INTEGRATED COST AND SCHEDULE CONTROL: VARIABLES FOR THEORY AND IMPLEMENTATION

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ABSTRACT
The purpose of this paper is to identify the variables for integrated cost and schedule control in terms of reducing required workload. Potential variables including project delivery system, contract type, level of outsourcing, degree of specialization, progress measurement methods, budget format, management detail, vertical integration, and so on are identified first.

The variables are then reviewed in order to detect any interdependencies. An evaluation of these variables is performed by estimating the potentiality of reducing workloads. Two real-world cases are briefly introduced in order to illustrate the practical application of variables identified in this paper. Details and implications of the case studies are outlined as well.

KEY WORDS
cost control, scheduling, integrated systems, EVMS, workload, variable, theory

INTRODUCTION
Cost and schedule are the two most important concerns for the successful construction project management. These two business functions are closely interrelated because they share a lot of common data in their controlling processes (Rasdorf and Abudayyeh 1991; Jung and Gibson 1999). Therefore, benefits by integrating cost and schedule control have been asserted by many researchers and practitioners.

However, the excessive management effort for 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). In order to maximize the benefits that this integration has to offer, tools and techniques to reduce the workload for integrated cost and schedule control should be investigated in a comprehensive manner.

Several different methods to alleviate this problem have been proposed by researchers. Those include utilizing advanced information technology, automating data acquisition, controlling the level of detail, standardizing work processes, applying flexible WBS, and so on. No single method can be effective enough as each project has different managerial requirements. Moreover, these methods are interrelated with each other. Effective combination of solutions can be easily identified if the variables affecting the workload are systematically understood.

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In this context, the purpose of this paper is to identify the variables for integrated cost and schedule control in terms of reducing required workload. Potential variables were identified first. An evaluation of these variables was performed, and driving factors for different project characteristics are illustrated. Details and implications of the case study are outlined as well.

**EVMS THEORY ADVANCEMENT**

The basic concept of integrated cost and schedule control is utilizing the focal point for the integration of scope, cost, and scheduling (Rasdorf and Abudayyeh 1991; Fleming and Koppleman 1996). According to a document of American National Standard Institute (ANSI), a control account (CA) as the focal point acts for “a management control point at which budgets and actual costs are accumulated and compared to earned value for management control purposes” (EIA 1998).

Benefits from integrating cost and schedule control have been continuously asserted by many researchers and practitioners since it was first promoted in the 1960s. Earned value management system (EVMS), formerly known as C/SCSC by U.S. Department of Defense, is one of the best practices implemented on the real-world projects. Recently, the adoption of EVMS has been gaining popularity, and several national and international standards bodies have started developing EVMS standards. However, this promising concept has not been plentifully investigated in ASCE journals.

The introductory papers related to EVMS include the articles by McConnell (1985) and Stevens (1986). These two papers presented the concept, principal methods, and benefits along with practical issues using cases and examples.

Next group of papers discussed practical issues in further details. Eldin (1989; 1991) analyzed project WBS and numbering systems for engineering and construction projects. Numerical examples were used in order to illustrate the procedure. Singh (1991) added an interesting point of EVMS, which is the management issue for successful implementation. Such issues as change management and role-relationship formulation in an organization were stressed.

The first paper that comparatively analyzed several different methodologies for combining cost and schedule data (i.e. formulating control accounts) was performed by Rasdorf and Abudayyeh (1991). In this paper, issues for “providing a unified view” with an “inexpensive data-processing environment” were discussed, and utilizing information technology for data acquisition was recommended as well. Based on their previous research, Abudayyeh and Rasdorf (1993) developed an automated solution using relational database management systems and bar codes.

Systematic efforts to represent the EVMS components, indices, variances, and their relations in mathematical expressions followed. Carr (1993) developed very detailed equations for the purpose of computer applications. Lee and Yi (1999) introduced mathematical matrices in order to describe the interrelationship between time and cost data sets.

Issues for standard numbering systems were brought up as EVMS data should be shared with many different project participants and across different business functions. Reuse of historical data is also critical. Kang and Paulson (1998) proposed a four level classification system for civil works. The proposed system facilitates EVMS information sharing
throughout the project life cycle. Jung and Woo (2004) developed a flexible work breakdown system that utilizes the standard numbering system while allowing full flexibility in its structure. The major purpose of this flexible WBS was to reduce the EVMS workload. The paper by Jung and Woo (2004) firstly attempted to quantify the EVMS workload.

Finally, an interesting attempt to apply a stochastic model to the progress measurement baseline (Budgeted Cost Work Scheduled – BCWS) was developed by Barraza (2000). It is noteworthy that the accuracy of a planned schedule is very important in order to maintain EVMS indices more meaningful.

Different studies have different research perspectives, scopes, and practical implications. Each study contributed remarkably within its research perspective for the EVMS advancement. Even though the papers outlined above are interpreted within the research interest of the writer, it is inferred that the EVMS research efforts have been narrowed down from concepts into the details such as mathematical arrangements, control account (CA) formulating methods, and automation techniques.

Nevertheless, no previous research addressed one critical issue yet, which is the managerial variables affecting the EVMS workloads.

**EVMS WORKLOADS**

Integration of two different aspects of business functions (cost and schedule) 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.

**SCHEMES FOR WORKLOAD ALLEVIATION**

Therefore, optimizing (or minimizing) the additional effort required for EVMS is the critical success factor for its practical implementation. This optimization can be achieved by 1) **automating data acquisition**, by 2) **reengineering the cost and scheduling control processes**, or by 3) **adjusting the level of details**.

Advanced information technology is a definite solution and a driving force for the recent increasing interest in integrated cost and schedule control worldwide. Automating data acquisition can be obtained by applying data acquisition technologies (e.g. bar code or RFID) or by electronically connecting relevant business functions (e.g. material management or daily work report). However, utilizing information technology (IT) is less specific to a project. In other words, similar tools and methods can be generally applicable to any project.

On the contrary, the scheme of reengineering varies extensively depending on projects, organizations, or localities. For example, EVMS reengineering guidelines for Korean general contractors (Jung et al. 2000), developed based on the results of a survey of seventeen contractors, recommend early budgeting, using 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.
Finally, adjusting the level of detail is also a very project specific matter. Basically, the level of detail is determined by the managerial requirements of each project (Jung and Woo 2004).

Three schemes discussed above should be deliberated in a comprehensive way because they complement each other. Therefore, in order to identify optimization opportunities for a project, general variables of project constraints need to be incorporated.

**MEASURES FOR WORKLOAD ALLEVIATION**

There might be many different measures for determining the EVMS workload. The number of ‘control accounts’ (CAs), the number of ‘budget accounts’ (BAs), and the number of ‘operation accounts’ (OAs) developed by Jung and Woo (2004) are used in this case study.

The 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 BA 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. The 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). One single operation account may require many actual transactions because of the different time, different prices, substitutes, or the number of installments (Jung and Woo 2004).

Table 1 illustrates the number of CAs, BAs, and OAs. An utmost case is the C1-B1 where each of six CAs (rows 1 through 6 beneath the title in column 2 of Table 1) has six

<table>
<thead>
<tr>
<th>Control account (CA)</th>
<th>Activity</th>
<th>Case (Activity)</th>
<th>Item</th>
<th>Case combination</th>
<th># of CAs</th>
<th># of BAs</th>
<th># of OAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1st floor - A zone concrete</td>
<td>B1</td>
<td>Forms (material)</td>
<td>C1-B1</td>
<td>6</td>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>2nd floor - A zone concrete</td>
<td></td>
<td>Formwork (labor)</td>
<td>C1-B2</td>
<td>6</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>3rd floor - A zone concrete</td>
<td></td>
<td>Rebar (mat'l)</td>
<td>C1-B3</td>
<td>6</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1st floor - B zone concrete</td>
<td></td>
<td>Rebar (labor)</td>
<td>C2-B1</td>
<td>3</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2nd floor - B zone concrete</td>
<td></td>
<td>Concrete (material)</td>
<td>C2-B2</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3rd floor - B zone concrete</td>
<td></td>
<td>Concrete pouring (labor)</td>
<td>C2-B3</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C2</td>
<td>1st floor concrete</td>
<td>B2</td>
<td>Forms (labor &amp; mat'l)</td>
<td>C3-B1</td>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2nd floor concrete</td>
<td></td>
<td>Rebar (labor &amp; mat'l)</td>
<td>C3-B2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3rd floor concrete</td>
<td></td>
<td>Concrete (labor &amp; mat'l)</td>
<td>C3-B3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C3</td>
<td>1st, 2nd, and 3rd floor concrete</td>
<td>B3</td>
<td>Concrete structure</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Note that the number of OAs is not always the product of number of CAs by number of BAs. This table is simplified for easy understanding.
budget accounts (BAs). Therefore, the number of operation accounts (OAs) for C1-B1 case is thirty-six. In Table 1, three cases of organizing CAs coupled with three different ways of arranging budget items can generate nine different combinations. Number of OAs for the nine combinations ranges from 1 to 36. When considering the number of transactions (TAs) stemming from these OAs, the variation of workloads for nine different cases is tremendous. Of course, this example is somewhat exaggerated. The two extreme cases (C1-B1 and C3-B3 in Table 1) would not be considered within the same project because of the managerial constraints. More realistic and complex evaluation of CAs, BAs, and OAs is illustrated by Jung and Woo (2004) where they analyzed a real-world project under given managerial conditions.

VARIABLES FOR EVMS WORKLOAD

‘Level of detail’, frequently used in EVMS literature, may best describe the degree of workload required for EVMS. Determining level of detail directly confined within the project characteristics. Those characteristics include contract type, project delivery system, level of outsourcing, budget format, management detail, progress measurement methods, degree of specialization, and vertical integration.

Understanding project characteristics that affect the EVMS workload would provide the practitioners with good starting points where they can alleviate the workload in their projects. Note that, in this study, these variables are investigated from a perspective of the construction company as a general contractor or a CM.

PROJECT DELIVERY SYSTEM (PDS)

Typical types of project delivery system (PDS) as a research variable include Design-Bid-Build (DBB), Design-Build (DB), and Construction Management (CM). As for the EVMS workload, in general, the CM for fee projects have the most control over the numbers of CAs and BAs. In other words, CM people may effectively control the project with less detailed CAs and BAs, while DBB or DB requires more details. This argument is more pertinent to the BA than CA. A DBB or DB project may have less potentiality to reduce the number of BAs under the given project conditions than to reduce the number of CAs.

Table 2: Potential to Reduce EVMS Workload

<table>
<thead>
<tr>
<th>Variable</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDS</td>
<td>DBB</td>
<td>DB</td>
<td>CM</td>
</tr>
<tr>
<td>Contract Reimbursable</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Outsourcing</td>
<td>Low</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Speicalization</td>
<td>High</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Measurement</td>
<td>Physical</td>
<td>L</td>
<td>L</td>
</tr>
</tbody>
</table>

* CA: Control Account, BA: Budget Account
* Scores for potentiality: L - Low, M - Medium, H - High
In this sense, the first low (PDS) of Table 2 is filled out. The ‘H’ denotes relatively high potentiality (the ‘M’ and ‘L’ represent medium and low, respectively).

Therefore, the ranking (H, M, L) indicates the opportunity to reduce workload. For example, if the PDS of your project is DBB, you have very low opportunity (L) to reduce the number of BAs according to Table 2.

**Contract Type**

One of the roles of construction contract is allocating risk among project participants. Thus, the contract type affects the level of cost and schedule control. Among three different contract types in Table 2, lump-sum project may have the most chance to reduce the workload. In the cost-reimbursable or unit price contract, detailed data should be maintained, which indicates relatively low potentiality to reduce the number of BAs. As discussed, the number of CAs is easier to modify, but the number of BAs is relatively more difficult to decrease.

**Outsourcing**

Outsourcing engineering or construction packages to specialty designers/contractors directly affects the workload. It is obvious that a general contractor highly outsourcing would focus on oversight management of the subcontractors. Therefore, the possibility of alleviating EVMS workload may increase in proportion to the level of outsourcing. Another issue here is that the general contractor can still maintain detailed data provided by the subcontractors while using limited number of CAs and BAs for its management purposes.

**Specialization**

Specialization in terms of the construction product type (constructed facilities) for an organization also requires different level of detail. This variable is related to the corporate strategy. Regardless of other variables including PDS, contract type, outsourcing, and progress measurement method, a highly specialized company would pursue accumulating detailed cost and schedule data.

**Progress Measurement Method**

Three types of progress measurement methods are compared in this paper; those are physical measurement, earned value, and estimated percent complete. This classification of measurement methods directly represents the degree of measurement accuracy. Therefore, chances for reduce the workload under physical measurement is extremely limited.

**Others**

Other variables such as ‘budget format’ and ‘vertical integration’ are also good candidates. Budget format mainly indicates whether the budget is organized by work sections (commodities) or by the facilities. It is an important concern for EVMS implementation. Vertical integration deals with the logical or organizational functions throughout project life
cycle (e.g. planning, design, procurement, construction, operation and maintenance, and disposal).

However, budget format is inherent in the way of counting CAs and BAs in this study. The vertical integration is also somewhat interrelated with PDS, outsourcing, and specialization. Therefore, this study ruled out these two variables.

VALIDATION AND IMPLICATIONS
Effects of five variables discussed above may be a reasonable speculation. However, a survey questionnaire would more systematically validate the variables (which is planned but not performed yet). Even though less objective, this study evaluated the practical viability of the proposed variables using simple statistics and two case studies. The writer have involved in both case studies as a principal investigator or a consultant. The concept of ‘action research’ is applied as a research methodology in this paper.

IMPACT OF VARIABLES
In order to evaluate the degree of influence in terms of reducing workload, each variable in Table 2 was scored based on the writer’s experience and observation. Each variable has three cases, and each case is evaluated in two criteria (i.e. control account and budget account). Five different variables coupled with three cases generate 243 (3^5) combinations. Scores of potentiality for each combination (e.g. CM - Lump-sum - High outsourcing - Low specialization - Estimated percent complete method) are calculated as follows.

First, the potential to reduce the number of CA and BA is scored using a scale of high, medium, or low as described in Table 2. Five, three, and one were assigned for this scale as high, medium, and low, respectively. The sum of ten scores for each combination (in the same row in Table 3) is then defined as the Potentiality Index for Alleviating EVMS workload (PIA) as shown in Table 3. The PIA score ranges from 14 to 46 if the evaluation in Table 2 is applied. This index indicates the relative easiness of reducing workload under given project conditions. Note that the PIA only considers the numbers of CAs and BAs. If the OAs and TAs are taken into account, the variance will be immense.

It is very obvious that the variable with the widest variation in its scores assigned in Table 2 will affect the PIA most in Table 3. In other words, ‘outsourcing’ and ‘specialization’ must have high correlation with PIA. The coefficients of correlation for PDA, contract, outsourcing, specialization, and measurement are 0.45, 0.30, 0.52, 0.52, and 0.38, respectively, for the 243 combinations.

Therefore, ‘outsourcing’ and ‘specialization’ are the most influencing factors that facilitate workload alleviation. This fact is also supported by the following case studies.

CASE STUDIES
Two case studies are introduced in order to examine the variables. These two case studies have several features in common. Two general contractors of the case studies have been developing company-wide multi-project EVMSs. They are both top ten general contractors in Korea, and most of their works are DBB. Most often used contract type is ‘total cost with unit price’ that is popular in Korea (Lee et al. 2004). The companies highly outsource their
construction work packages to the specialty contractors and material suppliers. The major differences between two case study companies are the areas of specialization and the methods of progress measurement.

The first case is an effort by “S” company in Korea, which has pursued to equip job sites with an integrated cost and schedule control system since 1998. The S company is specialized in building construction. The company’s managerial policy emphasizes overall soundness of cost and schedule performance. Therefore, accurate indices are more important than particular details. Under these circumstances, an attempt to alleviate EVMS workload was focused on reducing the number of CAs considering the high level of ‘outsourcing’ because other variables were very difficult to change. As described in Table 2, the higher outsourcing provides the higher potentiality for EVMS workload alleviation. Formulating CAs is carefully reviewed considering the number of subcontractors and characteristics of tasks in order to reduce the number of CAs. After running several pilot projects, it was found that maintaining accurate progress data for each CA is important. Another research followed in order to address this issue in 2003. Evaluating CAs in terms of their micro and macro accuracy of progress measurement was performed (Jung et al. 2004). Based on this research, the second attempt to alleviate workload was made by changing the measurement methods. They had used the physical measurement method only, as an official method. However, earned value methods that have medium potentiality (in Table 2) were introduced in order to reduce the workload. The result was also used to standardize and to automate CA generation for the company (Jung et al. 2004). In the first case, the variable of ‘outsourcing’ and ‘progress measurement method’ successfully located the areas for workload alleviation.

The second case is an on-going development of “P” company. The EVMS system is planned as part of a large-scale business process reengineering (BPR). Unlike the first case, the P company is specialized in industrial construction, even though the company constructs

<table>
<thead>
<tr>
<th>No</th>
<th>PDS</th>
<th>Contract</th>
<th>Outsourcing</th>
<th>Specialization</th>
<th>Measurement</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CA</td>
<td>BA</td>
<td>CA BA</td>
<td>CA BA</td>
<td>CA BA</td>
<td>PIA</td>
</tr>
<tr>
<td>1</td>
<td>CM</td>
<td>Lump-sum</td>
<td>High</td>
<td>Low</td>
<td>Estimated</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>5 3</td>
<td>5 5</td>
<td>5 5</td>
<td>3</td>
</tr>
<tr>
<td>168</td>
<td>DBB</td>
<td>Lump-sum</td>
<td>High</td>
<td>Medium</td>
<td>Physical</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>5 3</td>
<td>5 5</td>
<td>3 3</td>
<td>1</td>
</tr>
<tr>
<td>243</td>
<td>DBB</td>
<td>Reimbursable</td>
<td>Low</td>
<td>High</td>
<td>Physical</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>3 1</td>
<td>1 1</td>
<td>1 1</td>
<td>1</td>
</tr>
</tbody>
</table>
residential housing, infrastructure, and commercial buildings, too. An interesting fact is that the company utilizes different EVMS details for different types of construction. The decision is largely based on the variable of ‘specialization’. The number of CAs in industrial construction is much greater than that in infrastructure construction. However, in order to reduce workload, an intensive earned value (the variable of measurement method) is adapted to the industrial construction projects at the same time. For the second case study, the variable of ‘progress measurement method’ was used to reduce the workload for industrial construction while the variable of ‘specialization’ was adapted for other types of construction. In other words, different variables are used for different types of construction.

For both case studies, ‘PDS’ and ‘contract type’ were not the major concern because the companies have little control over these two variables.

CONCLUSIONS
Reducing workload is a crucial issue for EVMS implementation on the job sites. However, this important issue has not been comprehensively addressed. Understanding project characteristics that affect the EVMS workload would provide the practitioners with good starting points where they can alleviate the workload in their projects. In this context, this paper identified and examined the major variables of EVMS.

Undoubtedly, five variables of PDS, contract type, level of outsourcing, degree of specialization, and progress measurement methods can not be modified only for the purpose of EVMS. However, it is noteworthy that different variables can provide various chances of EVMS workload alleviation. Therefore, the variables should be thoroughly reviewed.

This study evaluated the five variables by using simple measures and by analyzing two case studies. Among the five variables, ‘outsourcing’, ‘specialization’, and ‘measurement method’ are in-house strategic decisions of an organization. Therefore, it is also found that corporate strategy and managerial requirements are important in designing an effective EVMS. This fact is strongly supported by Jung and Gibson (1999), where they developed an information systems planning methodology.

Finally, optimizing the workload needs to incorporate automating data acquisition, reengineering the cost and scheduling control processes, and adjusting the level of details, as a whole. Again, this optimizing would make the EVMS implementation more viable and effective.

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