COST- AND SCHEDULE-CONTROL INTEGRATION: ISSUES AND NEEDS

By William J. Rasdorf[1] and Osama Y. Abudayyeh[2]

ABSTRACT: Cost control and schedule control are two of the most important management functions in the construction industry. Major research efforts are focused on developing procedures for improving the effectiveness of cost and schedule control. As a result, researchers are concerned with the quality, integrity, and timeliness of data that flow through such control systems. A number of data models have been proposed to integrate cost- and schedule-control functions, because such integration is viewed as the solution to the many problems facing construction projects today. This paper provides an overview of cost- and schedule-control functions, defines the desired control cycle, and discusses the problems and needs of cost- and schedule-control functions. A number of integrated cost- and schedule-control data models, which represent the state of construction research in this area, are discussed. The work-packaging model is briefly described and is suggested as the most likely existing model to achieve the desired cost and schedule integration. Finally, the conceptual design of a foundational data model for control, based on relational concepts, is provided. The recommended design adopts the conceptual structures of the work-packaging model.

INTRODUCTION

The primary objective during the construction process is completing the project on time and within the budget while meeting established quality requirements and other specifications. To do so requires a substantial focus on managing the construction process. However, managing a construction process is impossible without a plan and a control system ("Project Control" 1987). A plan establishes goals for a project's schedule, cost, and resource use, as well as the tasks and methods for carrying out the work. The plan is usually developed based on historical data bases as well as past experience with similar projects. On the other hand, a control system collects actual data (feedback) on a project's schedule, cost, and resource use; compares existing progress to the planned schedule (analysis) to highlight potential problem areas needing special attention; and makes decisions based on analysis results. To support construction-process management effectively, an integrated cost-control and schedule-control function is needed to collect quality data in a timely fashion and to provide quality historical data bases for future planning of new projects.

A majority of construction projects employ some method of cost and schedule control. Still, many projects suffer from ineffective control due to inefficient flow of information. This inefficiency is a fundamental problem in construction management. Specifically, the quality of information flowing in the control system is the essence of the problem (Kratt 1989). Problems are observed both in projects themselves at the time of their construction and in

[1]Assoc. Prof., Dept. of Civ. Engrg., North Carolina State Univ., Box 7908, Raleigh, NC 27695.

[2]Res. Asst., Dept. of Civ. Engrg., North Carolina State Univ., Raleigh, NC.

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the corporate historical data base. A solution to this problem imposes two challenges: integrating cost- and schedule-control functions; and controlling data quality, integrity, and timeliness.

As for the first challenge, construction projects exhibit complex relationships between schedules and costs. Although the interdependency between schedule and cost is obvious, it is rare to find project-control systems that integrate cost- and schedule-control functions (Hendrickson and Au 1989). Rather, they remain two separate functions that are performed independently from each other and that use two different control structures: the work breakdown structure (WBS) and the cost breakdown structure (CBS). The difficulty of integrating both functions lies in the level of detail that each function uses, as opposed to the level of detail needed. The cost-control function, represented by the CBS, is performed at a less detailed breakdown level than that of the schedule-control function, represented by the WBS. This difference in the level of detail used by each function creates a fundamental difference in the way cost and schedule data are maintained. Each collection of data becomes independent from the other and is maintained separately. Project managers must then relate the information coming from two sources, which reduces the efficiency of obtaining meaningful information.

As for the second challenge, construction data, which are acquired using a variety of different forms, are difficult to control due to either the limited time available to commit to this task or inefficient manual data-collection methods. However, controlling data is crucial to the success of any control function. If erroneous data enter the system, analysis, reporting, and decisions based on these data are meaningless. Thus, improving the quality, integrity, and timeliness of construction data is a well-recognized need (Ibbs et al. 1987; Teicholz 1987).

Thus, to achieve the desired integration, cost and time data must be acquired and maintained at an established common-denominator control account defined at a sufficiently detailed level. However, it is not enough to establish and maintain a common denominator. An automated method is also needed for acquiring and storing data that support this concept and level of detail. In other words, there is a need for a computing data-acquisition and -storage model that supports the integrated cost- and schedule-control concept and provides quality data in a timely fashion.

Previous Related Work in Cost and Schedule Integration

Researchers are trying to find better ways for performing cost- and schedule-control functions in an integrated approach by developing data representation models that facilitate the integration. A model is needed that can truly integrate cost- and schedule-control functions while acquiring, storing, and presenting quality data and information in a timely manner. A number of documented research efforts can be cited that address this issue. The following subsections describe and discuss some of the research findings related to integration models.

Teicholz's Model

Teicholz (1987) recognized the differences in the level of detail existing between the CBS and the WBS. Fig. 1 illustrates Teicholz's perception of the difference in the disaggregation between the CBS and the WBS. In the

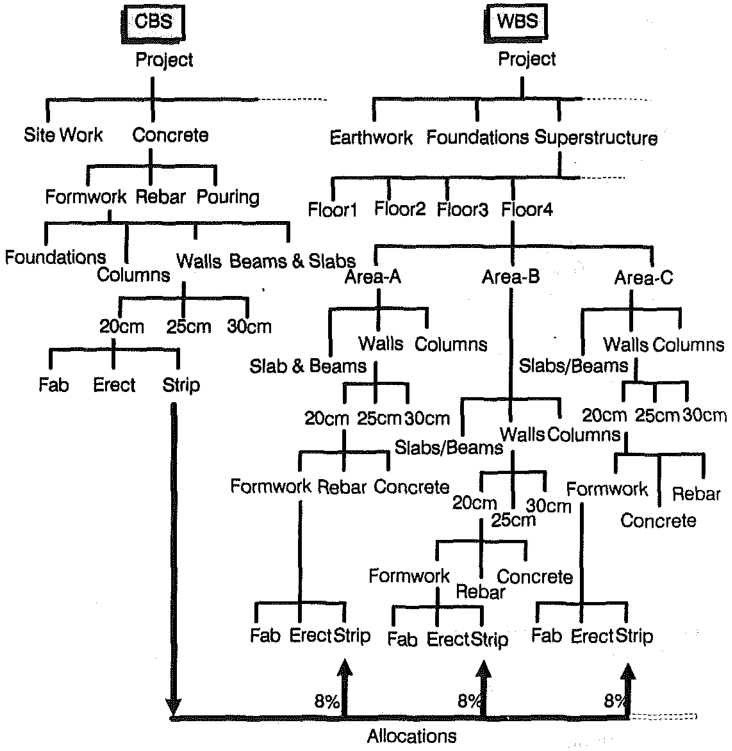
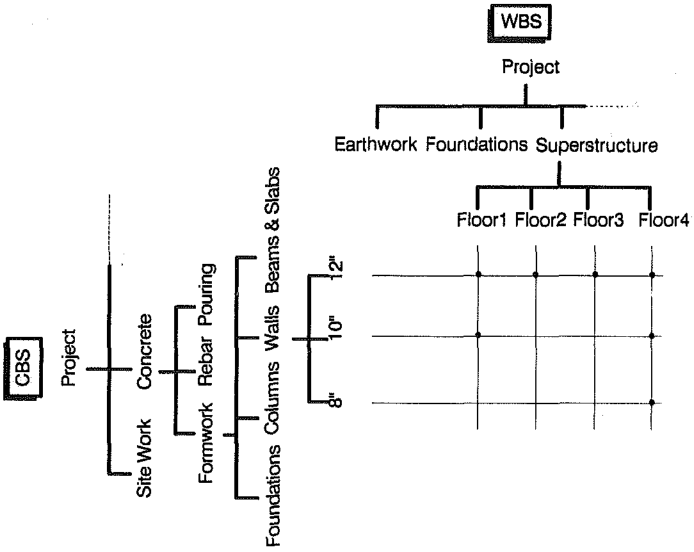


FIG. 1. Teicholz's Model (Percent-Allocation Concept)

figure, an account for recording cost data of the task of "strip 8-in. walls" on the CBS corresponds to many tasks on the WBS, including "strip 8-in. (20-cm) wall—area A" and other similar tasks for areas B and C of floor 4.

Teicholz proposed a mapping mechanism between the CBS and the WBS. The mechanism allows the mapping between a given cost account and one or more activities (tasks) that relate to that account. The way this mapping mechanism works is by the concept of percent allocation, where a cost account has specific percentages that specify the amount of a given resource (such as labor hours and material quantities) in a cost account on the CBS that should be allocated to a given task on the WBS. The mapping mechanism is illustrated in Fig. 1.

Teicholz's model does not attempt to address the fundamental causes of the difficulty in achieving the desired integration, namely the level of detail. He uses current approaches in cost- and schedule-control to develop an expedient solution (the mapping mechanism) to the problem. His percent-allocation concept is approximate and based on judgment. Teicholz identified a number of limitations of this approach that should be carefully considered when implementing his model. Specifically, when the cost and schedule functions become out of synchronization with respect to the level of detail, a cost account may exist that has no remaining costs linked to uncompleted



Work Element Matrix

		First Floor	Second Floor	Third Floor	Fourth Floor
Cost Accounts	30cm Walls	X	X	X	X
	25cm Walls	X			X
	20cm Walls				X

X : work element

FIG. 2. Hendrickson's Model

activities. This synchronization issue exists because there are two separate views of data and no attempt to integrate these views physically. Additionally, maintaining the links between the cost- and schedule-control account creates an extra computational overhead that may affect the effectiveness and efficiency of data processing and reporting.

Hendrickson's Model

Hendrickson and Au (1989) proposed using a work-elements concept for integration. The model is adopted from a three-dimensional work-element definition proposed by Neil (1983). A work element is a control account defined by a matrix of work packages from the WBS and cost accounts from the CBS, as shown in Fig. 2. In this model, a work element provides a link between the WBS and the CBS, where a cost account may relate to one or more activities, and at the same time an activity may relate to one or more cost accounts. This relationship again uses a work element as a common denominator that achieves the desired integration. Therefore, problems occurring on a specific activity can be easily isolated and analyzed since both cost and performance data associated with the activity are accumulated at the same disaggregated level. Clearly, this leads to improved project control.

Hendrickson and Au (1989) recognize the need for a common denominator for acquiring and maintaining data for effective project control. They also recognize that the success of this model is contingent on developing better automated data acquisition and representation methods because of the burden of data collection and storage. Additionally, the model still maintains two different views of project data (the CBS and WBS) even though they are linked by work elements for data-collection and -storage purposes. Keeping two separate views of project data adds to the overhead involved in summarizing data for cost-control and schedule-control functions, i.e., it creates an extra computational overhead.

Ibbs's and Kim's Model

Ibbs and Kim (Kim 1989) are developing a computer data model for improving construction project planning and control using an object-oriented programming (OOP) approach. The data model they proposed attempts to integrate not only construction cost and schedule control data, but design data as well. It relies on the development of a new element called the basic construction operation required by a design object (BOD). The BOD is defined as the lowest-level construction task needed to build a specific design object. Thus, a BOD is an entity that provides a linking mechanism between a design object and its corresponding construction operation control functions (WBS and CBS). An example of this model is shown in Fig. 3.

A BOD has three dimensions: a work package on the WBS, a cost account on the CBS, and a design object on a drawing. For example, the following five BODs can be generated for an 8-in. (20-cm) concrete wall object of area A on the fourth floor: "fabricate formwork," "erect formwork," "place rebars," "pour concrete," and "strip formwork." Each BOD is then linked to one cost account on the CBS and one work package on the WBS. Relevant cost accounts may include "labor cost for 8-in. walls formwork fabrication," "labor cost for 8-in. walls formwork erection," "labor cost for 8-in. walls formwork stripping," and others for material and labor costs of placing rebars and pouring concrete. Relevant work packages may include "formwork for 8-in. wall of area A—floor 4," "rebar work for 8-in. wall of area A—floor 4," and "concrete work for 8-in. work for 8-in. wall of area A—floor 4."

While this model addresses the data representation aspects of integrating cost and schedule control by developing storage and manipulation mechanisms using the OOP approach, it also ignores data acquisition support. Additionally, each BOD is defined at such a refined level that it may be impossible to acquire data to support the model. Indeed, one may reach as detailed a level as desired when developing a data-processing model, but its utility is limited because of the difficulty to acquire the data needed to support the model. Furthermore, the model still maintains the dual WBS and CBS views, which creates an extra computational overhead.

Work-Packaging Model

The work-packaging model (discussed in further detail in the next section) is the model we deem most likely to achieve the desired cost and schedule integration and at the same time solve the problems associated with data as

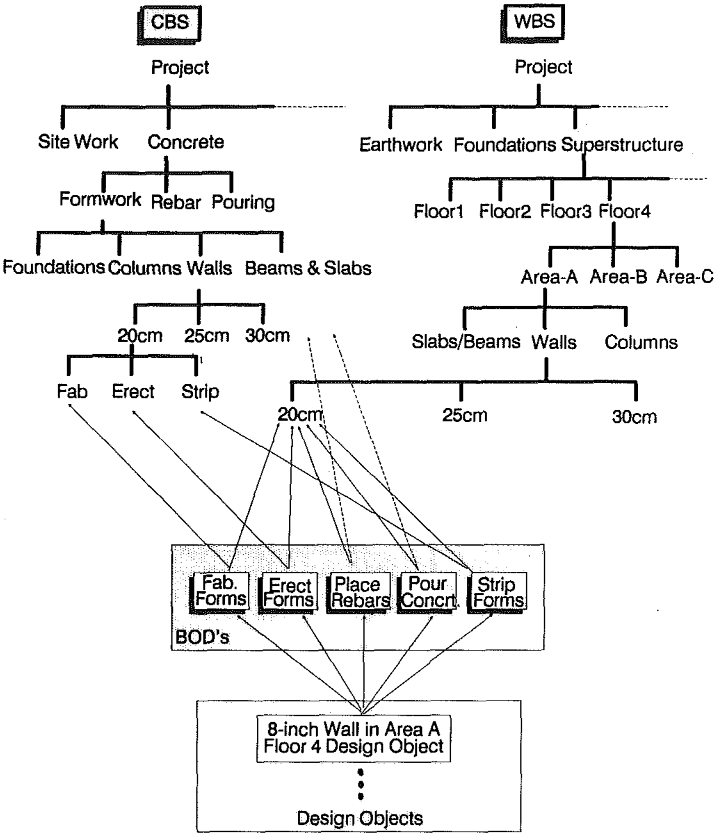


FIG. 3. Ibbs' and Kim's Model

described earlier. It was developed by the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD) for design-build projects in the aerospace and defense industries. It relies on the WBS for breaking down a project into manageable work packages that have well-defined scopes of work ("Project Control" 1987). The lowest level on the work-packaging model represents the actual tasks that will be used in the project's activity network.

In this model, the concept of activity-based cost control has been used, which has been recognized as a potential means for improving project control (Moder et al. 1983). The concept suggests using each activity in an activity network as a control account against which both cost and time data are acquired and accumulated. Because of the bookkeeping burden and impracticability of the activity network for control, the activity-based control was not widely accepted and has been modified. The modified model uses work packages on the WBS as the basis for control, where a package may exist at a higher level than the actual activity level. This modified model is called the cost/schedule control system criteria (C/SCSC). Fig. 4 shows a WBS

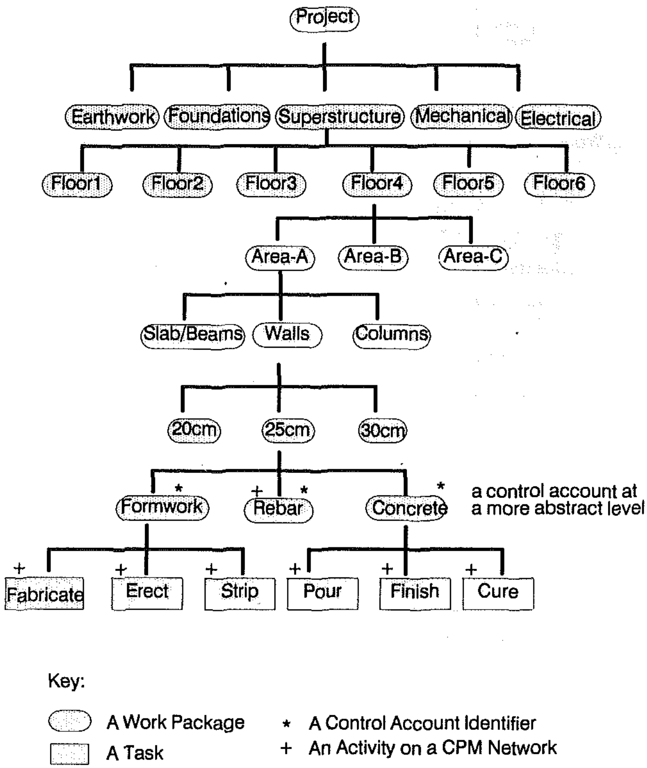


FIG. 4. Work-Packaging Model

used by the work-packaging model to perform integrated cost and schedule control.

The work-packaging model creates a unified view of project data by adding cost data to the WBS and eliminating the CBS. The model realizes the need for a common denominator in the hierarchy for acquiring and maintaining data for effective project control. This is illustrated by the activity-based or work-package–based cost-control concepts introduced by the model. This common denominator is considered a major contribution to the achievement of true integration.

While the work-packaging model addresses the data-processing and -representation aspects of integrated cost and schedule control, it ignores the data-acquisition phase. The amount of data needed at a detailed level is so large that problems and resistance to the model have occurred (Moder et al. 1983).

Model Assessment

In summary, researchers have recognized and strongly stated the need for integrating cost- and schedule-control functions, and have developed models that attempt to provide the desired integration. They suggest that integration is better achieved when common denominators are established. Their models define linking mechanisms between the WBS and the CBS as the common denominators but still maintain both views. However, the work-packaging model is the only one that truly achieves integration by providing a unified view of project cost- and schedule-control data using one structure, the WBS, for defining common denominators. Moreover, eliminating the linking mechanisms needed by other models creates a computationally inexpensive data-processing environment for cost and schedule control. This is particularly true when compared with the extra effort required in and the complexity of maintaining the links between the CBS and the WBS in other models. Furthermore, automation in support of the work-packaging model requires less development effort, and may indeed be more efficient to execute for the mentioned reasons. These facts contribute substantially to the improvement of the efficiency of an automated cost- and schedule-control system, and hence to the timeliness of the reporting system.

Another issue is that in most models the data-acquisition task is ignored. Yet data acquisition in an integrated fashion, and supported by an integrated data-storage model, is believed to be such an important task that a model's success is in most cases contingent on it. Though this paper focuses on the data-storage aspects of integrated cost and schedule control, it does provide a brief discussion of data acquisition.

Therefore, the work-packaging model is suggested as a strong integration-model candidate. However, some limitations still exist, particularly with respect to the automation of data storage and the data-acquisition support capability.

WORK-PACKAGING MODEL

The development of the work-packaging model was meant to create a unified view of project data—specifically time and cost data—to make the analysis and decision-making processes easier to perform. This view imposes a change in the planning and budgeting philosophy as well as a new approach to defining and using control accounts. Each of these needs and issues are addressed in the following, along with a description measuring work progress.

Planning and Budgeting

Medium to large construction projects usually involve thousands of operations. The WBS effectively captures the details of these operations. Another breakdown structure is also recognized by the work-packaging model: the contractor's organization breakdown structure (OBS), shown in Fig. 5. This structure assigns organizational functional responsibilities to each control account established at the desired level of detail on the WBS. For example, the civil superintendent is responsible for the "concrete work in walls on area A of floor 4" control account, shown enlarged at the bottom of Fig. 5.

Planning and budgeting in the work-packaging context refer to the scheduling of all authorized work and assigning budgets to manageable units of work (control accounts) ("Cost and Schedule" 1980). The work-packaging model requires the use of the WBS early in the project life cycle. This means that work must be scheduled in accordance with the WBS, and budgets of resource (materials, labors, and equipment) consumption and costs must be

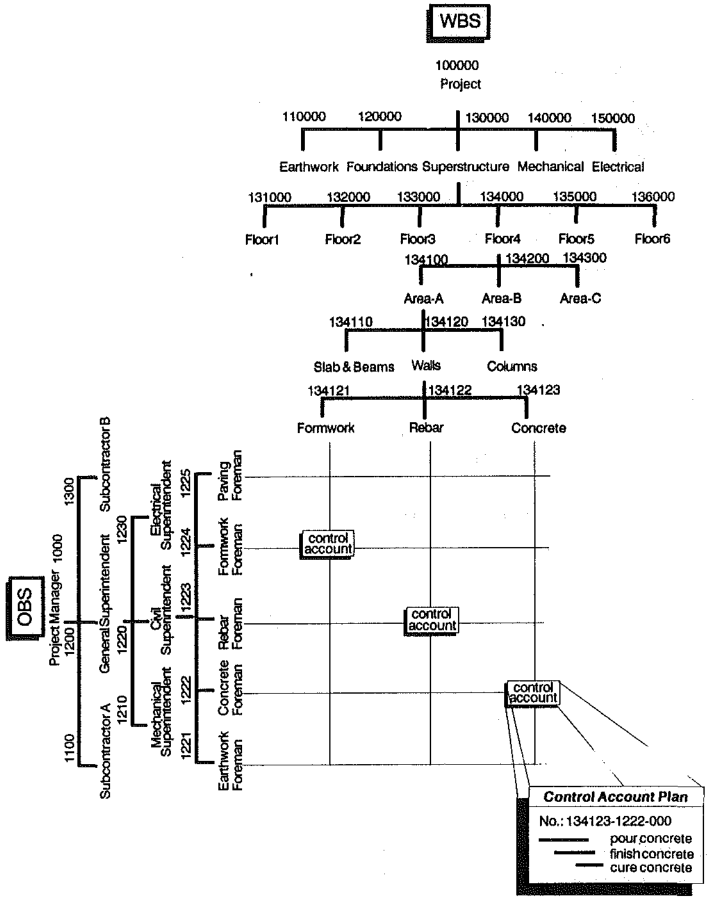


FIG. 5. Integration of WBS and OBS

prepared for each control account defined on the WBS. Then, the sequence of and logical relationships between control accounts are established, making each control account an activity on the activity network. Each control account then becomes a depository of control data that describes the work involved in it. Therefore, because of the change in the planning and budgeting philosophy and because of the cost- and schedule-control functions integration needs, a unified data organization is imposed on each account. Such an organization must provide the following for each control account: a scope of work, code number, planned start and end dates, a budget for resource consumption, actual start and end dates, and an actual resource consumption.

An identification system is then needed to support the work-packaging model. It must be designed to provide an easy addressing mechanism for each work package. This means that a coding scheme must be able to identify all of the processes and resources of a construction project. Therefore, to be able to satisfy the addressing mechanism needs, six components are needed in the coding scheme: a WBS, an OBS, a resource, a workers' identification, an activity-network identification, and task-coding schemes. These components are typically developed and standardized within a company.

Measuring Work Progress

Measuring work progress in the work-packaging context can be accomplished by a variety of methods, with the objective of estimating the progress (percent complete) of every control account, then aggregating these values to arrive at an overall estimate for the project's progress. The methods for measuring work progress are accumulated and described in references ("Project Control" 1987; Riggs 1987; Cost and Schedule" 1980). One method used for measuring work progress uses the units completed in a control account. This method is suitable for control accounts that have easily measurable units of work. An example would be pouring concrete in slabs where concrete volume can serve as the measurable units of work. The percent complete for a control account is estimated by dividing the actual units completed by the total units budgeted. Once the percent complete for each control account is estimated, the overall project percent complete can be computed. The project percent complete is estimated using the earned-value method, where an earned value is computed for each control account and combined with the other earned values. Individual earned values are computed by multiplying the percent complete by the budget for the account, where the budget for a control account can be a dollar value and/or work hours. Thus, the progress in all control accounts can be reduced to earned dollars or work hours, thus providing a mechanism for combining the progress in all accounts to compute the project's percent complete. This is achieved by:

$$\text{project percent complete} = \frac{\sum_{\text{accounts}} (\text{earned dollars or work hours})}{\sum_{\text{accounts}} (\text{budgeted dollars or work hours})} \quad \text{.......} (1)$$

CONCEPTUAL DESIGN OF CONTROL DATA MODEL

The integrated cost- and schedule-control data model proposed in this paper, based on the described work-packaging model, focuses on the conceptual design of a computing data-storage model. The model is concerned with providing the necessary storage and manipulation mechanisms (e.g., inserting, retrieving, deleting, and updating) to store data effectively and provide distributed access to it.

Design Methodology

The design of the conceptual data model consists of three major activities. The first activity involves determining what data items are needed by the cost- and schedule-control functions. This is accomplished by analyzing and extracting the data contents of actual construction data-collection forms. The forms selected for this investigation were taken from the R. S. Means Company forms book (*Means Forms* 1986). The second activity involves analyzing the extracted data to eliminate redundancies and to restructure the data to fit the integration needs dictated by the work-packaging model; the third involves developing a conceptual relational data model using relational concepts that include tables, columns, and rows. The relational model has advantages for modeling cost- and schedule-control functions, since tables and records are the natural mechanisms for representing and processing time and cost data.

Construction Data Forms Analysis

Currently, construction data are acquired using a variety of forms. A number of data-collection forms are available in the literature and from construction firms (Adrian 1986; *Means Forms* 1986; Halpin 1985; Carlsen and McHugh 1978). These forms are designed to collect fundamentally the same data items, though in different formats and structures. Because of these similarities and their standardized format, forms from the R. S. Means Company are selected for the analysis described in this paper (*Means Forms* 1986).

Means has developed a large set of construction forms that can be used in their present format or customized to fit the needs of a variety of construction jobs and companies. Six of these forms that are believed to support the cost- and schedule-control functions are selected; daily time sheet, weekly time sheet, daily construction report, labor cost record, job progress report, and project schedule.

The selected subset of forms was analyzed to determine what data items are acquired in support of cost- and schedule-control functions. The analysis yielded a large number of data items currently being collected on a construction job site. Many redundancies were observed in these forms. This was to be expected because the two functions are not integrated: Some forms are designed to support cost control, and others support schedule control separately. For example, labor hours are collected by the daily time sheet and summarized weekly on the weekly time sheet for payroll purposes. These hours are acquired and accumulated on the basis of each worker and are allocated to the appropriate work items (schedule control). On the other hand, labor hours are acquired and accumulated on the basis of each craft (man-hours) for cost-control purposes using the labor cost record, and are allocated to the appropriate cost accounts. By comparing the acquisition of data using these forms, it is obvious that on one hand there is a duplicate effort in acquiring a data item (labor hours) to support the two separate functions, while on the other hand, there is a redundancy in data recording because man-hours can be easily derived from the labor hours acquired by the daily time sheet.

A final list of data items acquired from the specified Means forms follows, and are grouped into five major categories.

- General data items. This category includes such data as the project's name, code number, and location; the weather condition on the date of filling the form; and the name of the person filling the form.
- Direct labor hours and labor costs. This category includes such data as cost-account code, worker's name and identification, regular and overtime hourly pay rates, and regular and overtime hours expended on different work items by each worker and craft.
- Direct material quantities and material costs. This category includes such data as total quantities of direct materials (e.g., concrete and rebars) used on different work items and charged to different cost accounts, unit costs

of the materials, and a description of each material.

- Direct equipment hours and equipment costs. This category includes such data as equipment code, equipment description, hourly rental rate, and hours of operation on each work item.
- Task time data. This category includes such data as the task code, task description, and actual start and finish dates.

Relational Modeling of Work-Packaging Model

Relational data modeling uses the concept of a relation to represent data in a two-dimensional tabular format (Date 1987). In other words, a relation is a table with columns and rows. Each column has a domain, which is the set of possible values that a column can assume. Each row is accessed by a unique identifier called a primary key, where a key can be a single column or a combination of columns (a composite key). Also, the relational model provides the needed standardized and automated mechanisms for data storage and retrieval. It consists of a collection of interrelated tables and a set of operators that allow adding, deleting, modifying, and retrieving data from tables.

A conceptual relational data model in support of the work-packaging model is described next. The data items needed by the cost- and schedule-control functions were identified in the preceding section. They were then restructured to satisfy the data structure and integration needs of the work-packaging model. The restructuring process yielded five groups of tables, which are described in the following, with each table in the following standard shorthand format: table name (column 1 name, column 2 name, . . .). In the tables directly related to the Means forms, only the acquired data items are incorporated into the design. Computed data items were intentionally left out since they are easily derivable from the acquired data items and can be created as needed.

The first group of tables defines the work-packaging model by describing each package, defining the hierarchical representation depicted by the WBS, identifying which of the packages are control accounts, defining the OBS, identifying the organizational elements responsible for the different control accounts, and describing the project at hand. The tables included in this group are the following:

- Work package–catalog (WBS code, parent code, level of detail, description).
- OBS-catalog (OBS code, parent code, level of detail, description).
- Control account (CA)–general information (CA code, OBS code, task code, start event, end event, actual start date, actual finish date).

The second group of tables defines resource codes and resource general information. These tables have the generic title of *name* codes, except for the worker-information table, where *name* indicates the resource type, such as materials and crafts. The tables included in this group are:

- Material codes (material code, description, units, budget unit cost).
- Equipment codes (equipment code, description, budget hourly rate).
- Craft codes (craft code, description, budget pay rate).
- Task codes (task code, description).

- Worker information (worker identification, worker name, craft code, regular pay rate, overtime pay rate).

The third group holds the budgeted information for the control accounts. These tables have the generic name of control account–budget *name*, where *name* indicates the type of data held by this table, such as materials and worker data. The tables included in this group are:

- Control account–budget workers (CA code, craft code, man-hours).
- Control account–budget materials (CA code, material code, quantity).
- Control account–budget equipment (CA code, equipment code, work hours).

The fourth group of tables holds the actual data acquired on the site. These tables have the generic title of control account–actual *name*, where *name* indicates the type of data held by this table, such as materials and workers data, except for the daily man hours plan. The tables included in this type are:

- Control account–daily man-hours plan (CA code, record date, man-hours).
- Control account–actual workers (CA code, worker ID, record date, regular hours, overtime hours).
- Control account–actual materials (CA code, record date, quantity).
- Control account–actual equipment (CA code, equipment code, record date, work hours).
- Materials–actual unit cost (material code, record date, unit cost).
- Equipment–actual hourly rates (equipment code, record date, hourly rate).

The final group holds historical data, thus creating the historical data base. These tables have the generic title of control account–historical *name*, where *name* indicates the type of data being held by this table, such as materials and workers data. The tables included in this group are:

- Control account–historical workers (CA code, craft code, regular man-hours, overtime man-hours, regular cost, overtime cost).
- Control account–historical materials (CA code, material code, quantity, cost).
- Control account–historical equipment (CA-code, equipment code, work hours, cost).

Data-Acquisition Issues

Manual data-acquisition systems are subject to human errors in many ways: (1) Filling data-collection forms out by hand; (2) summarizing these paper forms onto others; and (3) keying this information into a computer workstation. Therefore, automating data acquisition should improve the quality of data substantially by eliminating error-prone tasks and processes. Additionally, summarizing data would be performed by the computer, thus improving the timeliness of the control system. Furthermore, acquiring data for an integrated cost- and schedule-control system is more efficient than for a nonintegrated system because redundant data acquisition would be eliminated. The following is a brief summary of some of the recent research efforts on data-acquisition technologies and on our objectives with regard to developing an automated data-acquisition system.

Previous Work in Data Acquisition

New, automated data-acquisition technologies are currently being evaluated for construction applications in academic institutions by a number of researchers (Rasdorf and Herbert 1990a, b; Bell and Gillis 1989; Beliveau 1989; Bernold 1989; Songer et al. 1989; Bell and McCullouch 1988; Pearce and Stukhart 1988). These technologies include bar coding (BC), magnetic stripes (MS), radio frequency (RF), optical character recognition (OCR), voice recognition (VR), and magnetic-ink character recognition (MICR). Additionally, some construction firms—such as Bechtel, San Francisco, California, and Brown & Root, Houston, Texas—have explored ways to improve materials management, inventory control, and document control by using automated data acquisition technologies, in particular BC (Dorris 1989; "Binary" 1987). Also, the Ministry of Transportation of Ontario, Canada, has tested the use of BC in inventory control and concluded that BC is an effective and promising technology (*Bar Coding* 1990).

From a careful study of these efforts, it has become clear that BC, RF, and VR are the only technologies that have been substantially evaluated. BC technology in particular has been proven to be an effective automated data-acquisition tool in materials and equipment management systems for identifying and tracking a variety of information on a construction job site. The general consensus that emerged from these research efforts is that automating data acquisition to support the different management functions is evolving as a key issue in the design of future project management systems. Furthermore, the research efforts of Bechtel and Brown & Root, in conjunction with other construction innovators and with university researchers, will increase the acceptance and use of automated data-acquisition technologies in the construction industry.

Research Objectives in Data Acquisition

Our intention in this phase of the research is to develop an automated data-acquisition system to support the existing relational data model design using bar-coding technology. To build the automated data-acquisition system, the final list of data items (after eliminating redundancy) will be analyzed to determine which will be bar-coded. Bar-code labels will then be developed for the data items identified here. Next, the bar-code labels will be organized on sheets or in a log book for use by the system operator(s). Then, a data-acquisition program will be designed and implemented on a portable remote reader device called the transaction manager (TM), which can understand bar-coded data items entered through a scanner as well as data entered using the TM's keyboard. Finally, the data stored in the TM will be uploaded and stored in the relational data base by using an automated process, thus eliminating the key-in, error-prone manual process.

Conclusions and Future Extensions of Research

The integration of cost- and schedule-control functions and the quality, integrity, and timeliness of data entering and flowing through cost- and schedule-control systems have long concerned construction researchers and professionals. This paper suggested that the work-packaging model is currently a well-integrated existing model that can achieve these goals. However, to improve the performance of the work-packaging model, it was suggested that automated data-acquisition and data-storage mechanisms are needed. The research effort described in this paper focused on the data-storage issue. The conceptual design of a relational data model in support of the work-packaging model was developed and described. The relational data model provides the necessary, standardized, and widely accepted automated mechanisms for data storage and retrieval. Then, a brief discussion of the previous work in automated data acquisition was provided and the selection of bar coding as an implementation technology was stated. The research activities involved in the upstream coupling of the relational model with an automated data-acquisition capability was discussed. However, the actual implementation and evaluation of the system remains to be completed, and the interactions that would result between the data acquisition and storage remain to be investigated.

The fact that the work-packaging model has unified cost and schedule data by using one structure, the WBS, is a major contribution of the model not only for construction planning and management but also for adding the design view into the picture. The writers believe that a WBS can in fact be used for detailed design or possibly for preliminary design. Many political issues among the different organizations involved in a project (designer, architect, contractor) must be resolved first before any true integration of design and construction can occur. The successful implementation of a work-packaging approach from the design phase requires a commitment to integration from all parties and a willingliness to share data and information. However, for companies that undertake design/build types of contracts, the work-packaging approach may be a promising one. Thus, a natural future extension of the research addressed in this paper would be to investigate the potential implementation of the work-packaging model in the construction industry starting with the design phase, and study the willingness of different organizations to adopt such an approach. Then, modeling of design and construction data would follow to develop an automated data-acquisition and -storage model. The development of this model would essentially extend our existing relational construction model.

We hope that by combining the automation of data acquisition and data storage with the integrated cost- and schedule-control concept represented by the work-packaging model, we can provide a good automated solution to the problems as described in the introduction. We also hope to lay a foundation for integrating other managerial functions, such as material management, as well as integrating design and construction data.

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