Bar Coding in Construction Engineering

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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, Optical Character Recognition, and Radio Frequency as viable solutions to the information and production control problems they encounter. The usefulness of one of these technologies, namely bar coding, is slowly being utilized in civil engineering.

This paper presents a *Construction Information Management System (CIMS)* for the control of information used by project management. One unique aspect of this system is that it successfully transfers a Resource Identification and Tracking (RIT) technology, namely bar coding, from a manufacturing environment to control data acquisition needs for construction. In addition, *CIMS* integrates scheduling, inventory, cost, and document control application programs with a central database management system (DBMS) using stand-alone software, a DBMS programming language, and a spreadsheet.

An introduction to the objectives and unique contribution of *CIMS* is presented, along with a review of other related construction industry research. The information needs of construction engineering are reviewed to determine how a system such as *CIMS* can satisfy those needs. A generic system architecture is described, and an implementation of the architecture is presented.

1 Introduction

Keeping track of information flow on a construction job site is a vital, yet commonly overlooked, aspect that is directly related to the completion of a project on schedule. Many project schedule overruns are caused by inadequate resources needed to accomplish individual activities on time. Accurate and timely status information of project resources is needed by construction management to make the best possible decisions about activity scheduling with due consideration given to resource availability.

Presented in this paper is the development of a testbed integrated software system to control information flow on the project job site. To accomplish this task with the speed and accuracy desired, an automated identification technology (Bar Coding) was used in the initial data collection and in support of the ongoing process of information updating.

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1.1 Objectives

The overall goal of the research conducted at North Carolina State University was to provide project managers with the information needed 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 tracking construction materials and equipment using bar codes,
- To develop and demonstrate an integrated construction labeling, information storage, and retrieval database, as well as a comprehensive construction application program environment, and
- To determine the potentials and limitations of bar coding technology in computer-integrated construction.

1.2 Work By Others

Many research efforts have been undertaken in various manufacturing disciplines to expand the use of automated data acquisition technologies [2,10,15,18]. Moreover, many new and unique applications are emerging that extend the use of technologies such as bar coding beyond the realm of assembly line manufacturing. The Construction Industry Institute, in particular, has investigated bar coding with respect to construction materials management [3,4,5]. 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 effectively be used as an automated data acquisition tool for the purpose of identifying and tracking a variety of construction resources.

In general, previous efforts reflect the present state of the construction industry in terms of 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 in terms of standardization and applications, at present there has been little actual documented use of bar coding technology in a construction environment to facilitate the task of materials management and inventory control. In particular, the integration aspects of bar coding technology into construction systems, in a meaningful way, remains to be investigated.

1.3 Feasibility Issues

The feasibility of implementing a resource identification and tracking (RIT) system such as CIMS, as with any new technology, relies on many factors including:

- Technology Transfer—the ability to successfully transfer and use a technology, such as automated data acquisition, in a different environment than for which it was originally developed,
- Work Force Involvement—systematically introducing the technology through education and training and allowing for feedback and suggestions from the work force, and

- Inventory Improvement—materials and equipment account for 50 to 60 percent of total construction costs [5,25], which in 1979 equalled 80 billion dollars in the U.S. construction market [24], or about 9 percent of the U.S. GNP [19,26], thus providing financial incentive for automation and improvement.

1.4 Unique Contribution of *CIMS*

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

- Integrates an RIT technology to facilitate identification and tracking of resources and activities,
- Suggests an integrated database schema for project management, achieved by an exploration of construction applications and needs,
- Explores the impact of application programs on the database design and interface programs,
- Integrates the hardware of a data acquisition system with a software system of construction engineering applications, and
- Addresses the impact and implications of labeling technologies on designers and on material and equipment suppliers and vendors.

2 Application to Civil Engineering

This section defines the specific civil engineering applications of *CIMS* and the types of information the system presently tracks. A typical scenario involving the tracking of construction resources and job site activities using bar coding is presented. The impact of bar coding on fabricators, suppliers, and designers is also discussed.

2.1 Overview

There are many construction *environments* in which bar coding in general can be useful, such as:

- Heavy construction that involves highways and bridges,
- Power construction that involves fossil and nuclear power generating plants,
- Industrial construction that involves manufacturing plants and warehouses, and
- Building construction that involves commercial and institutional buildings

In addition to these construction environments, the identification and tracking needs of the *components* comprising a constructed facility must be considered. Examples of components include the

brick, block, concrete, beams, columns, air handling units, elevators, etc. of which the facility is constructed. Also, the identification and tracking of the components of the construction *process* itself, including everything needed to build the facility, is important. Examples of such components include the formwork to support curing concrete, scaffolding to support workers, earth moving equipment, cranes, etc. These components are a part of the process, but not the structure. The initial scope of *CIMS* research focused on the components of the constructed facility in the building construction environment.

On a construction job site, resources can be separated into a number of categories, some that are of interest here are:

- Uniquely identifiable materials and equipment such as steel beams, precast concrete items, door frames, and pumps. These resources are identified as unique because a bar code label can be directly attached to the single item,
- Bulk materials such as fill dirt, a gravel pile, and concrete. These resources are identified as bulk because they cannot be directly labeled, and
- Both bulk and unique such as steel bolts and anchors. These resources are placed in a container, such that, although the bulk material cannot be directly labeled, the container can, e.g., a box of bolts.

2.2 Job Site Resource Identification

Different labeling techniques are proposed for each category of resources and are described in the following paragraphs.

Uniquely identifiable resources can be individually marked with a bar code label, thus identifying the resource by its own specific piece mark. An example of a structural steel beam label is shown on the left side of Figure 1. For uniquely identifiable resources, data acquisition is performed by scanning each item individually or, for multiple occurrences, one item is scanned and a quantity entered.

Also shown on the right side of Figure 1 is a bar code label for structural bolts, which are both a unique and bulk resource. Encoded on this label is the piece mark and container quantity. Thus, both the resource piece mark and quantity supplied can be identified directly by scanning this label.

For resources which are of a purely bulk nature, an indirect labeling method using Resource Identification Sheets, as shown in Figure 2, is suggested [1,3,6,13,14,18]. These sheets include a complete listing of the bulk resources that are to be used on the job site. The resource piece mark and its equivalent bar code label are listed, along with other encoded information required to support resource identification. The particular resource is identified by wand or scanning the appropriate bar code label corresponding to the piece mark.

2.3 Job Site Activity Identification

Typical activities on a construction job site include laying brick, placing concrete, fabricating steel, installing fixtures, wiring, etc. Each activity must be performed in a given sequence, as

Figure 1: Bar Code Labels for a Structural Steel Beam and Bolts

BITUMINOUS SEALER - NA	FILL - GRAVEL 1" - FA
GALVANIZED PANT - NB	FILL - CLAY - FB
CONCRETE - 3KSI - 1A	FILL - SAND - FC
CONCRETE - 5KSI - 1B	W/F6X6-4.0X4.0-TR

A	B	C	D	E	F	G	CR	BS	0
H	I	J	K	L	M	N	7	8	9
O	P	Q	R	S	T	U	4	5	6
V	W	X	Y	Z	DEL		1	2	3

PROJECT: 023	<div style="border: 1px solid black; padding: 5px; text-align: center;"> ACTIVITY COL 1: ERECT COLUMNS COL 1A: ERECT BEAMS </div>
SUBPROJECT: BLOS	

STATUS
START

FINISH

DELAY

RESUME

IN PROGRESS

1	2	3	4	5
6	7	8	9	0

A	B	C	D	E	F	G
H	I	J	K	L	M	N
O	P	Q	R	S	T	U
V	W	X	Y	Z	DEL	

Figure 2: Resource Identification and Activity Assignment Sheets

defined in the project schedule, to complete the project in a timely manner. Thus, tracking of the activity start and stop dates is as important as the tracking of inventory information.

As a construction project progresses, the identification of the start and stop times of scheduled activities can be handled in much the same way that resources are identified. Since material use is directly related to activity requirements, another set of sheets similar to those used for bulk inventory can be used. These are referred to as activity assignment sheets [13,14,23]. Activity assignment sheets are sheets that contain a listing of all the daily or weekly activities that occur on a job site. Figure 2 provides an example of one of these sheets.

As an activity is performed, its bar code label is scanned from the assignment sheet and its status entered. Possible activity statuses used in *CIMS* include START, FINISH, DELAY, RESUME, and IN PROGRESS, which indicate the initiation and completion of an activity. As resources are used to perform the activity, they are scanned and the quantities are entered.

2.4 Impact on Fabricators, Suppliers, and Designers

Bar code labels are assumed to be attached to resources as they arrive on site. This assumption transfers the task of bar code labeling to the suppliers and fabricators who provide materials, components, and equipment. Thus, it is essential that suppliers and fabricators actively participate in label design, 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.

Architects and engineers can incorporate bar coding in the design process to assist in identification at the documentation, drawings, and schedule development levels. Labeling coordination between documentation and the physical objects is essential. Bar coding can provide designers in all disciplines with one means of 'paper' control, which is a key factor in office productivity.

The ultimate goal is to provide a set of labeling technologies that are accepted industry-wide to support resource identification and tracking. This requires a standardized bar code language or symbology, label layout, format and text positioning, printing standards, and label materials [20]. Specifications of this type have been widely used in the industrial and automotive sectors, health industry, and government [20]. Research into both bar code language and label standardization for the construction industry has been addressed by Pearce and Stukhart [21]. If not standardized, the use of multiple symbologies and label formats will cause incompatibility, thus isolating the use of bar code technology in the industry.

3 *CIMS*: Construction Information Management System

This section provides an overview of the *CIMS* architecture, including the system's hardware and software. In addition, scheduling, inventory, cost control, and document control needs are reviewed.

3.1 Architecture

Figure 3 illustrates the *CIMS* architecture. A central database, designed and implemented using the R:BASE System V database management system by Microrim, operating in an MS-DOS PC environment, holds the construction data necessary to support a set of scheduling, cost, inventory, and drawing applications [13,14]. Figure 3 also depicts links to present and future data acquisition areas, and to other programming languages and shells.

Five major applications are integrated with the *CIMS* database. In the first application, a commercially available DOS-based scheduling program called PLANTRAC provides the database with estimated activity and resource information [7]. PLANTRAC can generate a detailed time analysis, activity diagrams, resource usage charts, CPM, PM, PERT schedules, and GANTT charts.

A project cost control application was created using LOTUS SYMPHONY, which 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 SYMPHONY with the database required the use of interface programs. These programs were written in the R:BASE application programming language.

The third application, inventory control, was written in R:BASE. This application uses both the scheduling information generated by PLANTRAC and the actual field information collected by the bar coding hardware. It provided a simple weekly status report on resource inventory, in addition to forecasting future needs.

The fourth application, construction drawings, was also written in R:BASE. This application provided information on the number and types of drawings used in a project, in addition to providing additional drawing detail in terms of notes and revisions.

The last application inputs information using the hardware-based data acquisition aspects of *CIMS*. Bar codes are the fundamental element in this system architecture since they control all the actual activity and resource data entry into the system. Data collection programs were developed using Intermec's Personal Computer Interactive Reader Language (PCIRL) [17]. An interface program written in R:BASE was also required to transfer information into the database. Bar code labels to support data acquisition were developed using Intermec's Personal Computer Label Manager (PCLM) software [16].

3.2 Database

A central database is an essential and basic component to support the level of integration sought and provided in *CIMS*. The R:BASE database management system is based on the relational data model. A data model defines the overall logical structure of a database and provides a structural framework into which data is placed. A relational data model is a collection of interrelated tables, as shown in Figure 4 [9].

Figure 4 represents a portion of the BEAM relation from the JOBSPEC database. Note that in the following discussion a reference to a table or relation is interchangeable; both refer to the same conceptual structure containing rows and columns of data items. The BEAM table illustrates the

general structure of a relation. The rows of a relation are called TUPLES and its columns are called ATTRIBUTES. A DOMAIN is the set of allowable values an attribute may possess. The values for the attribute LENGTH in Figure 4, for example, are drawn from the domain of positive real numbers. Each tuple represents an individual component and contains a value for each attribute. All tuples are distinct; duplicates are not allowed [9]. Tuples and attributes have no order; they may be arbitrarily interchanged without changing the data content or its meaning.

The overall logical structure of the database is called its schema. When all relations have been defined and their attributes and associated properties specified, the schema is completely defined [9].

3.3 Database Schema

CIMS relies heavily on a construction database of dependent and independent data [13,14]. Dependent data is dynamic, in a sense that it changes from project to project. Examples of this data include the equipment, resources, and activities that comprise the project. Independent data are static in nature, meaning that it does not change from project to project. Examples of these data include material supplier names and the AISC steel beam properties. Figures 6 through 10 illustrate relations that contain project dependent data. The STATUS, ACTIVITY, DRAWINGS, DRAWNOTE, and REVISION tables shown constitute a portion of a larger construction database necessary to support the construction process. A portion of the database schema, is shown in Figure 5. A complete description of the entire *CIMS* database is provided in reference 12.

The STATUS and ACTIVITY tables describe the process of resource transactions and activity procurement, respectively, on the job site. As resources are delivered to and used on the job site, they need to be identified and all pertinent inventory information must be recorded. The STATUS table shown in Figure 6, conveniently documents resource transactions that occur on the job site.

As activities are performed they too need to be identified. In addition, resources used to support an activity must also be identified as such. This portion of project control is provided by the ACTIVITY table shown in Figure 7. The ACTIVITY table documents the process of performing an activity, including the resources used.

In addition to resources and activities, drawings are essential to the construction process. The tables shown in Figures 8, 9, and 10 describe construction drawings and their content. The DRAWINGS table identifies and briefly describes the content of each drawing used. Other information that is both useful and necessary on construction drawings are notes and revisions. This information is conveyed to the user in the DRAWNOTE and REVISION tables shown in Figures 9 and 10. The DRAWNOTE table contains information about project drawing notes. The REVISION table provides a way to record the number and types of revisions that have occurred on a set of drawings.

These five tables are used extensively to support a variety of the *CIMS* applications. The applications are discussed in detail in the next section. It should be noted that the database schema presented here is a portion of a larger prototype schema that was designed specifically to support the *CIMS* system and to conduct integration and data flow experiments.

3.4 Scheduling Application

The proper scheduling of a construction project is one key to a profitable job. Two integrated tools are used to develop and maintain a project schedule. These are bar coding and PLANTRAC.

Bar coding provides *CIMS* with automated data acquisition. On the construction job site, workers perform an inventory on incoming resources, including both individual and bulk items. A transaction manager, an inventory data acquisition program, and a laser scanner are used to gather bar code data from resources. After all the resources have been inventoried, the data stored in the transaction manager are uploaded to the PC for storage in the construction database for subsequent processing and analysis.

As activities are performed on a project, resources are used. The identification of resource usage for each activity follows the same procedure as general inventory, except that an activity program is used to gather data. After the data is gathered, it is imported into the project database and updated with new information.

As activities are completed throughout the project, updates are supplied to the database and in turn, a new project schedule is generated. The new schedule provides a more accurate project model that includes a history of in-place work. This loop of information transfer continues until the project is finished. After each run, the schedule incorporates an additional increment of actual activity information. The project manager can compare these new schedules with the initial schedule on which the project was based. If the schedules are run often enough, major problems can be anticipated before they occur and the project manager can take the appropriate action to avoid delays.

3.5 Inventory Control Application

Inventory control is a necessary task in any production oriented environment. General inventory control, in addition to forecasting resource needs, can be accomplished through the use of the *CIMS* inventory control application. Both bar coding and PLANTRAC are used to develop inventory reports and provide resource forecasting in *CIMS*.

The *CIMS* inventory control application program is used to determine the status of the basic resource inventory. Possible transactions indicate that an item has been brought on site, installed, or is estimated to be installed. To generate an inventory report for a specific resource, the DBMS searches for all the resource transactions that occurred over a specified period of time. The inventory report lists resources by piece mark and piece name, and reports the corresponding quantity and date that those items were inventoried or installed. It then computes the available quantity.

The forecasting of resource needs is accomplished in much the same way. To generate an inventory forecast report for a specified time period, the DBMS searches for all the estimated resources used during a specified time period. Forecasting is performed by comparing the net resource amount available, i.e., current inventory, to future resource needs. If resource needs for the next week exceed the quantities available, the report would state the potential problem. An example inventory report, which uses a seven day forecast is shown in Figure 11.

The inventory application is an ongoing, integrated processing task. As more activities are ac-

completed, bar coding promptly and accurately records actual activity dates into the construction database. As the project schedule is updated, this information is incorporated, providing a better overall project model that accurately monitors job progress and permits accurate forecasting. This model is in turn used to provide a more accurate inventory report.

3.6 Project Cost Control Application

To be able to finance a construction project, a project manager must not only estimate the overall project duration and total cost, but he must also know how the cost varies during the project.

On a construction project, the project is normally billed when resources are delivered. As a result, the following assumptions are used in the cost control application. First, delivery of any resources required by an activity will be scheduled one week prior to the estimated activity start date. The second assumption is that payments will be made to the supplier two weeks after the delivery date.

The cost control program works as follows. First, estimated resource installation dates are used to estimate a cost schedule. As the project progresses and actual delivery dates are known, this information updates the estimated data. Using this information, the program can determine which resources have been used and which will be required. The quantity of each resource used is provided on a per week basis. Next, the program applies unit costs to these weekly resource totals.

The cost control program stores the basic cost data in a file for transfer. This file is then imported to SYMPHONY, which computes weekly cash flow estimates for the entire project regardless of percent completion. Listed are the costs, the partial payment, and the cash flow status. This report can be compared to the initial weekly project cash flow estimate on which the contractor based his financing to identify any major discrepancies. Figure 12 shows an example of an abbreviated cash flow report.

3.7 Job Site Data Acquisition

Two key factors that effect data acquisition in the *CIMS* system are the timeliness and accuracy of the data collection process. Accurate data input means that data integrity is maintained while data are being transferred between the bar code label and the bar code reader. Although an essential factor in any process, accurate data collection is especially important in *CIMS* since the input data supports all of the other integrated applications.

The timeliness of data acquisition is also vital since project managers cannot make the best possible decisions regarding resource allocation if they have belated information. A time lag of more than one day can reduce the effectiveness of decision making for a large project.

CIMS uses a variety of configuration modes to support data collection, all of which require the use of different hardware and software components. Figure 13 shows the *CIMS* hardware. A brief summary of these components is provided in the following paragraphs.

3.7.1 Data Entry Devices

Three input mediums are provided with the transaction manager; a full alphanumeric keyboard, including function keys for transmitting and receiving data; a light wand; and a laser scanner. The latter two devices are connected directly to the wedge reader for real time data acquisition, or to the transaction manager for remote data acquisition.

The light wand is a pencil-like device that scans bar codes through direct contact on the bar code label. To scan a label, the wand is run over the bar code in a smooth, continuous fashion. The laser scanner is a pistol grip scanning device that can accurately scan a bar code from a distance away from the label surface. This device is used in situations where direct contact scanning using a wand is not possible.

3.7.2 On-Line Data Acquisition

On-line in this scenario implies 'hardwired,' meaning that the wedge reader is directly connected in-line with the keyboard, thus allowing both to operate concurrently. This configuration is not used for remote data collection; it is only used for data collection purposes at the terminal. The light wand is connected to the wedge reader for bar code label scanning purposes. The wedge reader decodes bar codes and emulates keyboard action, thus sending the information to the PC, where it is displayed on the monitor.

Application programs that are driven by screen prompts can easily and efficiently be run using the bar code wand for data input. One example of this is the drawings application program, which uses number and character prompts to execute programs.

3.7.3 Remote Data Acquisition

The term remote means that data collection is not directly on-line with the PC, as it is when using a wedge reader. The remote data collection device, a transaction manager, is a hand held, portable mini-computer that can be programmed for specific data collection tasks and sequences. Data is input according to the specific program, stored in a file format required by the database, and then uploaded to the PC.

3.7.4 Information Download/Upload

The transfer of information is made possible through the use of an interface cable connected from the front port of the transaction manager to the communications port on the back of the PC. In addition, software is also required to support this operation.

Downloading comprises transferring computer programs developed on the PC down to the transaction manager. These programs direct the sequence of data acquisition by the remote wand or scanner. They are primarily user prompting data acquisition programs that are used for identifying resource inventories, activity procurement, and resource use.

Uploading comprises transferring acquired data from the transaction manager to the PC for

storage in the database. Data accuracy is maintained throughout the uploading process because of the accuracy of the hardware and the stability of the software. As with downloading the programs, interface software is required for uploading stored data.

3.7.5 Importing Uploaded Data to the Database

To import inventory and activity data to the database, the bar code interface program written in the R:BASE application language is used.

3.7.6 Bar Code Label Development

The PC was used in conjunction with Intermec's Personal Computer Label Manager (PCLM) software to develop a variety of different bar code labels to support data acquisition [16]. The thermal printer is connected to the PC communication port by an interface cable. To support label development, the thermal printer has several label formats. These formats can be uploaded to the PC via the interface link, edited and modified, and then downloaded to the thermal printer for final printing. New label formats can also be developed using the PCLM label editor.

3.8 Drawing Application

Bar codes can be used to facilitate information flow with respect to both drawing revisions and notes. Revisions can represent either minor or major changes to a drawing set during design or construction. These changes are reflected in the content of both the drawing and revision block. If drawings are not properly updated to alert shop personnel, fabricators, designers, engineers, and management to the changes, problems with material availability, scheduling, and cost overruns can occur. To alleviate these potential problems, a bar code label on each drawing, specifically identifying that drawing, can be used for drawing inventory and to access revision information stored in the database.

The availability of drawing information in the database can provide easy access for all members of a design/build team whether they have the project drawings themselves or not. This availability is accomplished by using the DRAWINGS table which identifies all project drawings for a given project number. From this table an individual can determine which drawings are used on a specific project simply by referencing the drawing number and description. Other drawing information can also be cross-referenced to other relations.

Figure 14 shows a partial drawing title block using bar codes. Both current and previous revisions for the drawing can be added or reviewed from one database table by scanning the specific bar code for the drawing of interest. The database provides for complete revision documentation, which is usually not available on the drawings themselves due to space limitations.

In addition to revisions, bar codes can be used to incorporate notes on drawings in an efficient and straightforward way. Applicable notes for each drawing can be stored in a database table and accessed in much the same way that revisions are. The notes referred to here are of the cut and paste variety. Examples include installation procedures, certain subcontractor responsibilities, and additional information with respect to revisions. While it is inevitable that some notes must stay on

drawings for contractual purposes, the removal of extraneous notes simplifies the drawings, making them easier to read and interpret.

The drawings system functions ideally using bar codes because they are both an accurate and efficient way to access information as well as to gather it. However, to retain system flexibility, all data can be entered via the keyboard to run the application. Figure 15 shows a portion of a sample drawing report.

4 Future Extensions

At present, the scope and quantity of the information controlled by *CIMS* has been limited to the base level prototype system. With the base system completed, other areas of information flow and data acquisition can be more fully investigated in future research. This section addresses some of the possible extensions to the *CIMS* research.

4.1 The Construction Process

The prototype version of *CIMS* addressed the labeling needs and applications of the materials and equipment comprising the constructed facility itself. Future work on *CIMS* should consider the construction process as well. This would include the materials and equipment utilized, as well as the activities performed in building the facility. RIT techniques used in tracking resources and activities presently incorporated in *CIMS* could also be used to track activities and resources specific to the construction process. By tracking the construction process additional applications for automated identification may be discovered.

4.2 Job Site Labor

Presently, most tracking of the construction work force is done using time cards. Extracting and compiling the information contained in these cards is relatively slow, complicated, and error-prone [12]. The application of bar coding technology to this aspect of construction can enormously improve and expand the scope of data acquisition for labor on the job site. An on-line system, using a fixed bar code scanner, would be recommended for this application. In this way, workers can scan a bar coded badge to identify themselves when entering or leaving the site, in much the same way they have been accustomed to using time cards. A unique identification number or social security number could be encoded onto the badge to identify each worker. *CIMS* presently identifies workers by using their social security number.

The question of who is using job site equipment is another factor of interest in the construction process. Worker identification tags, used in conjunction with bar coded equipment identification tags, can be scanned and linked together in the database. This information is useful to project managers because it facilitates the tracking of tool and equipment use on the job site by the individual or by a specific trade. Identifying both high and low usage of certain tools and equipment can allow inventories to be adjusted as required, thus optimizing costs.

In addition to tracking the worker, other information can be incorporated that identifies each

worker's craft and status. Using this information, daily reports on attendance can be generated quickly so that project managers can anticipate possible manpower needs before problems arise. Employees can also be identified in terms of what work they do as well as by their craft. As each activity is performed, each member of a crew can be identified as working on that activity. Employee badges can be scanned and the crew information can be stored in the database. By retaining this information, managers can have a better idea of labor distribution throughout the project, in addition to determining labor productivity.

4.3 Construction Equipment

By expanding *CIMS* to track the construction process, certain manual data acquisition techniques, especially those related to construction equipment maintenance and inspection, may be greatly improved. Presently, maintenance and inspection reports are usually completed by hand, and are both complex and time consuming to complete [11]. To partially alleviate this problem, bar coding could be used to identify each piece of equipment used on the job site. Standard reports could be converted to equivalent bar coding menu sheets which can be quickly scanned to collect the needed information and load it into a remote reader, or directly into the database through the use of an on-line reader. By automating this aspect of maintenance and inspection, project management would have timely information on equipment status, without the paperwork of present methods. Again, the timeliness of this information could prove to be extremely vital in situations where the forecasting of activity procurement is based on equipment availability and readiness.

Other aspects of equipment tracking include identifying when and where equipment is used. This information can prove to be beneficial when determining the frequency of equipment use or its maintenance and servicing requirements. By accurately identifying equipment surpluses and needs with respect to the historical trends of activity equipment use, the overall level of rental equipment used on the job site can be more efficiently determined in an effort to reduce costs. In these situations both remote readers and on-line readers can be used to track equipment status during periods of use, regular service, and major and minor repair.

Note that one key aspect of information generation is the speed with which data can be provided. On-line systems are recommended so that the data can be gathered, supplied, and analyzed in real time. An on-line system can be easily incorporated in any job site material storage warehouse. Remote terminals linked to the database, in conjunction with bar code scanners, can be readily used to track and monitor equipment use in real time.

4.4 Other Information

In addition to the dynamic, project specific data obtained from daily data acquisition, other useful, project independent information can be stored in the database. The AISC steel section properties are one example of this type of data. In the *CIMS* prototype, this information was incorporated into the database to support general information needs.

Future work on *CIMS* is intended to focus on integrating project estimating and bid development data with the database. This may occur by including the R.H. Means database, including construction related resource, labor, and activity cost information typically used to develop estimates for bid purposes. By integrating this information into *CIMS*, the completeness of the system

would assist the contractor in developing preliminary job bids. In addition, it could facilitate the development of costs resulting from change orders, project delays, and other unanticipated events.

The integration of a cost database has already been facilitated in the present *CIMS* system which incorporates the Construction Specification Institute (CSI) coding scheme to support construction activities and resources [8]. By using this scheme, an activity and the resources it uses can be directly related. The R.H. Means cost database presently supports this coding scheme for all the resource and activity information contained therein [25].

5 Conclusions

The primary concept advocated by the research effort described is resource identification and tracking. With this in mind, *CIMS* was designed to support a key construction activity—scheduling. Yet, even though the system emphasizes scheduling as a fundamental component of its design, it still supports a wide variety of other applications and components. Thus, another fundamental component is effective integration among a variety of hardware and software tools. It follows that a central database, operated on by a number of independent applications, and structured to support them all, is essential. The third fundamental component of *CIMS* is the bar code identification system technology. Effectively coupling this technology with both the database and application programs is a unique contribution of this research. The following conclusions can be drawn from the *CIMS* investigation to date:

- *CIMS* can effectively provide the project manager with a construction information storage and retrieval database to facilitate the task of job site information management,
- *CIMS* can provide both project managers and suppliers with an expanded means of resource identification and tracking (RIT) including both materials and equipment management,
- *CIMS* integrates construction application programs that address the needs of project managers in terms of scheduling, inventory, cost, and drawing control, and
- *CIMS* integration has been demonstrated to be achievable using available hardware and software technologies.

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References

1. Allias, D. (1984). "Bar Code Symbolology: Some Observations on Theory and Practice," Intermec, Inc.
2. Bell, L.C. (1986). "Computer Systems for Construction Materials Management," *Proceedings of the Fourth Conference on Computing in Civil Engineering*, American Society of Civil Engineers, Boston, MA, Pages 454-460, October.
3. Bell, L.C. and McCoullough, B. (1988). "Bar Code Applications in Construction," *Journal of Construction Engineering and Management*, American Society of Civil Engineers, Volume 114, Number 2, Pages 263-278, June.
4. Bell, L.C. and Stukhart, G. (1986). "Attributes of Materials Management Systems," *Journal of Construction Engineering and Management*, American Society of Civil Engineers, Volume 112, Number 1, Pages 14-21, March.
5. Bell, L.C. and Stukhart, G. (1987). "Costs and Benefits of Materials Management Systems," *Journal of Construction Engineering and Management*, American Society of Civil Engineers, Volume 113, Number 2, Pages 222-234, June.
6. Burke, I.E. (1984). *Handbook of Bar Coding Systems*, Van Nostrand Reinhold Company, New York, NY.
7. Computerline Inc. (1987). *PLANTRAC, Version 4A-1*, Pembroke, MA.
8. Construction Specification Institute. (1987). *Masterformat, CSI Document MP-2-1*, June.
9. Date, C.J. (1986). *An Introduction to Database Systems*, Fourth Edition, Addison-Wesley, Reading, MA.
10. Eisenberg, A. (1987). "A Little Bar Code Over The Radio," *ID Systems*, Volume 7, Number 6, Pages 33-36, July/August.
11. Frein, J. (1980). "Handbook of Construction Management and Organization," Van Nostrand Reinhold Company, NY.
12. Graves, A. (1987). "Timing is Everything," *ID Systems*, Volume 7, Number 9, Pages 59-62, November.
13. Herbert, M. (1988). "CIMS: A Construction Information Management System," Masters thesis, North Carolina State University, Raleigh, NC.
14. Herbert, M. and Rasdorf, W. (1988). "CIMS Users Guide," Version 1.0, Department of Civil Engineering, North Carolina State University, Raleigh, NC, July.
15. Ibbs, C.W. (1986). "Future Directions For Computerized Construction Research," *Journal of Construction Engineering and Management*, American Society of Civil Engineers, Volume 112, Number 3, Pages 326-345, September.
16. Intermec, (1986). Inc. *PCLM, Version 1.0*, Lynwood, WA.
17. Intermec, Inc. (1987). *PCIRL, Version 1.0*, Lynwood, WA.

18. Knight, P. (1987). "A Horse is a Horse," *ID Systems*, Volume 7, Number 6, Pages 11-14, July/August.
19. National Research Council. (1987). "How To Increase Productivity In The Construction Industry," *News Report*, Volume 37, Number 3, Pages 15-16, March.
20. Parsons, K. (1985). "Specifications: What Are They and Where Do You get Them?," *Scan-Journal*, First Quarter, Pages 41-47.
21. Pearce, S. and Stukhart, G. (1988). "Uniform Bar Code Standards in Construction," Materials Management Taskforce Meeting, Austin, TX, March.
22. Rasdorf, W. and Herbert, M. (1988). "CIMS: A Construction Information Management System," *Proceedings of The Fifth Conference on Computing In Civil Engineering*, American Society of Civil Engineers, Alexandria, VA, Pages 33-45, March.
23. Rasdorf, W. and Herbert, M. (1989). "Bar Codes in Construction Management," *Proceedings of the ID EXPO Conference and Exhibition*, ID Systems Magazine, Los Angeles, CA, March.
24. Stukhart, G. (1983). "Materials Management Report: Business Roundtable Construction Cost Effectiveness Project (CICE)," *Transactions of The American Society of Cost Engineers-27th Annual Meeting*, American Society of Cost Engineers, Pages K.6.1-K.6.6, June.
25. R.H. Means Co. (1986). *Building Construction Cost Data*, 44th Edition, Kingston, MA.
26. U.S. Department of Commerce. (1987). *Construction Review*, Volume 33, Number 6, November-December.

Figure 3: CIMS Architecture

RELATION

PCMARK	IDENT	SECDESIG	LENGTH	WEIGHT	SUPP#
BA	1B1	W10X26	19.92	518	S2
BB	1B2R	W18X24	28.29	679	S2
BC	1B3	W8X10	10.92	109	S2

ATTRIBUTE TUPLE

Figure 4: BEAM Relation From the JOBSPEC Database

Schema:

ACTIVITY(ACTNUM, ACTID, DESCRIP, DURATION, EARLSTRT, LATEFIN, ACTSTART,
TIMESTRT, ACTFIN, TIMEFIN, MILESTON, CREWSIZE, PCMARK1, PCMARK2,
PCMARK3, PCMARK4, PCMARK5, QUAN1, QUAN2, QUAN3, QUAN4, QUAN5)
STATUS(PCMARK, IDENT, PCNAME, TRANSACT, DATE, TIME, QUANTITY, MEASURE,
INPUT_BY)
DRAWINGS(DRAW#, DDESCRIP)
DRAWNOTE(DRAW#, NDATE, NOTES)
REVISION(DRAW#, DATE, REV#, BY, COMMENT, CHKD)

Relations:

ACTIVITY = project activities
STATUS = resource status
DRAWINGS = project drawings
DRAWNOTE = drawing notes
REVISION = drawing revisions

Attributes:

ACTNUM = unique activity identifier
DESCRIP = activity description
PCMARK1 = first unique resource of five possible
resources for use on an activity
QUAN1 = quantity of the first resource used for an activity
PCNAME = resource description
MEASURE = unit measure of a resource
DRAW# = unique drawing number
REV# = drawing revision number

Figure 5: Partial Database Schema

PCMARK	IDENT	PCNAME	TRANSACT	DATE	TIME
CA	1C1	COLUMN	INSTALL	05/09/88	9:00:00
BA	1B1	BEAM	ESTINST	05/10/88	-0-

QUANTITY	MEASURE	INPUT BY
2	PCS	355-60-9793
2	PCS	-0-

Figure 6: The STATUS Relation

ACTNUM	ACTID	DESCIP	DURATION	EARLSTRT	LATEFIN
10	COL1	erect 1st. fl. cols.	2	-0-	-0-
20	BEAM1A	erect 1st. Fl. beams	2	5/10/88	5/12/88

ACTSTART	TIMESTRT	ACTFIN	TIMEFIN	MILESTON
5/09/88	8:10:00	5/11/88	4:45:00	-0-
-0-	-0-	-0-	-0-	-0-

PCMARK1	PCMARK2	PCMARK3	PCMARK4	PCMARK5
CA	-0-	-0-	-0-	-0-
BA	-0-	-0-	-0-	-0-

QUAN1	QUAN2	QUAN3	QUAN4	QUAN5
2	-0-	-0-	-0-	-0-
2	-0-	-0-	-0-	-0-

Figure 7: The ACTIVITY Relation

DRAW #	DESCRIPTION
AB1	Anchor bolt plan, cols. A1 to G1
S1	Structural frame, 1st. floor
U1	Utilities, general site utility layout

Figure 8: The DRAWINGS Relation

DRAW #	NDATE	NOTES
P2	12-4-87	See sheet U1 for additional work in this contract
M1	12-6-87	Provide vibration isolation suppression for all motorized equip.

Figure 9: The DRAWNOTE Relation

DRAW #	DATE	REV. #	BY	COMMENT	CHKD.
S1	10-2-87	1	MJH	Added base plate detail	RAE
M1	9-3-87	1	MJH	Added condensate pump detail	RAE

Figure 10: The REVISION Relation

INVENTORY REPORT

CURRENT DATE 6/01/88
 STARTING DATE 6/02/88
 ENDING DATE 6/09/88

PIECE MARK	PIECE NAME	TRANSACTION	DATE	QUANTITY
BA	BEAM	ONSITE	06/02/88	4
		INSTALL	06/02/88	2
		INSTALL	06/05/88	2
		ONSITE	06/07/88	3
TOTAL REMAINING QUANTITY:				3

4 ITEMS WILL BE NEEDED WITHIN 7 DAYS OF
 06/09/88. PLEASE ORDER ACCORDINGLY.

Figure 11: An R:BASE Inventory Report

TIME/PROGRESS PAYMENTS: BALANCED

Note: PAYMENTS BEGIN IN WEEK 3. "COST" MUST BE ENTERED FOR EACH WEEK.

WEEK	START	END	COST	COST-TO-DATE
1	06/05/88	06/11/88	0	0
2	06/12/88	06/18/88	200.00	200.00
3	06/19/88	06/25/88	3224.23	3424.23
4	06/26/88	07/02/88	11508.50	14932.73

PAYMENT	PAY-TO-DATE	RETAINAGE	CASH FLOW
***	***	***	0
***	***	***	-200.00
0	0	0	-3424.23
193.50	193.50	21.50	-3230.73

Figure 12: Cash Flow Report

Figure 13: The *CIMS* Hardware

XYZ, INC.		
ARCHITECTURE AND ENGINEERING DEPT.		
DRW. BY	CHKD.	DATE
LOCATION RALEIGH, NC.
PROJ #	
	021	
SHEET TITLE SPECIFICATIONS
DRAW #	
	SP-1	

Figure 14: Portion of a Drawing Title Block

PROJECT DRAWINGS: JOBSPEC DATABASE

DRAWING NUMBER

M1

DESCRIPTION

-MECHANICAL, MECHANICAL ROOM LAYOUT,
PUMP DETAILS

DRAWING NUMBER

M1

REVISION

ADDED PUMP DETAIL

DATE

06/13/88

CHKED

LB

BY

MH

DRAWING NUMBER

M1

NOTES

WELD PIPE HANGER TO VALVE
WITH 3/8" FILLET WELD

DATE

06/14/88

Figure 15: Sample Drawing Report

TITLE: Bar Coding in Construction Engineering

KEY WORDS: Automation; bar coding; civil engineering; construction; database management; identification systems; information retrieval; information systems; inventory control; project management; resource identification

ABSTRACT: Automated inventory control technologies have been used for many years in manufacturing. One of these technologies, namely bar coding, is being used at an increasing rate in civil engineering applications.

This paper presents a *Construction Information Management System (CIMS)* for the control of information used by project management. One unique aspect of this system is that it successfully transfers a Resource Identification and Tracking (RIT) technology, namely bar coding, from a manufacturing environment to control data acquisition needs for construction. In addition, *CIMS* integrates scheduling, inventory, cost, and document control application programs with a central database management system (DBMS) using stand-alone software, a DBMS programming language, and a spreadsheet.

An introduction to the objectives and unique contribution of *CIMS* is presented, along with a review of other related construction industry research. The information needs of construction engineering are reviewed to determine how a system such as *CIMS* can satisfy those needs. A generic system architecture is described, and an implementation of the architecture is presented.

REPRINT SUMMARY: Bar Coding in Construction Engineering, by William J. Rasdorf and Mark J. Herbert. A brief introduction to a Construction Information Management System (*CIMS*) is presented. The information needs of construction engineering are reviewed to determine how a system such as *CIMS*, which uses bar coding technology, can satisfy those needs. A generic system architecture is described, and an implementation of the architecture is presented.

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