table it can be seen that bar codes and magnetic stripe technology both have significantly low substitution error rates. One of the reasons behind the high read rates and low substitution error rates of bar codes is that they are redundant; the height of the bars themselves allow the light wand or laser scanner to take multiple paths to read the same information. In addition, many codes, such as CODE-39, incorporate a self checking algorithm for character comparison, thus reducing the detrimental effects of poor label printing.

Note that the number of errors given by radio frequency (RF) technology is not listed in Table 1. This is due to the limited amount of test information available for this technology. However, radio frequency has been estimated to be an extremely accurate form of data acquisition [Ames87,Kitsz87].

Other criteria of ID system performance include durability and weather resistance of the system hardware. Durability in a construction application requires an ability by equipment to withstand physical abuse. Items such as scanners or readers, for example, may be jarred, dropped, or stepped on. Weather resistance requires a resistance to water, temperature extremes, dust, dirt, and mud. These issues are of particular concern in a construction environment. Equipment must be able to perform in these conditions or the overall ID system will not perform at significantly better rates than manual data entry techniques.

2.2 Bar Coding

A bar code represents a machine language that can directly represent the binary logic that comprises the basic internal logic of all digital computers [Allias84,Burke84,Keller87]. A bar code, as shown in Figure 1, is a pattern of dark and light bars that graphically represents a *cipher*. A *cipher* is an ordered pattern of ones and zeros designed to be easily read by electronic means. A string of one or more ciphers represents a *message* which relays information to humans or computers [Burke84]. Both the numeric cipher and the bar code shown in Figure 1 represent the character 'A'.

A *basic element* of a bar code is defined as the minimum width of bar or space which can be printed and detected by a bar code system. Coding variables that relate to basic elements include the number of dark bars, the relative positions of dark bars within the scheme, the variable widths of both light and dark bars, and their relative positions [Burke84]. The height of the bars contains no interpretive information [Allias84,Palmer]. However, the height of the bars does provide vertical redundancy which improves the readability of the bar code.

In a cipher, the 'one' represents an elemental dark bar and the 'zero' represents an elemental light bar or space. Figure 1 shows the bar code and equivalent eleven element binary cipher for the letter 'A' using the bar code language CODE-128.

Bar codes can be read with either a fixed input device or with a remote input device that is movable and portable. Remote input devices, such as a hand-held Light Wand or Laser Scanner, interpret a bar code by sensing the presence or absence of light reflected back from the code [Burke84]. Remote input devices are taken to the item that is identified with a bar code. Fixed input devices interpret a bar code in a similar manner; however since they are not movable, items identified with bar codes must be taken to the scanning device to be read.

The dark portions of the bar code absorb light, and light portions of the code reflect it. As light is cast on the coded label, the bar code reflects it back in the unique pattern that is a function of the bar code scheme. A sensor in the scanning device analyzes the varying intensities of reflected light as the light moves across the bar code. Note that multiple read paths can be taken through the bar code because the same information is encoded for the full height of the bars. As the bar code is scanned, the optical information gathered by the wand or scanner is converted into an electronic message and sent to the reader. An internal decoding algorithm in the reader then identifies, interprets, and converts this electronic message into a machine language which the computer can recognize and manipulate.

2.3 Optical Character Recognition (OCR)

OCR technology utilizes a form of pattern recognition to accomplish data acquisition. OCR enables the computer to read standard English text from a printed page and store it in a file. OCR incorporates printed characters that can be recognized by both a machine and a human. While OCR can increase the direct human read rate, it still has a low machine reading rate as compared to other ID system technologies [Burke84].

The most common OCR recognition process involves optically dividing each printed character into tiny grids or pixels [Burke84]. These pixels are illuminated by light from a reading or scanning device similar to that used in reading bar codes. As with bar codes, the scanning device floods the characters with light and the varying intensities of reflected light form a unique pattern of pixels that define the printer character [Adams86,Burke84]. The observed pattern is then compared with a stored template of known characters to identify it.

To achieve optimum data acquisition, OCR requires a rather stringent printing tolerance on certain font characteristics and sizes. The restrictions on the material being read include such items as character height, width, skew on the page, and the speed at which the reading head can be moved across the text [Allias84,Burke84]. If these constraints are not observed, low first read rates will occur because multiple read passes will be required for the same text. This, of course, means that it will take a longer time to read the printed information. Figure 2 shows some typical OCR specifications which have been developed by the National Retail Merchants Association (NRMA) in an attempt to standardize the technology [Burke84].

The advantages of using OCR technology include the following [Allias84,Burke84]:

- readable by humans or machines, thereby reducing the redundancy in labeling,
- high information density,
- standardization of OCR fonts, promoting supplier compatibility,

- can be used with many standard word processors,
- fonts which are easy to print and copy, and
- ability to read large amounts of text.

Some disadvantages of OCR technology are also evident [Allias84,Burke84]:

- high reading costs resulting from OCR font restrictions,
- slow read rate of printed OCR characters because the similarities in certain characters can cause read errors,
- restriction of the orientation of the read-scan head in terms of angle to the printed characters, i.e., it should be perpendicular to a page, and
- not suitable for use on construction job sites because
 1. the required physical precision is difficult to achieve, and
 2. direct contact reading is needed since OCR scanners are not beam scannable.

2.4 Magnetic-Stripe (MS)

MS technology has been used for many years as an automated data collection tool on identification cards and in-house manufacturing tickets. It has also been used with hand-held calculators for external storage of computer programs [Herbert88b]. MS is a technology that encodes data onto magnetic tape by location of positive and negative polarity on the tape surface. This concept is analogous to the dark and light bars of a bar code symbology.

Some advantages of MS technology include:

- unrestricted wandering or scanning speed,
- high first read rate,
- read and write capabilities,
- high information packing density,
- fairly rugged technology that has been used in many industrial factory environments, and
- low cost [Burke84].

Some disadvantages of magnetic stripes include the following:

- cannot be read by humans,
- may be sensitive to magnetic fields and high temperatures,
- cannot offer complete data integrity,

- not beam scanable; must be encoded and decoded using a contact encoder and reading device,
- cannot tolerate any form of cover to protect them [Allias84,Burke84], and
- is suited for only limited use in a construction environment because
 1. piece marks for visual identification of material and equipment are needed,
 2. the amount of encoded text in human readable messages does not justify its high information packing density or its cost, and
 3. protective covers cannot be used with it to shield it from adverse environmental conditions.

2.5 Radio Frequency (RF)

RF is a technology that utilizes radio waves to transmit data. An RF system uses either a receiver and/or a transmitter (transponder tag) coupled with a portable RF reading station for data transfer. Transponder tags can act as receivers, transmitters, or both [Ames87,Kitsz87]. The transponder tag is activated when it comes within the range of an RF reading station, usually five to twenty or more feet depending on the system configuration [Kitsz87]. Once activated, data in the tag is transmitted to the read station where it is stored [Kitsz87]. This can be thought of as reading the data in much the same way as a bar code label transmits its information to the scanner. However, if the tag is a receiver, it can also receive new information from the RF reader when activated. Bar codes do not possess this attribute since the data they encode is static.

The advantages of RF technology include:

- ability to read information and also change the information contained in the transponder tag's memory [Kitsz87],
- collection of information in real time, leaving no information uploading delays and no physical connections that need to be made between devices,
- ability to store much more information than bar codes because transponder tags can be equipped with computer memory,
- a variety of frequency combinations which range from low frequency to microwave [Kitsz87],
- high degree of data security provided when used with read only tags,
- well suited to construction job sites where dirt, grease, and heat can degrade the reading of labels [Ames87,Kitsz87], and
- ability to be integrated with other automated data acquisition technologies. When coupled with bar coding, RF can enhance the accuracy of bar codes by removing the need for manual data uploading. The result is truly real time data acquisition automation combining the best characteristics of these two technologies.

Some disadvantages of RF data collection and transmission include the following:

- low frequency systems under 1 MHz have short transmission ranges, usually under 5 feet [Kitsz87],
- low frequency systems may not be useful on a construction job site where portable readers would need to be used at long distances from a transmission base station,
- large microwave systems operating at 900 MHz or more have more flexible transmission ranges of 20 or more feet but usually require an FCC license to operate and can cause problems with other radio controlled devices such as those used in blasting activities [Kitsz87],
- lack of standardization and compatibility between RF suppliers, and
- need for integration with bar coding technology to be effective in a construction environment.

2.6 Automated ID System Conclusions

From the stated advantages and disadvantages it is apparent that an optimum construction data acquisition system is a combination of both bar coding and RF technologies. By integrating these two systems the best aspects of each are more fully utilized. Bar coding accuracy would be enhanced by RF real time data acquisition, while RF technology would become more useful on the job site through the use of physical labels which encode both human readable and bar code scannable information. As is often the case, the major drawback of such a system is the overall cost. The combination of these two technologies would be best suited to construction applications that can justify the high cost [Allias84,Eisenberg87]. However, as new technologies emerge, the cost of such a combined system should become more competitive.

3 Applying Bar Coding Technology

As bar coding use becomes more commonplace in the construction industry, it is important for civil engineers to know what the technology is, how it works, and how they can apply it to their ongoing engineering applications. Other papers have reported on bar coding standardization [Pearce88], bar coding applications [Bell88], and bar coding hardware/software system integration [Rasdorf88a,Rasdorf88b]. This paper focuses on the technologies themselves, examining them and their components so that a more realistic assessment of their role in construction applications can be made by individuals and organizations contemplating their use.

This section introduces the symbology in which bar coding technology is written, discusses the most commonly used bar code labels, and describes the types of materials upon which bar code labels are printed. In addition, this section presents the costs of current bar code labels; the system hardware architecture; and the applications of bar coding in construction engineering. Appendix 2 lists the definitions for the unique terminology used in bar coding and is useful to the reader as a guide to the technology.

3.1 Bar Code Languages

Bar code symbologies, like other languages, have their own syntax rules which act as guidelines for conveying information in a machine language format. The rapid growth in the use of bar coding technology in recent years has spurred the development of many new bar code symbologies. Each symbology represents a different bar code configuration. With the abundance of codes available today, it is important to consider what each specific code has to offer so that the advantages of its particular characteristics, relative to an application such as construction, are evident.

Table 2 is a partial, but representative, accumulation of codes presently used in various manufacturing industries. The code name for each symbology, along with a brief description of its characteristics, is given [Allias84,Burke84].

When reviewing the code characteristics listed in Table 2, one must consider the needs of civil engineering and construction applications. Both number and letter schemes are widely used to identify resources on a construction job site and, therefore, the ability to deal with both is essential. CODE-128 and CODE-39 are the codes that are best suited for use in construction because of their alphanumeric capabilities. Of these codes, CODE-128 is the better continuous code and CODE-39 is the better discrete code.

When comparing CODE-39 to CODE-128, the following observations emerge. First, CODE-128 is the less likely to have a low first read rate because of its shorter 11 element cipher. Second, CODE-128 has none of the inverse ciphers found in CODE-39, which could cause lower first read rates, thus further increasing the overall read time of the bar code. Finally, CODE-128 can provide three different character sets, one of which is the full ASCII character set. This capability allows more flexibility and range in developing a coded message, and supports interfaces to standard microcomputer software, such as spreadsheets, as well [Allias84,Burke84].

Despite the above observations, CODE-39 is the bar code 'standard' of the manufacturing and automotive industries, while CODE-128 has been used relatively little. CODE-39, like CODE-128, provides a full alphanumeric character set and can also encode the full ASCII character set; therefore, it too can support standard microcomputer software. Though CODE-128 has fewer elements per cipher than CODE-39, CODE-128's extended character set requires a more complex decoding algorithm which could offset the possible longer read time of CODE-39. However, unlike read times for high volume assembly lines, read times for construction applications are, for the most part, insignificant. Since CODE-39 is a discrete code, individual character ciphers are readable, though only with a great deal of time and effort, and messages are both easier and cheaper to produce. Finally, since only short messages are likely to be encoded on the bar code label, a longer cipher length does not create a physical space problem. In addition, a discrete code such as CODE-39 is easier to print since each cipher can be treated as if it were a single alphanumeric character. With a continuous code, a complete message must be printed in a single pass since the spaces between ciphers are a part of the code.

Considering these tradeoffs leads one to select CODE-39 for civil engineering construction applications. Proof of its performance in the manufacturing and automotive industries makes it much easier to accept in the construction industry. The use of CODE-39 has also been recommended by the Construction Industry Institute for use in construction applications [Bell88,Pearce88].

Figure 3 shows a CODE-39 bar code representing a structural steel member. The steel member's

designation is W8x10.

3.2 Selection of Bar Code Labels

A bar code label is the physical medium onto which a bar code language is printed. High quality labels are essential to making a bar code system work efficiently. Inferior or inappropriate labels can cause many unwanted data acquisition problems, thus reducing the overall efficiency of the bar coding system. This section briefly reviews various label types and their specific applications, and recommends labels for construction applications. (NOTE: Because these recommendations largely reflect conclusions by one vendor, further testing in a construction environment is recommended.)

Two key issues in selecting a label are addressed below: the durability of a label with respect to its scanability and its attachment to a component, both over extended periods of time and under adverse conditions. The following is a summary of label types, descriptions and suggested applications [Computype85]. Some of the labels below, such as PolyII labels (which have a protective film coating), cannot be printed in the field but must be obtained preprinted from the manufacturer.

- Metal Labels

- These labels, made of specially treated anodized aluminum or stainless steel, are intended for use in harsh industrial environments, where bar codes must endure intense heat, high humidity, dirt, contaminants, and abrasive actions without losing any of its scanability.

- PolyII labels

- These labels, made of paper stock that has been bonded with a protective polyester film, can be used in a variety of warehousing and material handling operations. These labels are intended for use in primarily dry environments.

- Plastic Labels

- These labels are constructed from a dense polystyrene or vinyl material and are protected with a polymer coating. These labels are recommended for use in areas not directly affected by weathering, such as items on material storage areas or inside warehouses. Possible uses include manufacturing, printed circuit board tracking, and property management (i.e. activity assignment and resource identification sheets).

- Therm Labels

- These labels are developed from either a paper or polyester base stock, with a protective heat resistant laminate cover. The paper stock variety is intended for use in relatively dry environments. Protective clear plastic films can also be applied over paper labels to facilitate using them in more hostile environments. The polyester stock is intended for harsh environments where spraying is likely to occur, as in printed circuit board production.

In addition to the label being readable over an extended period of time, it also must remain attached to the item it identifies. Therefore, in conjunction with choosing a bar code label, an

adhesive must also be selected that will enable the label to adhere well with the base material. On a construction job site, there will be a wide variety of base materials onto which the labels will be attached including steel, aluminum, wood, plastic, and nylon. Since all of these materials can be finished with both smooth and rough textures, each will have its own adhesive bonding level. The range of both base materials and textures is therefore quite large. Table 3 shows a partial listing of label adhesives and their adhesion and resistance characteristics [Computype85].

The adhesive thickness must also be considered. The following general guideline can be used to select the adhesive thickness: thin layered adhesives work better on smooth surfaces such as steel, aluminum, and plastics and thick adhesives work best on rough or textured surfaces such as cast iron pipe, checkered plate, and precast sections [Computype85].

3.3 Related Label Issues

3.3.1 Size

Just as there is a variety of material used on a construction job site, a variety of label types and sizes are required to properly identify all materials used. Certain material such as steel beams, joists, and precast items require large labels so that the material identification number can be visually identified by job site personnel. A majority of this material will require either steel or plastic labels due to the outdoor environment they will be stored and used in. Other applications, such as Activity Assignment Sheets, require smaller labels so that more information can be included on a single menu sheet. Similarly, bar code labels for drawings must be relatively small since they will need to fit into a title block.

3.3.2 Costs

Table 4 shows some approximate costs measured in dollars for bar code labels printed using the CODE-39 language [Dennison88]. The specific label costs shown in the figure are based on a mass production rate of 5,000 labels and the costs listed are in decimal dollars per label. Higher production rates result in lower costs. The cost of a label depends more on the quantity of labels ordered than on the label size, given a specific label material. For example, if 100,000 of the 3/4" x 1-3/4" paper labels are ordered, the unit cost per label shown in Table 4 would drop from 38 cents to approximately 22 cents per label. Figure 4 provides an actual size example of the structure and content of one of the large labels listed in Table 4.

3.3.3 Implications for Contractors

Label sizes, costs, and availability would be particularly important to contractors, engineers and architects, and material suppliers if bar code labeling becomes integrated beyond the confines of the job site. Upstream and downstream integration of bar coding would require manufacturers and suppliers to mark all of the materials they provide with bar code labels. In addition, at the design stage, drawings would also need to be identified properly by the engineers and architects who prepare them. Contractor labeling needs would include small and medium labels for the tracking of office and field paperwork. In addition, large, medium and small labels would be required to

identify the various types of job site equipment. A mix of metal, plastic, and paper label stock would be required to support the different durability needs present on a construction job site.

Suppliers and manufacturers would need to be concerned with the costs of the large metal and plastic labels that directly identify material they supply to the contractor. Large labels are essential for visual identification of construction materials but they are costly. Finally, engineers and architects need to be concerned with the cost of small plastic or paper labels to identify construction drawings for primary use in the home office or in the field.

3.4 Bar Coding System Hardware

This section presents a proposed system hardware architecture that could be used as an automated inventory control system in a construction application. The system presented is generic, and is similar in overall composition to those used in a typical manufacturing environment. The key difference between using a system in one environment or another is in the definition and organization of the database, which is software dependent and external to the bar coding hardware system architecture itself. The architecture to be discussed is that shown schematically in Figure 5.

The top level element in the system is a computer, which may or may not be a personal computer (PC). As a stand-alone unit, a PC may be used to provide the main data storage resource for the system. When connected on-line with a mainframe computer, the mainframe provides additional storage and the PC provides isolation for the system by acting as a buffer between the user and the mainframe. Another attribute of the PC is its real time capability, which is helpful in dealing with the temporal aspects of bar coding. Examples include the arrival time of materials on a job site and the time when a specific item was installed. In addition to its real time capabilities, keyboard functions provided by the PC are helpful for transferring data throughout the system.

The next element in Figure 5 is a unit called a concentrator [Intermec86a]. This device connects the computer and all other elements of the bar coding system together, providing the network with a communications capability. The concentrator interacts between the PC, the printer, and the remote readers to support simultaneous uploading and downloading of programs and data to and from remote readers. If multiple remote readers are not required in a system, the concentrator is not necessary. When a concentrator is not utilized, the transfer of programs and data is done through a series of independent interface connections between the PC and the remote devices.

The printer's function in the system is twofold: the first is to provide users with a hard copy of the information the system collects; the second is to print bar code labels. Bar code printers are available that are specifically designed to produce high quality labels. In addition, many existing CAD systems can produce labels.

The remote reader and scanner (or wand) really act together as a data acquisition unit. As discussed earlier, the reader can be remote or fixed. A remote reader is particularly suited to use on a construction job site since it can operate using battery packs. After collecting data, the remote reader can upload its stored information to the PC via the communications network. Conversely, a fixed reader is one that is permanently hardwired into the system. Such a reader is best used in an office situation where continuous and automated real time data acquisition is required, yet is performed in a contained area.

The generic hardware system described here could be used in many possible environments without major changes. Each specific application, though, will require its own customized software to organize and manipulate the data that is collected. One such construction engineering application is discussed in detail in reference [Rasdorf90]. Figure 6 shows the bar code hardware that was used to support a Construction Information Management System (CIMS), an ongoing construction engineering research project at North Carolina State University [Herbert88a, Herbert88b, Rasdorf88a].

As shown in Figure 6, the Transaction Manager (lower right corner) is a portable data terminal which is used for remote data collection and is analogous to the generic system's remote reader. The capacity to download field data directly makes this device particularly valuable. The Wedge Reader (center) is an on-line bar code reading device that is connected directly to the PC. The Laser Scanner and Light Wand are the two bar code scanning tools that are used in conjunction with the Transaction Manager and Wedge Reader for data input. The Light Wand (center) is a contact scanning device. The Laser Scanner (lower right corner) can scan a bar code from a distance. The Thermal Printer (upper right corner) is a high resolution printer specifically and exclusively designed to print bar code labels.

Personal Computer Label Manager (PCLM) software is used to create and edit bar code labels on the PC screen [Intermec86b]. These labels can then be printed using the thermal printer. The Personal Computer Interactive Reader Language (PCIRL) software is used to develop, debug, and execute data acquisition programs on the PC [Intermec87]. PCIRL also provides a utility for downloading these programs to the Transaction Manager for remote data collection tasks. In addition, it allows collected data to be transferred back to the PC from the Transaction Manager. Other equipment includes a battery charger, which is required to keep the Transaction Manager battery charged for remote use. The interface cables provide the physical connections for data transfer between the PC and the Thermal Printer, Wedge Reader, and Transaction Manager. Operating system manuals for the hardware, plus users manuals for the software, are also required. The bar code hardware and software costs for such a PC based system currently total approximately \$10,000.

3.5 Applications of Bar Coding In Construction

There are many possible construction applications in which bar coding can be useful. Applications of this technology can be used to 1) help identify and track material and activities on a construction job site; 2) track documents such as drawings, orders, and requisitions, both on the job site and in the home office; 3) track and manage small and large equipment on the job site; and 4) track job site labor. Many construction applications of bar coding were reported in reference [Bell88]. A different approach to the elements contained within these applications are more fully discussed in the following paragraphs. Note that to support all these applications, a database, populated with application specific and application independent data, is a necessity. The implementation of such a database and its integration with applications similar to those mentioned above has been addressed [Herbert88a, Herbert88b, Rasdorf88a].

On a construction job site, material used to support activities can be identified and tracked using bar coding technology. Non-bulk material such as steel beams and columns, bar joists, precast concrete sections, and HVAC equipment can be directly identified by attaching a bar code label directly to the item. Bulk material such as concrete, fill dirt, and gravel can be indirectly

identified using a Resource Identification Sheet. In this way, a bar code scannable sheet, for example, would contain the identifying label, not the resource. Other construction material are both bulk and unique, such as bolts and steel roof decking. This material can be identified by attaching the bar code label on the container in which they are shipped, e.g., a box of bolts or a pallet of roof decking.

Just as bulk material can be indirectly identified, so too can activities. In a manner similar to the bulk material identification sheets, Activity Assignment Sheets can be used to provide a means of correlating a job site activity to an encoded bar code label. In such a scenario, each project activity would be identified by an activity identification number. This number would be encoded on an Activity Assignment Sheet to allow for easy identification by project personnel. Such a system would also support the needs of commercial scheduling software which generally allows users to enter any type of code using either numeric or alphanumeric characters.

In addition to material and activities, documents such as drawings, purchase orders, and requisitions can be identified and tracked using bar codes. To do so requires a centralized database populated with drawing data (in conjunction with bar codes that are encoded with a project number and drawing number and attached to the drawings themselves), to track the status of notes and revisions of each project drawing. In a similar way, the tracking of purchase orders and requisitions can be streamlined by attaching bar codes to these documents. Bar codes, encoded with the corresponding project number, can be used to quickly, accurately, and efficiently identify these documents in an effort to facilitate office paper work. Note, however, that the documents referred to here are not after the fact reports. Rather, they are the operational documents that are needed to drive the design/construction process. A uniform application of bar coding to both data acquisition and document control enhances the flow of information as well as material through the process.

In construction engineering, the management of both large and small equipment is a vital task to project productivity. The status of equipment in terms of maintenance and repair work is another application for bar coding technology. In this situation, bar codes can accurately identify each piece of construction equipment, and in conjunction with a central database, can provide management with timely information on the equipment's maintenance history and operational status.

The last application to be discussed is that of job site labor. Bar coding technology can be used to track the status of the labor force in a much more efficient manner than that of presently used time cards, which are both difficult to use and can provide inaccurate time metering. Employee badges with encoded bar code identification numbers can be quickly and accurately scanned any time during the day. In conjunction with a central database that contains employee data, this application can provide project management with up to date information on the total work force status.

4 Summary

This paper introduced automated identification systems and emphasized bar coding technology. The main benefits of this technology include the accuracy and integrity of encoded data and the timeliness of data acquisition. Some examples of the key construction areas to which automated identification system technologies, such as bar coding, can be applied are enumerated below:

- Job site material management,
- Project activities,
- Document control,
 - Purchase orders,
 - Requisitions,
 - Drawings, and
- Construction equipment management.

By using an automated identification system technology for data acquisition in support of data processing and analysis, information flow throughout all levels of management and all stages in the design/construction process can be enhanced. In this way, management can make better informed decisions that more positively affect project performance.

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Appendix 2-Bar Coding Terminology

To understand any new technology, one must first be familiar with its unique terminology. This section provides a brief introduction to some of the bar coding terminology used in this paper [3,7].

- Numeric System: A system that only uses numbers.

- **Alphanumeric System:** A system that uses both numbers and letters.
- **Bar:** The darker element of a bar code.
- **Space:** The lighter element of a bar code.
- **Bar Code:** A bar code is a pattern of light and dark bars that graphically represents a cipher.
- **Basic Element/Module/Unit:** The narrowest nominal bar or space in the code. Wider bars and spaces are taken as multiples of this width.
- **Cipher:** An ordered pattern of 'ones' and 'zeros' designed to be easily read by electronic means.
- **Continuous Code:** A bar code or symbol in which the space between two characters is a part of the code. A continuous code begins with a bar and ends with a space.
- **Discrete Code:** A bar code where each cipher begins and ends with a bar. The spaces between the ciphers are not a part of the code and can vary in width within set tolerances.
- **Message:** A finite string of ciphers which can carry a complete unit of information to humans or computers.
- **First Read Rate:** Expressed as a percent, the number of correct readings obtained by an input device per 100 read attempts.
- **Substitution Error Rate:** Expressed as a percent, the number of incorrect cipher interpretations per 100 read attempts.
- **Self Checking Bar Code:** A bar code that uses a checking algorithm which can be applied against each character such that substitution errors can only occur if two or more independent printing defects appear within a single character.
- **Start/Stop Characters:** Distinct characters used at the beginning and end of a bar code symbol which provide direction of reading information to the decoding logic.
- **Quiet Zone:** The area immediately preceding the start character and following the stop character, which is free of markings.
- **ASCII:** American National Standard Code Information Interchange. The ASCII code set consists of alphanumeric, control, and graphics characters.
- **Wand:** A pen-like handheld device used to read bar codes by passing its tip over, in contact with, the printed bars of a bar code and optically transmitting the data for subsequent electronic decoding.
- **Scanner:** A non-contact input device that converts bar code symbols to electronic signals for data input and storage. Scanners can be fixed or hand-held. Scanners can identify bar codes at a distance from the coded surface.
- **Reader:** A device that interprets the electronic signals from a bar code input device such as a wand or scanner and decodes them using bar code decoding algorithms to produce human readable messages.