CIMS: A Construction Information Management System

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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, and Optical Character Recognition as viable solutions to the information and production control problems they encounter. As a result these technologies are becoming commonplace in many production oriented environments but not in construction. This paper presents a Construction Information Management System (CIMS) for the control of information used by project management on a construction job site. A unique aspect of the system is that it utilizes Bar Code technology for both initial and ongoing data acquisition. In addition, it integrates cost, inventory, and scheduling application programs, utilizing stand alone software, a database management system (DBMS) programming language, and a spreadsheet, respectively, with a central DBMS.

A brief introduction to bar code technology and hardware is presented along with an analysis of present codes and labels. Construction engineering is reviewed in terms of its information resource needs to determine how a system such as CIMS, which uses bar code technology, can satisfy those needs. Construction application programs and their relationship to both CIMS and to bar code technology are considered and a generic system architecture for CIMS is proposed and described. An implementation of the architecture is discussed.

1 Introduction

Keeping track of information flow on a construction job site is a vital task that has a direct bearing on the timely completion of a building project. The majority of project schedule overruns are caused by the lack of adequate resources needed to accomplish individual activities in a timely manner. Accurate and timely information on the status of project resources is needed by construction management so as to make the best possible decisions about activity scheduling with due consideration given to resource availability. What is presented in this paper is the development of a testbed integrated construction information management system to control information flow on a project job site. To accomplish this task with the speed and accuracy desired, an automated identification technology (Bar Code) is being used both in initial data collection and in support of the ongoing process of information updating. The result is the effective coupling of a data acquisition hardware technology with an integrated software environment.

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1.1 Objectives

The overall goal of the research underway at North Carolina State University is to provide project managers with the information they need to ensure greater productivity, higher profits, and increased control over their projects. The specific objectives discussed in this paper are as follows:

- To explore the feasibility of implementing an expanded means of construction materials and equipment tracking,
- To develop and demonstrate an integrated construction labeling, information storage and retrieval database, and application program environment, and
- To determine the potentials and the limitations of bar code techniques in computer-integrated construction.

1.2 Work By Others

Many research efforts have been undertaken in various manufacturing related disciplines to expand the use of automated data acquisition technologies (4, 5, 9, 15, 16). However, many new and unique applications are emerging that extend the use of technologies such as bar coding beyond the realm of assembly-line manufacturing (9, 15, 10). Some of these efforts have been directly supported by the construction industry including those enumerated below.

- In 1982 the Business Round Table reported on the benefits of modern material management systems and their lack of use in the construction industry (14).
- In 1984 the Construction Industries Institute (CII) organized a materials management taskforce to address the needs of materials management in construction (14).
  - In 1985, phase one of the taskforce (at Texas A&M and Auburn Universities) focused on materials management performance (13).
  - Phase two of the taskforce analyzed the costs and benefits of materials management systems (14).
- In the Fall of 1986, Lance Bell at Auburn University started a feasibility study for CII on the use of bar code technology to facilitate materials management.
- In the Summer of 1987, Lance Bell presented a quarterly report to CII on the potential applications of bar codes in construction (15).

The general consensus that has emerged from these efforts is that a variety of modern material management techniques can be effectively utilized in a construction environment. Additionally, in support of materials management, bar codes can be effectively utilized as an automated data acquisition tool for the purpose of identifying and tracking a variety of construction resources.
In general, the above research reflects the state of the construction industry in terms of modern materials management and automated data acquisition. While a substantial effort has been made to raise the construction industry’s awareness of the benefits of such technologies, at present there has been little actual documented use of bar code technology in a construction environment to facilitate the task of resource control.

1.3 CIMS Unique Contribution

CIMS unique contribution is that it extends previous work in the following areas:

- *CIMS* provides an expanded means of resource identification and tracking including both materials and equipment,
- *CIMS* suggests an integrated database schema for project management, achieved by an exploration of construction applications and construction needs,
- *CIMS* explores the requirements of application programs on the database design and interface programs,
- *CIMS* integrates the hardware of a data acquisition system with a software system of engineering applications, and
- The *CIMS* research effort considered the impact and implications of labeling technologies on designers and on material and equipment suppliers and vendors.

2 Identification Systems Technology

There are a variety of automated identification technologies in use today. These technologies include, among others, Bar Code, OCR, Magnetic-Stripe, and Radio Frequency. Although each of these technologies is appropriate for different data acquisition applications, this paper will concentrate only on Bar Code technology.

2.1 Introduction to Bar Codes

A bar code represents a machine language that can directly represent the bit streams of ones and zeros that comprise the basic internal logic of all digital computers (1). A bar code, as shown below 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 ciphers represents a message which relays information to humans or computers (1). Both the numeric cipher and the bar code shown in Figure 1 represent the character “A” also shown there.

The pattern of dark bars and spaces of a bar code determines its meaning just as the pattern of ones and zeros of a cipher determine its meaning. 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 (1). In a cipher the ‘one’ represents an elemental dark bar and the ‘zero’ represents an elemental light bar or space in the bar code. The following figure shows the bar code and the equivalent eleven element binary cipher for the letter ‘A’ using the bar code language CODE-128.

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>CODE-128</th>
<th>CIPHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>![Bar Code Image]</td>
<td>01000011000</td>
</tr>
</tbody>
</table>

Figure 1: Character, Bar Code, and Cipher

Bar codes can be read with either a fixed reading device that is mounted on a fixture, or with a hand held wand that is movable and portable. The reading device interprets a bar code by sensing the presence or absence of light reflected back from the code. The dark portions of the code absorb light and the light portions of the code reflect it. As light is cast on the coded label, the bar code reflects it back in a unique pattern that is a function of the bar code scheme. A sensor in the wand analyzes the varying intensities of reflected light as the wand moves across the bar code. An internal decoding mechanism in the reader then interprets and identifies the code being read.

### 2.2 Bar Code Languages

All languages have rules of syntax that are used as guidelines for constructing valid and legal words and expressions using the language. Bar code languages too each have their own rules which act as guidelines for conveying information in a machine language format. The rapid growth in the use of bar code technology in recent years has spurred the development of many new bar code languages. With the abundance of different codes available today, it is important to consider what each specific code has to offer so that its characteristics, relative to a particular application such as construction, are evident. The following list represents an accumulation of bar code languages presently available, some of which are used in the automotive, retail, and manufacturing industries (1).

- UPC
- CODE-39
- I-2/5 CODE
- CODABAR
- CODE-128
- MSI CODE
- TELEGREN
- TELEPEN
- CODE-93
- CODE-11
- EAN

Of the codes listed above, CODE-128, TELEGREN, and CODE-39 are well suited for use in the construction industry because they can encode both numbers and letters. Of these three codes, CODE-128 is the best continuous code and CODE-39 is the best discrete code. The difference between discrete and continuous codes is that the spaces between complete characters in a continuous code are a part of the code, whereas the spaces between complete characters in a discrete code convey no meaning and can vary somewhat freely. Of these codes CODE-39 is the most desirable for the following reasons. CODE-39 is widely used and is a manufacturing industry standard. It provides a full alphanumeric character set,
plus a partial ASCII set that would help support standard microcomputer software such as LOTUS 1-2-3. Also, since CODE-39 is a discrete code, individual character ciphers are easy to read and messages are both easier and cheaper to produce. Finally, since only short messages are to be encoded on the label, the longer cipher length of CODE-39 will not be subject to space limitations.

The following figure shows a CODE-39 bar code representing a structural steel member. The steel member’s designation is a W8×10.

![Figure 2: CODE-39 Bar Code](image)

### 2.3 Bar Code Labels

A bar code label is the physical label onto which a bar code language is printed. High quality labels are essential to making a bar code system work efficiently. Inferior labels, or labels that are not well suited for their application can cause many unwanted data acquisition problems, thus reducing the overall efficiency of the bar code system.

Bar code labels are most commonly made of metal, polyester, plastic, and paper (8). Since CIMS data acquisition will often be done outdoors and certainly in a generally uncontrolled environment, the choice of bar code label material is very important. On a construction job site a bar code must endure intense heat, high humidity, dirt and contaminants, and abrasive actions, without losing any of it’s scanability. Of the above listed labels, the metal labels would generally be the best choice because they are designed and tested for exposure to weather.

In addition to the label being readable over an extended period of time, it also must stay attached to the base material of the item it identifies. In conjunction with choosing a bar code label, an adhesive must be selected that will adhere well with the base material. On a construction job site there are a wide variety of base materials to which labels will be attached including steel, aluminum, wood, plastic, nylon, and teflon. Since all of these materials can be finished with both smooth and rough textures, each will have it’s own adhesive bonding level. In addition to the base material and its surface finish, resistance to chemicals, ultraviolet light, heat, and humidity must also be considered when choosing a label adhesive.

### 2.4 Bar Code System Hardware

The following hardware elements combine together to create a bar code identification system.
The first element in a bar code identification system is a personal computer (PC). When used in a standalone mode the PC provides the main storage for the system. Alternatively, it can be connected to a mainframe, thus providing additional data storage, data reduction, and data processing capability for the system. The next element is a unit called a concentrator (5). The concentrator links the computer and all other elements of the bar code system together, providing the appropriate network communications. Additionally, the concentrator coordinates multiple remote reader signals, and in fact is needed only if multiple remote readers are used in the system.

The printer's function in the system is twofold. The first is to provide a hard copy of the information the system collects and the second is to print bar code labels if their medium is paper. The remote reader and scanner act together as a data acquisition unit. The reader is referred to as remote because in a building construction environment, the reader and scanner will be used on a job site gathering data, and will most likely not be online. When data collection is finished, information in the reader is uploaded to the PC. The function of the scanner is to translate a coded label into a message that the reader can understand. This is accomplished by translating the label's reflected light into an electrical signal which the reader then decodes into a message that the computer can recognize and manipulate.

3 Application to Civil Engineering

This section defines the scope of CIMS in Civil Engineering. In addition, it provides a typical scenario showing how an inventory of construction resources and job site activities could be automated using bar codes.

3.1 Review of Construction Types

There are many possible construction environments in which bar coding can be useful. Different construction types, such as Heavy, Power, Industrial, and Building construction, have different identification and tracking needs. In addition, one must consider the identification and tracking needs of the components comprising the finished product as well as the construction process itself, including everything needed to build the facility. What we are focusing on in this paper is the construction product rather than the construction process and we are specifically using building construction as an example.

On a construction job site resources can be separated into a number of categories, two of which are uniquely identifiable materials and equipment, and materials that occur in bulk form. Unique materials include such items as steel beams, precast panels, and pumps. Bulk materials include such items as steel deck, conduit, and concrete. Our work considers both of these but does not address other resource identification and tracking categories such as labor.
3.2 Job Site Resource Identification

On a construction job site resources enter the site in various states. The two discussed above are items which arrive at the site as identifiable units and those which arrive in a bulk form. To achieve uniform inventory control with these resources, two different labeling techniques are proposed. Uniquely identifiable resources such as steel beams, pumps, and door frames would be individually marked with a bar code label. This label would identify the resource by its own specific piece mark. Using this method, each item would need to be scanned with the bar code scanner. The remote reader would then prompt the user to keypad enter any additional necessary information required by the database that was not supplied by the code itself.

The second type of resource used on the construction job site is of a bulk nature, e.g., concrete, wire rope, and bolts. Since this material cannot be easily labeled with bar codes, an indirect method using resource identification sheets is suggested (1, 9, 15). These sheets include a complete listing of all bulk resources that are to be used on the job site. The resource piece number along with its equivalent bar code label and piece name would be listed. The particular resource would be identified by wanding the bar code label corresponding to the piece mark. Inventory would then continue in the same manner as with non-bulk resources by entering additional information at the prompts from the remote hand-held reader. The upper half of Figure 3 provides an example of a portion of a resource identification sheet.

3.3 Job Site Activity Identification

As a construction project progresses, the identification of the start and finish times of scheduled activities can be handled in much the same way as resources are identified. Since material use is directly related to activity requirements, another set of sheets similar to those used for bulk inventory identification can be used. These are referred to activity assignment sheets.

Activity assignment sheets are sheets that contain a listing of all the daily or weekly activities that are scheduled to occur on a job site. In CIMS these listings include the activity name, its identification number, and its equivalent bar code label. An example of a concrete activity sheet is shown in the bottom half of Figure 3. As an activity is performed its bar code label would be scanned from the assignment sheet there by signaling the start or finish of that task. As resources are used to perform the activity, either in bulk or non-bulk form, they themselves would be scanned and the quantities entered into the hand-held reader as they are taken from stock. Non-bulk items would be scanned directly, while bulk items would be identified using resource identification sheets. As stated earlier, the hand-held reader currently prompts the user for any additional activity information that must be keypad entered.

By using both direct and indirect labeling of resources, in addition to the labeling of activities, the bar code system is used to its fullest advantage on the construction site. As a result, project management will be able to keep track of all information on the job site (handled via a labeling technology) using a single data acquisition technology.
3.4 Impact on Fabricators, Suppliers, and Designers

Up to this point in the discussion it has been assumed that bar code labels are already attached to resources as they arrive on site. This assumption transfers the task of bar code labeling to the upstream construction process participants; the suppliers and fabricators who provide materials, components, and equipment to the construction industry. With this in mind, it is essential that suppliers and fabricators realize the benefits of utilizing bar coding in their own operations as well as on the job site, and that they actively participate in label installation and use. Bar coding should be perceived not as a task to fulfill a possible bid requirement, but as a way to reduce inventory supply costs in addition to facilitating information flow into and out of the shop. The ultimate goal is to provide a set of labeling technologies that are accepted industry wide to support material identification and tracking.

In addition to fabricators and suppliers, architects and engineers can incorporate bar coding in the design process to assist in identification at the documentation, drawings, and schedules development levels. Labeling coordination between documentation and the physical objects it represents is essential. Bar codes can provide designers in all disciplines with one means of 'paper' control, which is a key factor in office productivity enhancement.

4 CIMS: Construction Information Management System Architecture

This section provides an overview of the CIMS architecture. In addition, construction inventory needs, project cost control, and project scheduling are reviewed and a CIMS solution strategy to support these construction applications is presented.

4.1 Overview

Figure 4 illustrates the overall CIMS system architecture. The central database used in CIMS is R:BASE System 5 version 1.0 (7). The R:BASE DBMS is based on the relational data model (2). Associated with the data model are a set of operators that perform the data insertion, deletion, and retrieval functions as well as a programming language for developing database applications. Figure 4 shows a central database holding the construction data necessary to support a set of inventory, cost, and scheduling applications. The figure also shows links to future applications including construction drawings and document tracking, to bar code data acquisition hardware, and to additional applications using other languages and shells. The target computer environment for which CIMS is currently being developed consists of an IBM XT microcomputer running the MSDOS operating system.

Three major applications are integrated with the database. PLANTRAC, a commercially available scheduling program provides the database with estimated activity and resource information (12). PLANTRAC as a stand alone program can generate all the standard project management information one would expect from such software including a detailed time analysis, activity diagrams, resource usage charts, CPM, PM, and PERT schedules, and GANTT charts.
LOTUS 1-2-3, a widely recognized spreadsheet program, was used to create a general cost and cash flow analysis program (10). The program utilizes actual and estimated PLANTRAC schedule information obtained from the database to determine actual and estimated weekly project costs. The integration of both PLANTRAC and LOTUS with the database required the use of interface programs. These programs were written using the R:BASE application programming language (7).

The third application, involving inventory control, was developed using only the R:BASE application language. A separate interface was therefore not required; the application would communicate directly with the database. This application utilizes both the scheduling information generated by PLANTRAC and the actual field information collected by bar coding. It simply provides a weekly status report on resource inventory, in addition to forecasting future needs.

Bar coding is a key element in this architecture since it controls all the activity and resource information entered into the system. Bar code data acquisition is expected to be done by job site personnel and will most likely be done on an ongoing basis.
4.2 Construction Inventory Needs

Construction inventory needs are generally dictated by the activities that define the construction process itself; these appear in a project schedule. Construction needs vary from activity to activity, but generally materials, labor, and equipment are all required to accomplish an activity, and the loss of any one of these resources can delay or stop the activity's completion. Two common reasons for project cost overruns at the activity level are delays caused by the lack of materials and delays caused by equipment breakdowns. These problems can cause a delaying chain reaction throughout the project that extends the overall project schedule.

General inventory control and resource needs forecasting can be accomplished through the use of the CIMS inventory control application. Figure 4 provides a schematic representation of the three interrelated tools used to support the development of inventory reports and to provide resource forecasting. On the construction job site a field engineer(s) will perform an inventory of selected incoming resources using a remote bar code reader and scanner. Inventory information collected will initially include the resource piece mark, the resource name, date and time of arrival on the job site, and the quantity of items delivered. After the resources have been inventoried, the reader will upload the information to the PC for storage in the construction database.

Inventory reports are generated directly from the R:BASE database based on the actual resource quantities determined to be available on site. Forecasts of future resource requirements are generated by PLANTRAC. The bar code resource information stored in the database can then be compared with the resource needs generated from PLANTRAC to determine the status of the work and the availability of resources to support activities.

4.3 Project Cost Control

To be able to successfully finance a construction project a contractor must not only estimate the overall project duration and total cost, but he must also know how the actual cost actually varies over the project duration. The contractor generally pays his subcontractors and suppliers using intermediate payments he receives from from the owner as the job progresses. The information needed by the contractor to assess the percent age of job completeness is, therefore, very important. It is, in fact, strongly tied to the amount of materials installed and the amount of labor and equipment used.

In CIMS, the PLANTRAC application program uses data obtained from the database to provide an estimate of the project schedule. The estimate can subsequently be used to determine resource costs on a weekly basis using the SYMPHONY cost control application. At any time during construction the contractor is able to analyze the status of the project's cash flow by using the cost control application. The costs that have accrued during each week are calculated by R:BASE utilizing the project schedule information in the database and they are transferred to SYMPHONY. The weekly costs provided by R:BASE are based on the delivery times of the resources which in turn are based on the start dates of the activities. Some of these costs are actual and some are estimates, depending on the extent to which construction progressed. The SYMPHONY cost control application computes weekly cash flow estimates for the entire project regardless of how far along it is and lists
the costs, partial payment, and the cash flow status. This report can be compared to the initial weekly project cash flow estimate to identify any major discrepancies.

4.4 Project Scheduling

The proper scheduling of a construction project is one of the keys to a more profitable job. CIMS uses the PLANTRAC precedence method to generate project schedules. As with the other applications in CIMS, bar codes provide the inventory information for resources as they arrive on site. In the early stages of a project PLANTRAC provides a PM schedule using all of the estimated activity and resource information initially stored in the database. As construction proceeds over time and activities are actually performed, activity and resource information is supplied to the database via bar code. R:BASE then provides PLANTRAC with actual dates that are incorporated into a new schedule run enabling it to obtain a more accurate project schedule. After each run the schedule has incorporated a little more actual activity information. Since the information is updated in a very timely manner, the contractor can frequently compare changing schedules with his initial estimated schedule. In this way the contractor can use CIMS both as a planning tool and as an analysis tool to assess the status of his progress at any point in time.

5 Conclusions

The following conclusions can be drawn from the CIMS investigation to date:

- CIMS can provide the contractor with a construction information storage and retrieval database to facilitate the task of job site information management.
- CIMS can provide the contractor with an expanded means of resource identification and tracking which includes both materials and equipment management.
- CIMS integrates construction application programs that address the needs of project management in terms of cost, inventory, and scheduling.
- CIMS integration has been demonstrated to be readily achievable using available software.

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