# Flexible Work Breakdown Structure for Integrated Cost and Schedule Control

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**Abstract:** Integration of cost and schedule control systems has been an issue of great concern for researchers and practitioners in the construction industry. Nevertheless, the real-world implementation of this promising concept has not been popular enough to maximize the benefits that this integration has to offer. One of the major barriers is the overhead effort to collect and maintain detailed data. The purpose of this paper is to propose a flexible work breakdown structure (WBS) that optimizes the overhead effort by means of reducing the amount of data to be controlled. In order to have a flexible structure, the WBS numbering system needs to utilize standard classification codes and should not have a common strict hierarchy for all components. A case study is analyzed in this paper in order to examine the proposed concept. Practical implications are outlined as well.

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## Introduction

Cost, schedule, and quality are three major measures for construction project performance assessment. Among these three measures, cost and schedule are objective and quantitative, while quality is somewhat subjective and qualitative (CII 1997). In addition, cost and scheduling are closely interrelated, because they share a lot of common data in their controlling processes. Therefore, integrating cost and schedule control functions provides an effective tool for monitoring the construction process. Many researchers have emphasized the benefits of this integration and several different methodologies combining cost and schedule control data have been developed (Rasdorf and Abudayyeh 1991; Fleming and Koppleman 1996).

However, the excessive management demands of collecting and maintaining detailed data has been highlighted by previous research as the major barrier to utilizing this concept over a quarter of a century (Rasdorf and Abudayyeh 1991; Deng and Hung 1998). Rasdorf and Abudayyeh (1991) stressed the development of automated data-acquisition systems that utilize advanced information technology in their research modeling a relational database for work packages. Advance information technology is a definite solution and a driving force for the recent increasing interest in integrated cost and schedule control worldwide.

Besides utilizing information technology, optimizing management methods can be another driving force that can result in reducing the amount of required data. Management requirements, even in a project, may vary depending on the characteristics of a work package. However, most research efforts have not addressed this issue in detail, especially various ways of work breakdown structure (WBS) usage as a solution for integrated cost and schedule control. In this context, this paper proposes a flexible work breakdown structure that allows us to assign different management approaches for different work packages.

## Cost and Schedule Integration

Cost and schedule are closely interrelated in terms of sharing common data for performance assessments. In an analysis of practical construction data forms for separate cost control and schedule control, Rasdorf and Abudayyeh (1991) detected many redundancies in the forms that eventually require repeated manipulations of the same data for different purposes. They also pointed out key-in errors that might occur during the redundant data entry process. Thus, integrating these two different control functions not only provides meaningful project information, but also improves the efficiency of control processes.

Systemizing cost and schedule control contributes highly to the overall enhancement of project management information systems as well. Jung and Gibson (1999) analyzed the degrees of contribution and the dependency of each construction business function to evaluate the integration effectiveness in terms of data sharing. The results of a case study revealed that the most important business functions, in terms of contribution to the integration, include cost control (125.1), design (115.3), estimating (114.7), and schedule control (110.1), where 100 means the exact average and median with which others can be compared. The higher contribution scores of cost control and schedule control indicate that

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the relative effectiveness for overall systems integration can be better achieved by data from these two business functions (Jung and Gibson 1999).

For these reasons, researchers and practitioners in the construction industry have aspired to develop an integrated cost and schedule control system for their effective project management. Several different methodologies for combining cost and schedule control data have been developed, and the best-known and most frequently cited one is the comparative analysis by Rasdorf and Abudayyeh (1991). In their study, Teicholz's model (Teicholz 1987), Hendrickson's model (Hendrickson and Au 1989), Ibbs's and Kim's model (Kim 1989), and a work-packaging model (DoD 1980) were studied. The work-packaging model utilizes an activity in a critical path method (CPM) schedule as a common denominator (named as a control account) where both cost and schedule data are gathered and analyzed. The concept of a control account is discussed in detail in the next section. Rasdorf and Abudayyeh (1991) conclude that the work-packaging model, developed by U.S. Department of Defense (DoD) and named the Cost/Schedule Control System Criteria (C/SCSC), satisfies in "providing a unified view" with an "inexpensive data-processing environment."

The earned value management system (EVMS), formerly known as C/SCSC, is one of the best practices for integrated cost and schedule control. Recently, the adoption of EVMS has been gaining popularity, and several national and international standards bodies have started developing EVMS standards.

However, integration of two different aspects of business functions into one requires more complex data structures and additional management efforts throughout the project life cycle. A survey by Deng and Hung (1998) revealed that "increase in labor force/staff" and "heavy project overhead and operational costs" were the most significant forms of overhead. Therefore, optimizing (or minimizing) the additional efforts required for integrated cost and scheduling control is the critical success factor for its practical implementation. This optimization can be achieved by reengineering the cost and scheduling control processes and/or by automating the data acquisition.

The scheme of reengineering varies extensively depending on projects, organizations, or localities. For example, EVMS reengineering guidelines for Korean general contractors (Jung et al. 2000b), developed based on the results of a survey of 17 contractors, recommends early budgeting, using a higher level of work packages as control accounts, and simplifying progress measurement. The results of the survey reflect the current practices in the Korean construction industry. Particular facts illustrating these practices include the fact that the final definite construction budget of general contractors is mostly issued after the construction has commenced (2.5 months after the commencement of construction on average), that the excessive number of activities on network scheduling hinders the operation of the critical path method (CPM) on job sites, and that current progress measurement requires a very detailed monthly report of the unit of work completed, even though the most work (over 80%) is performed by materials suppliers and subcontractors (Jung et al. 2000b).

Therefore, this paper focuses on a generally applicable solution for the reengineering process, which is "optimizing the number of control accounts by means of flexible work breakdown structures."

## Work Breakdown Structure and Control Account

The work breakdown structure (WBS) is defined as "a deliverable-oriented grouping of project elements, which organizes and defines the structure of the entire project. Each descending level represents an increasingly detailed definition of a project component" (*A guide* 1996). Fleming and Koppleman (1996) state that "the WBS provided an opportunity for all key functions on a project to view the project in the same manner, to speak a common project language for the first time." Thus, the significant characteristics of WBS in project control are twofold; one is its classifying mechanism, which decomposes the project elements into a manageable level, and the other is its integrating mechanism, which provides a common perspective to relevant construction business functions.

### *Control Account*

According to a document from the American National Standard Institute (ANSI), the control account (CA) in EVMS acts for "a management control point at which budgets and actual costs are accumulated and compared to earned value for management control purposes" and represents "the work assigned to one responsible organizational element" (EIA 1998). Fleming and Koppleman (1996) also describe the CA as a common denominator of WBS and organizational breakdown structure (OBS), where functional responsibility is assigned. Namely, the basic role of CA is the common denominator and focal point for the integration of scope, cost, and scheduling (Rasdorf and Abudayyeh 1991; Fleming and Koppleman 1996).

The interrelationship between WBS and CA for integrated cost and scheduling control is clearly explicated on network schedules. Particular work packages in WBS are chosen and shown as activities on the network schedule, and they are used as a common view for schedule and cost information.

The critical issue here is making a decision on the level of WBS to be selected as a CA for effective control and management. This issue directly relates to the additional management effort required to implement the integrated cost and scheduling control, because the number of CAs determines the amount of detailed data to be manipulated for performance measurements. In other words, the appropriate level of detail must be carefully determined considering the project characteristics.

### *Level of Detail*

As discussed earlier, determining the level of detail is critical in integrating cost and schedule information (Hendrickson and Au 1989; Rasdorf and Abudayyeh 1991; Fleming and Koppleman 1996). Level of detail deals with the size of the project, cost, duration, and technical complexity, namely, the manageability of a work package. The number of work packages is rapidly increased as a WBS is decomposed one or two more levels downward, because one work package includes various types of work items. It is obvious that having smaller (lower-level) CAs can provide more minute information for detailed analysis, but requires more extensive data manipulation.

For effective implementation of EVMS, Fleming and Koppleman (1996) recommend choosing larger (higher-level) CAs in order to reduce the number of CAs. However, employing larger CAs ordinarily implies a multifunctional team organization (Fleming and Koppleman 1996). From a general contractor's viewpoint, it might be ineffective for operating multifunctional

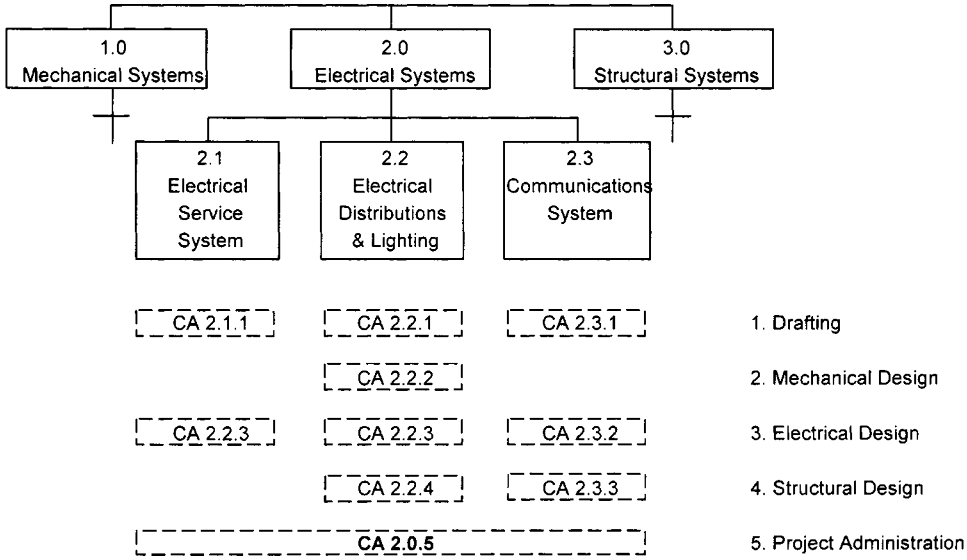


**Fig. 1.** WBS/OBS matrix example by McConnell (1985)

teams if a construction project is mainly performed by a direct-hired workforce that requires small work packages. On the contrary, a construction manager (CM), as an agent of the owner, would prefer large CAs for effective monitoring.

Several different situations can happen even in one specific project. For example, in some cases, larger (higher-level) CAs might be essential due to a small management team on the job site, while several smaller (lower-level) CAs are also required because of their impact on the project. A detailed example will be discussed later in this paper. Thus, the level of detail for CAs directly relates to the project characteristics, including project delivery system, contract type, subcontracting, and management policy of an organization.

## Flexibility of Work Breakdown Structure

Different levels of detail should be accepted and handled by CAs in order to manage a project effectively and to reduce the number of CAs, as previously discussed. In order to meet the complex requirements in terms of the level of detail, a WBS needs to be flexible in its structure.

Flexibility built into the work breakdown structure makes it possible to reduce the number of CAs and to meet the various levels of detail required for a project simultaneously. The flexibility of a WBS implies its sequence of classifications. The International Organization for Standardization (ISO) defines eight classification classes (facets) of construction information, which are facilities (e.g., factory, hospital), spaces (e.g., recreations spaces, office spaces), elements (e.g., foundations, exterior walls), work sections (e.g., excavation, cast-in-place concrete), construction products (e.g., steel bars, paint), construction aids (e.g., scaffolding, tools), management (e.g., contracts, cost control), and attributes (e.g., size, weight) (ISO 1994). Typically, the work breakdown structure of a construction project is the combination of the physical breakdown and commodity breakdown (e.g., concrete work for second floor of the main building).

The issue of WBS sequence for integrated cost and schedule control has not been addressed much in research. However, it can be observed that the traditional practice ordinarily establishes a rigid sequence of WBS levels, and the rule is strictly applied to all components. McConnell (1985), Eldin (1989, 1991) and Abudayyeh and Rasdorf (1993) illustrate the WBS structure, and the WBS used for the Incheon International Airport project in Korea also supports the popular use of the strict requirement.

### *Fixed Work Breakdown Structure Sequence*

McConnell (1985) offered an abridged example of WBS for a building design project. Three levels are used to represent a CA, which is in the order of work section, element, and functional team, as depicted in Fig. 1 and in column 2 of Table 1. For example, a CA numbered 2.3.3 is a communications system (2.3.x) for electrical systems (2.0.x) assigned to an electrical engineering design team (x.x.3). All CAs shown in this example follow the three levels WBS in the same way, but one CA (WBS 2.0.5) in Fig. 1 has a distinctive character whereby a project administration group (x.x.5) is in charge of whole electrical systems (2.0.x) because the work of this group is difficult to subdivide (McConnell 1985). In this case, some flexibility is achieved by selecting different levels for a specific functional team while the basic structure of three digits is adhered to.

Eldin (1989) developed and applied a four-level WBS for a construction project of an oil producing facility as described in column 3 of Table 1. A six-digit number is used to indicate the WBS in the order of two digits for major areas, one digit for work sections, two digits for elements, and an additional single digit for details. For example, the CA code for “pipe bridge 3 footings in ABQAQ plant” is GA-2-60-A, where GA, 2, 60, and A indicate ABQAQ plant, site work, foundation, and pipe bridge footings, respectively. Using selective combinations among the four WBS levels can generate various types of summary reports.

A similar WBS structure for design performance measurements by Eldin (1991) has five levels in the order of project identification number, facility number, engineering discipline type, document type, and a serial number (column 4 of Table 1). In this case, a separate package number is used for grouping several different control items into one work package (Eldin 1991).

These three cases have different research perspectives, scopes, and practical implications, and the structures defined for each case must be effective for their own requirements under different

**Table 1.** WBS Cases for Integrated Cost and Schedule Control

| Description | Case I ( McConnell 1985) | Case II ( Eldin 1989) | Case III ( Eldin 1991) | Case IV (This study) |
|---|---|---|---|---|
| Type of project | Building | Oil producing facility | Oil producing facility | Building |
| Major use for | Design performance management | Construction performance measurement | Design performance management | Construction performance measurement |
| WBS sequence | Work section–element–management | Facility–work section–element–dummy | Facility–work section–management–dummy | Not defined (flexible) |
| Numbering digit | 3 digit | 6 digit | 6 digit | Not defined (flexible) |
| Numbering example[a] | | | | |
| Level 0 | Project | Project | Project | Project |
| Level 1 | **2.0** | **GA** | **02** | **F01** |
| | **Electrical system** (work section) | **ABQAQ plant** (facility) | **Facility #2** (facility) | **Office building** (facility) |
| Level 2 | 2.**2** | GA**2** | 02-**3** | F01**W03000** |
| | **Electrical distributions and lighting** in electrical system (element) | **Site work** in ABQAQ plant (work section) | **Civil work** in facility #2 (work section) | **Concrete work** in office building (work section) |
| Level 3 | 2.2.**4** | GA2**60** | 02-3-**1** | F01W03000**S01** |
| | **Structural design** for electrical distributions and lighting in electrical system (management) | **Foundations** of site work in ABQAQ plant (element) | **Drawings** for civil work in facility #2 (management) | **First floor** concrete work in office building (space) |
| Level 4 | | GA260**A** | 02-3-1-**01** | |
| | | **Pipe bridge footings** for foundations of site work in ABQAQ plant (dummy, serial number) | **Document number 1** of drawings for civil work in facility #2 (dummy, serial number) | |

[a]Description in parentheses indicates facets defined by ISO (1994).

conditions. However, it is found that the WBS systems have a rigid sequence of facets in numbering systems. Even though some flexibility can be achieved, within this rigid sequence, by having a CA in a lower or higher level (for example, the control account number 2.0.5 in Fig. 1 is in a higher level, as it encompasses work packages of 2.1, 2.2, and 2.3), comprehensive flexibility in exchanging the sequence of facets for partial CAs is restricted because of the coding system.

### *Flexible Work Breakdown Structure Sequence*

The WBS proposed in this paper achieves comprehensive flexibility by allowing it to be placed in any kind of facet on any level of WBS. The proposed numbering system is illustrated in Fig. 2 and in column 5 of Table 1. The need for this comprehensive flexibility may occur especially when a project encompasses several units with different complexities, and each unit requires a different level of management detail.

For an illustration, the project named "A" in Fig. 2 consists of three packages in level 1: an eight-story office building, a laboratory facility, and the planting work. It is assumed that each package has distinct conditions requiring different management plans. Most of the construction packages are subcontracted in this model project. Planting for this project is also subcontracted to a specialty contractor due to distinct requirements and needs to be monitored separately. For this reason, a package of work section (planting) is located in level 1 with the other two facility packages. The packages with bold and italicized WBS numbers are CAs. Planting (W02900) is a CA in level 1. The first floor concrete work (F01W03000S01) is a CA in the third level, where space (first floor) is the key facet. Plastering (F01W09200) is also a CA on the third level, but the work section is the key facet in this case. Excavation (F01W02315) is a CA in the fourth level, because direct-hired workers do this work.

Thus, work packages in different facets can be placed in the same level, and the level of a CA can unrestrictedly vary depending on each CA's management requirements.

A practical shortcut of placing different facets on the same level under a fixed WBS sequence is occasionally used (e.g., using work section "concrete work" as a facility name). However, compounding facets in this way makes data integration and reuse very difficult, resulting in amassed historical data of no value. For this reason, a flexible WBS needs to be capable of placing any facet of information on any level of WBS hierarchy, while keeping independency of classification facets, which enables the related raw data to be used for other business functions.

## Work Breakdown Structure Numbering System

The fundamental aspects of WBS numbering investigated in this study are classifying mechanisms and integration mechanisms. Another relevant issue is that CA is the critical management point where scheduling and cost information is gathered and analyzed together. Therefore, CA itself must be controlled by a systematic instrument, and only a well-defined numbering system satisfies this requirement. A numbering system needs to have hierarchical definitions in classifying mechanisms and have independent facets for multipurpose uses of relevant data.

Particularly, the use of standard classifications enhances the integration of construction control systems and also improves the viability of integrated cost and schedule control systems by reducing the overhead efforts and by reusing historical databases.

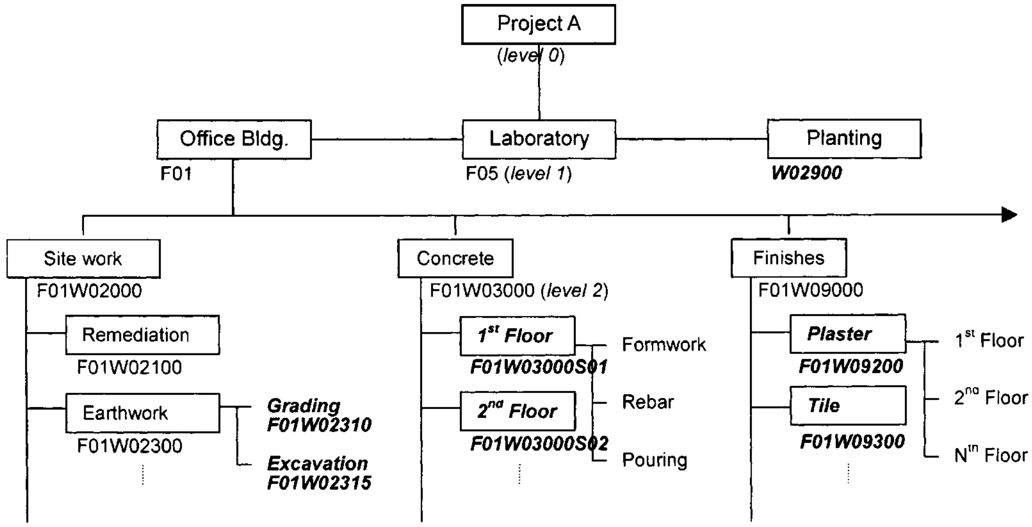


**Fig. 2.** Flexible work breakdown structure

For example, properly organized data from relevant processes such as labor cost reporting, inventory controlling, and equipment handling can provide computer-to-computer data directly to the integrated cost and schedule control systems. In other words, a specific process should generate data that can be used for other processes or for other projects without retyping, restructuring, or additional encoding. For this universal usage of data, each dataset must follow a predefined standard numbering system.

### *Independent Classifications*

Several facets, such as spaces, element, work sections, and materials, are used to classify the construction information. One or a combination of these facets composes code numbers to represent various forms of construction information. For example, foundations (element facet) and concrete work (work section facet) are used together to describe the concrete work for foundations in estimating.

Definition of facets is subjective and varies according to organization, but each facet needs to be defined independently in order to clearly represent the classes. Some organizations confound the facets in their classification system. Typical confusions occur between facility and work section (e.g., railways), or between work section and material (e.g., concrete). The International Organization for Standardization (ISO) suggested eight independent facets of construction information in 1994. Several classification standards complying with the ISO suggestion use a different letter at the beginning of the classification number so as to clearly indicate the facet represented (*Uniclass* 1997; *Integrated Classification*s 2000).

Flexible WBS requires the use of this explicit identifier for each facet because there is no rule set for positioning a facet, as shown in column 5 of Table 1. The rationale behind using the independent classifications as a rule in the flexible WBS is twofold: first, to have the identifier clearly indicating what facet the information is subordinated to, and second, to establish relationships between database tables for different business functions using the same standard code. Standard classification systems should be adopted at the company level for effective integrated cost and schedule control as well as for improved reusability of historical data for the future projects.

Among the classification facets, “facility,” “space,” and “element” can be more project specific than the others. On the other hand, facets such as “work sections,” “construction products,” and “construction aids” are less project specific and should strictly abide by the standards, because the project information of

**Table 2.** Coding Structure (Example)

| Control account | Budget item | Unit | Quantity | Budget unit cost | Cost code | Remarks |
|---|---|---|---|---|---|---|
| ……… | ……… | | | | | |
| *F01W03000S01* | CIP forms | $m^2$ | | | W03110 | First floor |
| *F01W03000S01* | Rebar | tons | | | W03210 | Concrete work |
| *F01W03000S01* | Concrete pouring | $m^3$ | | | W03310 | Office building |
| ……… | ……… | | | | | |
| *F01W03000S02* | CIP forms | $m^2$ | | | W03110 | Second floor |
| *F01W03000S02* | Rebar | tons | | | W03210 | Concrete work |
| *F01W03000S02* | Concrete pouring | $m^3$ | | | W03310 | Office building |
| ……… | ……… | | | | | |
| F01W09000 | Stucco finish | $m^2$ | | | W09221 | |
| F01W09000 | Gypsum board | $m^2$ | | | W09250 | |
| ……… | ……… | | | | | |

these facets is more frequently shared by many project participants and organizations involved even after the project is completed.

Maintaining a list of definitions and a conversion table is strongly recommended if any facet uses some project-specific codes. Employing industry standards for higher-level definitions and modifying extensions for lower-level definitions might be the best way to efficiently develop a company's standards. CSI MasterFormat (*MasterFormat* 1996) and UniFormat (DoC 1999) are the best examples of industry standards in North America, even though all eight ISO facets of classifications are not defined by these standards.

The numbering system proposed in this paper arranges the code numbers of several different classifications in the order of each package's WBS hierarchy. Even the code numbers of the same facet can be repeated in one sequence. A model project in this paper uses company-wide standard classifications for all facets, as shown in Fig. 2 and column 5 of Table 1. F01 and F05 in the facility facet show an office building and laboratory, respectively, and S01 and S02 in the space facet represent the first floor and the second floor, respectively, in Fig. 2. Note that the numbers and titles for "work section" in the model project use the CSI *MasterFormat* (1996). Also, the letter "w" standing for "work section" is added at the beginning of all numbers in order to indicate the facet so that the WBS number itself clearly designates the work package it belongs to.

Using standard classifications significantly enhances the reusability of historical data for estimating purposes as well (Jung et al. 2000a). Even though defining complex WBS numbers seems to be a troublesome task for users, the selection of classifications can be made using the descriptions without knowing the full list of numbers behind the screen.

### Multiattribute Keys

The relational database management system (RDBMS) is the most widely used tool for manipulating non-graphic data in the construction industry. In a flexible WBS, data retrieval and the relationships assigned between cost and schedule data tables necessitate more complex key definitions. This becomes more serious when an organization implements integrated cost and schedule control under a unit-price contract, because it requires evaluation of earned value and actual cost of the lowest level items, while keeping CAs at a higher level for effective management. The sums of the several work items' progression and actual costs should be maintained in a CA by using the RDBMS. In fact, a new regulation in Korea will oblige all major public construction projects to adopt EVMS in the near future, and the current style of contract for pubic works in Korea is lump-sum and unit-price contracts (Jung and Woo 2001).

Utilizing multiattribute keys can help make this process easier since various reports from several different viewpoints can be generated by selectively using the keys. For example, in the budget data structure of the model project, column 1 of Table 2 represents the CA code that is mainly used as a common denominator for cost and schedule control. Columns 2–5 of Table 2 describe the lowest level information for a detailed cost code of account (COA). A combination of CA code (column 1) and cost code (column 6) is the two-attribute primary key for a cost code of account. Under a unit-price contract, transactions for the actual cost usually occur at the lowest cost code of the account level because different cost items in the same CA might be assigned to different organizations (e.g., forms and rebar in the first-floor concrete work in Table 2). However, the budgeted cost for work scheduled (BCWS) and earned value can be measured at the CA level according to different progress measurement methods. Summarized cost reports by work sections can be generated by using column 6 only as a key. This type of report is frequently used and particularly useful for projects under a unit-cost contract.

Many construction business functions are directly interrelated to the cost and schedule control, as previously mentioned. The relations between cost and other business functions, including estimating, materials management, or subcontracting, initiate from the cost code (column 6 of Table 1). In other words, the cost code is a major attribute of primary keys in RDBMS for other business functions. These relations enable the automated data acquisition for integrated cost and schedule control only if related business functions are managed in consideration of CA. This is another reason why a higher level of detail is required for practical viability of integrated cost and schedule control.

An excessive number of attributes in a primary key can cause the performance problems of databases in terms of normalization, which here denotes the "method for identifying the existence of potential problems, called update anomalies" in the database design (Pratt and Adamski 1991). Making good use of the uniqueness of each project can minimize this problem. For example, a description of a budget item may vary slightly (e.g., from *concrete curing to reinforced concrete curing*) in order to make communication explicit in a project. However, the data classified by the same cost code number will not cause serious problems, because the description is not the major attribute for data analysis, while the other attributes such as unit, quantity, cost per unit, and WBS are more important.

The budget cost shown in Table 2 minimizes the multiattribute keys. In fact, the CA code (column 1 of Table 2) is working as a single attribute, but it is multiattribute in its nature since several facets are combined together. This structure is very efficient in terms of RDBMS, because the major indexing of a CA code is in the order of the WBS sequence, but a specific query of partial indexing based on a facet is also possible by the RDBMS.

Even though developing and maintaining a complete coding system that comprises a wide range of classification components is a daunting task, it is a prerequisite requirement for operating the multiattribute keys. A survey for large Korean general contractors (Jung 1998) shows that most large firms actively utilize a set of computerized charts of account for the facets of work sections, materials, and equipment. However, it is also found that less integrity and standardization are attained for the facet codes of facility, space, and element. Nevertheless, increasing emphasis on comprehensive standardization is observed for the purpose of multiproject management and historical database reuse (Jung et al. 2000a).

## Case Study and Findings

In order to evaluate the viability of the proposed "flexible WBS numbering system," a real-world case is analyzed in terms of attained reduction of overhead effort due to the flexibility. The case study uses a construction project of a research center located in a university. The research center mainly has an office building and a laboratory, as depicted in Fig. 2. Specifics of the project include 17,087 $m^2$ of total floor area, a 19-month project duration, and about 12,500,000 dollars of construction cost (6,250,000 dollars for site and architectural works). A general contractor's viewpoint is applied in this case study, and the site and architectural

**Table 3.** Outline of Case Study Project

| Description | Outline | Remarks |
|---|---|---|
| Main use | Research center | Office building and laboratory |
| Location | Suwon City, South Korea | In Sungkyunkwan University |
| Project delivery method | Design-bid-build | With third-party supervisor |
| Contract type | Lump sum and unit price | |
| Construction duration | 2000.01.19–2001.07.31 (19 months) | |
| Site area | 481,264 $m^2$ | |
| Building area | 2,347 $m^2$ | |
| Total Floor area | 17,087 $m^2$ | |
| Structure | Reinforced concrete; precast steel reinforced concrete | Composite precast members used for superstructure in office building |
| Construction budget[a] | 12,500,000 dollars | Construction only |
| Number of subcontract packages[a] | 27 | Civil and architectural 21, electrical 1, mechanical 5 |
| Percent of subcontract[a] | 70% | Amount of subcontracts /total budget |
| Number of staff members on site[a] | 8 | General contractor only |

[a]Descriptions are represented from general contractor's viewpoint.

works only are analyzed, excluding mechanical, electrical, and so on. An outline of the case project is provided in Table 3.

### Evaluating Measures

There might be many different measures for determining the overhead efforts for integrated cost and schedule control. The number of "CAs," the number of "budget accounts," and the number of "operation accounts" are used in this case study in order to quantify the overhead efforts, as these three numbers directly indicate the workload required to maintain the integrated system.

The budget account (BA) in this paper denotes a budget line item. The term of "cost account" is not used for the BA, because "control account" and "cost account" were used interchangeably in the early years of EVMS implementations. The operation account (OA) represents the lowest-level budget items allocated to a specific CA, which cause subsequent clerical transactions (e.g., any entry in journals or books) in the cost control procedure, especially in order to meet the WBS for an integrated cost and schedule control. One single operation account may require many actual transactions because of the different time, different prices, substitutes, or number of installments.

For example, as illustrated in Table 2, if each of two CAs for concrete work (first- and second-floor concrete, CA codes F01W03000S01 and F01W03000S02) has three identical budget items (W03110 CIP forms, W03210 rebar, and W03310 concrete pouring), the number of OAs for these two CA would be six. The number of derivative transactions caused by the six OAs would be much bigger. If they manage the cost ledger according to budget accounts (column 6 of Table 2), while neglecting the control account (column 1 of Table 2), the six OAs would be reduced to three. This assumption implies that the concrete work is managed neither by floors nor by facility units. In order to simulate the varying workload of CAs, BAs, and OAs, three different scenarios are established in terms of the level of detail.

### Conditions for Scenarios

Two major conditions that would influence the level of detail are considered. One is creating larger or smaller CAs. The other is increasing or reducing the number of BAs. Table 4 shows an example of a concrete work for a three-story structure, which considers these two conditions.

Three different cases of organizing CAs are presumed in columns 1 and 2 of Table 4. Case C1 has six very detailed CAs (rows 1–6 beneath the title in column 2 of Table 4) in CPM, as they divide one floor into two different zones. Conversely, in order to reduce the number of CAs, concrete work for three stories can be scheduled together as one CA, as shown in Case C3. Painting can

**Table 4.** Calculating Workloads (Example)

| Control account | | Budget items | | Workload | | | |
|---|---|---|---|---|---|---|---|
| Case | Activity | Case | Items | Case combination | Number of CAs | Number of BAs | Number of OAs |
| Case C1 | 1st floor: A zone concrete | Case B1 | Forms (material) | C1-B1 | 6 | 6 | 36 |
| | 2nd floor: A zone concrete | | Formwork (labor) | C1-B2 | 6 | 3 | 18 |
| | 3rd floor: A zone concrete | | Rebar (mat'l) | C1-B3 | 6 | 1 | 6 |
| | 1st floor: B zone concrete | | Rebar (labor) | C2-B1 | 3 | 6 | 18 |
| | 2nd floor: B zone concrete | | Concrete (material) | C2-B2 | 3 | 3 | 9 |
| | 3rd floor: B zone concrete | | Concrete pouring (labor) | C2-B3 | 3 | 1 | 3 |
| Case C2 | 1st floor concrete | Case B2 | Forms (labor and material) | C3-B1 | 1 | 6 | 6 |
| | 2nd floor concrete | | Rebar (labor and material) | C3-B2 | 1 | 3 | 3 |
| | 3rd floor concrete | | Concrete (labor and material) | C3-B3 | 1 | 1 | 1 |
| Case C3 | 1st, 2nd, and 3rd floor concrete | Case B3 | Concrete structure | | | | |

Note: The number of OAs is not generally the product of number of CAs by number of BAs.

**Table 5.** Workloads of Scenarios (Case Study)

| CSI division | Work section | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of CAs | Number of BAs | Number of OAs | Number of CAs | Number of BAs | Number of OAs | Number of CAs | Number of BAs | Number of OAs |
| 1. *Temporary facilities* | | *3* | *17* | *47* | *3* | *17* | *80* | *65* | *18* | *114* |
| 2. *Site construction* | | *16* | *116* | *154* | *24* | *139* | *209* | *35* | *169* | *235* |
| | Sitework | 14 | 105 | 120 | 22 | 105 | 175 | 33 | 135 | 201 |
| | Planting | 2 | 11 | 34 | 2 | 34 | 34 | 2 | 34 | 34 |
| 3. *Concrete* | | *50* | *17* | *224* | *83* | *31* | *414* | *90* | *31* | *423* |
| | Cast-in-place | 45 | 15 | 220 | 74 | 29 | 407 | 74 | 29 | 407 |
| | Precast | 5 | 2 | 4 | 9 | 2 | 7 | 16 | 2 | 16 |
| 4. *Masonry* | | *19* | *50* | *96* | *32* | *58* | *171* | *72* | *58* | *416* |
| | Masonry units | 8 | 33 | 67 | 13 | 37 | 108 | 34 | 37 | 290 |
| | Stone | 11 | 17 | 29 | 19 | 21 | 63 | 38 | 21 | 126 |
| 5. *Metals* | | *37* | *69* | *264* | *53* | *109* | *409* | *78* | *111* | *594* |
| | Structural framing | 16 | 39 | 225 | 28 | 76 | 363 | 47 | 76 | 531 |
| | Metal works | 21 | 30 | 39 | 25 | 33 | 46 | 31 | 35 | 63 |
| 7. *Thermal and Moisture* | | *33* | *41* | *82* | *46* | *52* | *128* | *73* | *60* | *232* |
| | Waterproofing | 16 | 22 | 47 | 21 | 30 | 81 | 35 | 32 | 132 |
| | Thermal protection | 14 | 12 | 25 | 22 | 12 | 37 | 35 | 18 | 90 |
| | Roofing | 3 | 7 | 10 | 3 | 10 | 10 | 3 | 10 | 10 |
| 8. *Doors and windows* | | *10* | *49* | *101* | *12* | *113* | *126* | *26* | *113* | *238* |
| | Doors and windows | 7 | 33 | 85 | 9 | 93 | 106 | 12 | 93 | 150 |
| | Glazing | 3 | 16 | 16 | 3 | 20 | 20 | 14 | 20 | 88 |
| 9. *Finishes* | | *71* | *168* | *336* | *91* | *193* | *555* | *188* | *204* | *1,016* |
| | Plaster | 27 | 55 | 120 | 33 | 66 | 232 | 75 | 70 | 533 |
| | Tile | 5 | 25 | 25 | 5 | 25 | 25 | 8 | 25 | 40 |
| | Ceiling, flooring, wall | 30 | 68 | 166 | 44 | 77 | 265 | 80 | 82 | 345 |
| | Paints | 9 | 20 | 25 | 9 | 25 | 33 | 25 | 27 | 98 |
| 10. *Specialties* | | *11* | *17* | *25* | *14* | *21* | *30* | *18* | *24* | *57* |
| *Total* | | 250 | 544 | 1,329 | 358 | 733 | 2,122 | 645 | 788 | 3,325 |

be another good example, because the time management requirements for exterior wall painting rarely require schedule monitoring by each story.

Columns 3 and 4 of Table 4 describe three cases of preparing budget items. Case B1 is assumed to have six budget items. In this case, only the items for labor will be subcontracted, and the general contractor is planning to purchase the materials, resulting in workloads for direct materials management. An opposite situation is assumed in Case B3. The general contractor decides to subcontract the entire concrete work (forms, rebar, and concrete) including the materials, labor, and equipment to a specialty contractor so as to reduce the number of budget items into one. As previously discussed, decision making for these considerations varies from project to project. Characteristics of a project, the management policy, and corporate strategy would govern this decision.

Three cases of organizing CAs coupled with three different ways of arranging budget items can generate nine different combinations. Columns 5–8 of Table 4 list the possible combinations. An utmost case is the C1-B1, where each of six CAs has six budget accounts (BAs). Therefore, the number of operation accounts (OAs) for C1-B1 is 36. Another extreme case, C3-B3, having only one BA and one CA for the entire concrete work, indicates that the number of OAs is also one. Note that, generally, the number of OAs is not exactly the product of number of CAs by number of BAs. The number of OAs is determined by totaling the number of BAs in all CAs, and the CAs with similar descriptions (e.g., concrete works) may have different budget items assigned. It is assumed identical in Table 4 for a simple example.

Reducing the number of CPM activities as well as budget line items are substantial recent trends in Korea, as general contractors are handling ever-increasing contracts while restraining the increase of employees (Jung and Woo 2001).

### *Three Scenarios and Implications*

Three different scenarios were then developed using the case study in order to investigate the variation in further detail. The number of CAs, BAs, and OAs of the scenarios are counted under different assumptions. An interview on the job site was conducted in order to incorporate the practical considerations for developing the scenarios.

The first scenario has a high level of detail (larger CAs) with 250 CAs, 544 BAs, and 1,329 OAs, as shown in columns 3–5 of Table 5. Major bulk materials including reinforcing bars, concrete, forms, cement, and sand are included in the subcontracting items. Many CAs for finish works are planned to comprise two or more stories, and zones in the same floor are not considered. The second scenario is in the middle level of detail. Major bulk materials are separated as independent budget items, and most of the activities are scheduled based on each floor. When compared with the first scenario, the number of CAs, BAs, and OAs are increased by 143.2, 134.7, and 159.7%, respectively, as shown in Table 6. The third scenario has the lowest level of detail (smaller

**Table 6.** Summary of Scenarios (Case Study)

| Description | Number of CAs | Number of BAs | Number of OAs | Number of OAs/number of BAs (%) |
|---|---|---|---|---|
| Scenario 1 | 250 | 544 | 1,329 | 244.3 |
| Scenario 2 | 358 | 733 | 2,122 | 289.5 |
| Scenario 3 | 645 | 788 | 3,325 | 422.0 |
| Scenario 2/scenario 1 | 143.2% | 134.7% | 159.7% | – |
| Scenario 3/scenario 2 | 180.1% | 107.5% | 156.7% | – |
| Scenario 3/scenario 1 | 258.0% | 144.9% | 250.2% | – |

CAs with the most detailed data). A few budget items of the second scenario were broken down in further detail in the third scenario. However, the concept of zones is employed for dividing CAs. When compared with the second scenario, the number of CAs, BAs, and OAs are increased by 180.2, 107.5, and 156.7%, respectively. Although it is case specific, the few additions in the space facet element (e.g., zones in the case study) intensively expanded the number of OAs.

It is inferred from the case study that a small increase in the number of CAs or BAs may cause enormous expansion of the number of OAs. Another interesting point is that the overall additional overhead efforts required for integrated cost and schedule control will increase in a geometric progression, because the increased transactions for each OA and the increased schedule update demand in each CA will boost the clerical efforts.

As discussed in the case study, reducing the number of CAs or BAs for integrated cost and schedule control requires rearranging the CPM activities or budget items. This task directly involves changing the classification facets and code numbers such as space (e.g., first floor, second floor, zone A), facility (e.g., laboratory, office building), work sections (formwork, concrete), element (beam, column), and so on. Therefore, the proposed flexible WBS structure can be one of the solutions for handling this complex manipulation.

This is of more importance when dealing with the data in a computerized system. Organizing data in a reusable form enables a multidimensional data analysis, which is known as on-line analytical processing (OLAP). A flexible WBS structure facilitates keeping cost and schedule data integrity for OLAP as well as reducing overhead efforts for integrated cost and schedule control.

## Conclusions

Integrated cost and schedule control has evolved as a primary technique for advanced and systemized project management. However, the increased management efforts required to manipulate detailed data has been the major barrier to practical implementation. The concept of flexible WBS proposed herein can greatly alleviate this problem by reducing the number of control accounts (CAs). Flexible WBS can be most effectively utilized when the characteristics for each work package are thoroughly perceived and the management plan is well defined at the beginning stage of a construction project.

The proposed method is more suitable for general contractors who have to manage their own laborers, materials, subcontractors, and equipment, because it is generally true for general contractors that many different types of data from many different organizations should be controlled in an integrated way. However, the concept of flexible WBS can be applied to all project participants, including owners, construction managers, architects, and subcontractors, for their own effective integrated cost and schedule control under any type of contract.

The benefits of using an integrated cost and schedule control system must be analyzed in a strategic perspective, because it requires substantial overhead efforts. For example, an organization that does not frequently repeat the same type of construction projects may not benefit from this complex system. However, the writers believe that the adoption of integrated cost and schedule control will increase worldwide for construction organizations in order to keep up with the trends of informatization as well as systematic performance measurement.

Different conditions in project delivery systems, contract types, and management policy will also affect the "practicability" of integrated cost and schedule control. Using flexible WBS can not only enhance its practicability, but also maintain valuable historical data for permanent reuse.

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