Management of Daily Progress in a Construction Project of Multiple Apartment Buildings

Yong-Cheol Yang¹; Chan-Jung Park²; Ju-Hyung Kim³; and Jae-Jun Kim⁴

Abstract: This paper presents the methods used and a case study of a project management system (PMS) to manage daily progress in the construction of multiple apartment buildings in South Korea. A dilemma encountered in previous research in the field of progress management is that efforts to enhance data accuracy cause the data handling workload to soar. A main feature of the method presented by the writers for calculating the budgeted cost work schedule is to allocate the project budget into control attributes, activities, and tasks that are defined in a work-packaging model, according to daily weight value. The method offers enhanced practicability by reducing data-handling workloads while not sacrificing the rationale of progress management. The work-packaging model is designed to enable project managers to acquire and process data for progress management at various levels of detail. The budgeted cost of work performed is measured daily at the tasks level using the earning percentage rate from daily work reports. The implementation of PMS focuses on functions to distribute the budget according to daily weight values and acquire the earning percentage from the daily work report. The PMS was applied to a construction project of 54 apartment buildings in South Korea. The case study of its use shows that company headquarters and managers in the field can acquire data for progress management without additional data-handling workloads, and can analyze the progress daily at various levels of detail.

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Introduction

In South Korea, approximately 500,000 residential dwellings are constructed annually, and 90% of these (450,000 residences) are apartments (Ministry of Construction and Transportation 2005). Apartment developments tend to be planned as blocks consisting of multiple apartment buildings and common facilities such as parking lots and communal areas. For this reason, multiple apartment buildings construction projects make up the bulk of business for major construction companies, roughly 50% of annual turnover. Thus, the timely management of progress is important to finishing a project within its budget.

The methods for progress management of measuring planned and actual costs over a project’s schedule have been extensively researched (Clark and Lorenzoni 1978; Rasdorff and Abudayeh 1991; Barrie and Paulson 1992; Carr 1993). The general process for managing construction progress is to define tasks at the lowest level of detail, to allocate resources to these tasks, and to calculate the budgeted cost of work scheduled (BCWS) by multiplying the quantity of resources for tasks by the unit prices of resources. The budgeted cost of work performed (BCWP) is measured by updating the work progress of tasks. The variance between BCWS and BCWP is analyzed for progress control.

However, for a multiple apartment buildings construction project, the number of tasks is too large to define and control them individually, as dozens of apartment buildings are constructed. In these cases, the cost and schedule data of numerous tasks from several apartment buildings construction sites must be processed at the same time. The challenge is that, even for a relatively simple project, attempting to keep cost records to minimum work levels results in an unmanageable cost system and the imposition of unnecessary extra work on material handling (Eldin 1989). The amount of detailed data needed is so large that problems and resistance have occurred (Moder et al. 1983). For this reason, planning and controlling the level of detail should be determined considering the efficiency of data handling.

Despite recognition of the need to manage the schedule and cost data of multiple apartment buildings construction projects, this has not been implemented in the systematic approach due to the challenges stated earlier. The writers present a method to control cost and schedule data at the lowest level of detail without additional data-handling workloads, to achieve accurate planning and control. The key feature of the method is to allocate the budget, instead of resources, at lower levels according to weight value in order to calculate the BCWS and to update the daily progress of tasks for measuring the BCWP. This method can increase data-handling workloads unless practical approach and method to manage cost and schedule data are introduced. Meth-
ods from previous research and current practices for controlling the progress of multiple apartment buildings construction projects in South Korea are likely to present a solution for practicability.

This paper describes a new method and reviews project management systems (PMS) currently in use for managing the progress of multiple apartment buildings construction projects. The new method maximizes the practicability of progress management and is supported by theoretical rationale in the field of progress management.

Theories on Progress Management

Progress is measured by analyzing schedule and cost data, which are interrelated and time dependent. For this reason, the individual tracking of either is not useful to construction managers. An integrated approach which enables them to acquire, store, and present information in a timely manner (Rasdorf and Abudayyeh 1991), has been continuously studied by researchers. The following subsections present a theoretical background for progress measurement and the integration of cost and schedule control.

Measurement of Work Progress

The weighted percent complete (WPC) method (Clark and Lorenzoni 1978) is widely used to determine work progress of a construction project. The computation steps of the WPC method are as follows: (1) to assess the progress (percent of completion) of a work item (e.g., a footing); and (2) to multiply the percent completed by the weight factor (WF) to determine the WPC for each work item. The WF is computed as the ratio of the budget of a work item to the total budget of work items of the same type (e.g., the WF of three footings is 0.32, 0.64, and 0.04 for the first, second, and third footings, respectively). However it does not explicitly address the breakdown of a work item (e.g., a footing) into its subcomponents (e.g., excavation, forming, rebar, and concrete). Neither does it clearly establish assessment rules to evaluate such a breakdown objectively (Eldin 1989).

Stevens (1986) presented a method to display a project’s cost profile and accomplishments curve on the same graph. In the graph, if the actual cost expenditure is less than the planned cost, an under expenditure is recorded. The magnitude of an under expenditure is equal to the difference between the two points on the cost scale. A shortcoming of the method is that the performance curve does not represent the actual work progress, although the method does offer an improvement over graphical progress reporting.

Eldin (1989) attempts to enhance the objectivity, accuracy, and practicability of the model presented by Clark and Lorenzoni (1978) by distinguishing the events used to measure earned value (EV). He sets control points throughout the life cycle of work items and develops earning rules for realizing these events. For instance, a footing foundation may include events such as excavation, forming, placing steel reinforcing bars, and concrete pouring. The EVs of each event can be expressed as a percentage. When excavation is completed, the earning percentage is 5%, formwork 10%, reinforcement 35%, and concrete 50% of the total progress. Eldin (1989) suggests that the method is practical because it only requires data that can be acquired from visual inspection of the project site. However, estimating progress by inspecting a site can also be subjective, and the level of control points for quantity distribution and schedule are not clear.

Barrie and Paulson (1992) presented a method to calculate progress which multiplies the percent of completed work items by the weighted value of manpower. The method uses the weighted value of manpower instead of costs because the latter can change over time, causing the monitored target to become unclear.

Cost Control and Schedule Control Integration

Control refers to the determination of whether a project has gone as intended, by calculating variances between actual cost and progress and planned budgets and schedules (Carr 1993). In progress control, base measures are produced directly from plans that measure actual progressions. In general, base measures are BCWS, BCWP, actual cost of work performed (ACWP), budget at completion (BAC), and estimate at completion (EAC). From these base measures, variances are used as decision criteria and interpretation indicators for judging the current status of a project. Cost performance index (CPI=BCWP/ACWP), schedule performance index (SPI=BCWP/BCWS), cost variance (CV=BCWP-ACWP), schedule variance (SV=BCWP-BCWS) and variance at completion (VAC=BAC-EAC) are derived measures. Concerns have developed as to the practicability and accuracy of these concepts implemented in real projects.

Practicability depends on the level of accounting at which the budgeting and scheduling are performed and mechanisms which connect the two. These attributes are normally defined from the work breakdown structure (WBS). However, the breakdown of work items frequently does not match the breakdown of cost item, and thus their integrated control cannot be implemented (Teicholz 1987). As a solution, Teicholz (1987) presented a mapping mechanism between cost breakdown structure (CBS) and WBS. In the map, a cost account of the CBS is allocated to given tasks on the WBS. Hendrinks and Au (1989) attempted to link the two parameters directly in a matrix, in which not only linked but also isolated work items could be easily analyzed.

Work-Packaging Model

Despite the contribution of research attempting to link the accounts of cost and tasks in a schedule with the aim of integrating cost- and schedule-control, practicability has been a challenge. It seems obvious that the accuracy of integrated control would be enhanced if the attributes were defined at the task level, the lowest level of WBS (e.g., lifting, placing, and removing forms under the activity known as “formworks”). However, this method is impractical because of the large data acquisition and handling burden. In addition, comparison between planned and actual progress at levels higher than the task level is necessary, although data should be collected at the task level. Thus, tasks need to be grouped into appropriate levels of detail. The work-packaging model was developed by the National Aeronautics and Space Administration and the Department of Defense. In the initial model, the concept of activity-based cost control was used; it has since been modified to present a single account by adding cost data to the WBS (Rasdorf and Abudayyeh 1991). The single account is determined at a higher level than the task or activities level and becomes the denominator for monitoring progress.

Challenges

The philosophy and methods for estimating progress from the perspective of cost- and schedule-control integration are plentiful.
in the literature. A key factor is to develop a system to acquire data for base measures at the lowest level in order to enhance accuracy without incurring cumbersome data-handling workloads. For managers, measures derived at an appropriate level of detail should be provided in the system, which can be implemented by means of a tailored work-packaging model that reflects the characteristics of a project.

Investigation into Current Practices

As part of the writers’ analysis for developing a PMS that is able to overcome challenges in progress management and that is also specialized for multiple apartment buildings construction projects in South Korea, current practices for progress management were investigated. As samples, 25 construction sites of 10 construction companies ranked among the top 100 best construction companies in South Korea were randomly selected. The investigation was conducted from October 2002 to April 2004. The investigation focused on scheduling, the production of basic measures (i.e., BCWS, BCWP, and ACWP) and control of the variance between basic measures.

A unique feature of apartment construction projects in South Korea needs to be considered to understand the investigation results. In general, an apartment consists of housing units with the same floor plan. A multiple apartment buildings block consists of apartments with similar patterns for floor plans. As a sequence, the type of work and resources show a unique pattern over the entire project. For this reason, field staff members group activities by floor or apartment and manage the work group accordingly.

**Scheduling**

The basic attribute for scheduling was a higher level of activity with basic floor units of each apartment as seen in Fig. 1 (e.g., 2–3 floors of concrete work abbreviated as “2-3F Con’c” in Fig. 1). Schedules at the sites are generally expressed using Microsoft EXCEL bar charts.

For finishing work, the schedule for just one apartment is given; it is used as a reference for other apartments because the number of activities for all apartments in the finishing stage would be too much to express in a single bar chart. For this reason, it is difficult to know the starting point of each activity, relationships between them, their duration, and critical paths in the finishing stage. These problems could likely be solved by using computer applications for project management. At the beginning of construction, scheduling data are prepared by the progress management teams at headquarters and presented in file formats of the computer applications. However, the applications have not been used at the site due to the workload of updating data as the project proceeds.

**Calculation of BCWS and ACWP**

Fig. 2 is an example of BCWS recorded in EXCEL. The BCWS is calculated from CBS accounts. The weight value of an apart-
The actual costs of works completed by the end of month are aggregated. The sum of actual costs is the ACWP. Its purpose is to prepare the payment report rather than to measure or analyze the project’s progress.

Most field managers prefer to use Excel for recording and processing cost data, notwithstanding the introduction of specialized computer applications for project management. Cumbersome workloads associated with data update in the commercial project management applications makes managers hesitant to use them. Thus, they try to handle not only cost but also scheduling data using EXCEL.

### Problems and Lessons

Under the methods investigated, integrating cost- and schedule-control for the management of daily progress seems impossible for three reasons. First, the level of control attributes in the WBS is too high to provide the data necessary for progress management. In particular, finishing works are not subdivided for individual apartments, activities and tasks. As a sequence, the accuracy of BCWS is not assured, as it is calculated subjectively by field staffs rather than by a mechanism to connect the detailed data estimating the budget and schedule. Second, the budgets of activities are evenly distributed by month as shown in Fig. 2. The main reason is that the same floor plan is repeated over floors and thus types of work show a pattern in monthly base. As a sequence, the budget is evenly distributed to the upper level of WBS according to the experience. In that case, the BCWS is not likely to be accurate from the beginning in a daily or weekly base. At a single project, the monthly differences between BCWS and ACWP can be ignorable. However, at the level of a construction company, the aggregated daily or weekly differences between BCWS and ACWP (or ACWP) of all projects are significant. Third, the BCWP is not currently measured. Instead, the ACWP is measured but the ACWP can only be updated monthly. Thus the variance between BCWS and ACWP can only be determined at the end of month. Analysis of a project’s progress over long intervals makes it difficult to track the actual situation on site and to identify delays in the work.

The investigations elucidated the specifications of the work-packing model and the preferred way to acquire and process relevant data. The floor-base work-packaging model is practical, as activities and tasks are repeated in a similar pattern floor by floor in an apartment building construction project. Given that the detailed budget and progress data can be obtained from the lowest level of WBS and CBS, the work-package should be defined at the lowest level of detail. However, additional data-handling workloads due to the detail of the work package are not allowed if practicability is to be secured.

Various reports have been produced on-site, the data from which can be used. For instance, the bill of quantity gives the quantity of resource items and their cost at the level of activity. The daily work report is another useful source of data on the daily progress of work. If the rationale and a mechanism to link the budget of control and daily progress exist, the cost control and schedule control can be integrated.

The concept of weighted values needs to be considered further.
The budget and progress have been distributed according to their weighted values in the projects investigated. Field staffs are familiar with this concept, and its rationale can be derived from previous research (e.g., Eldin 1989).

Proposed Method

The writers have developed a method of measuring and analyzing the progress of multiple apartment buildings construction projects while reducing data handling workloads. The key feature of the method is a work-packaging model that is developed by considering the lessons from the field investigation and which takes its rationale from research in the field of progress management.

Based on the work-packaging model, techniques to calculate the BCWS and to measure the BCWP daily are developed.

Work-Packaging Model

According to the investigation on current practices, the highest level of WBS for multiple apartment constructions consists of civil work, landscaping work, common infrastructure, parking lots and apartment buildings. The lower level of WBS is defined similar to other construction projects as shown in Table 1.

A unique feature of the WBS is that, according to the characteristics of work types, the criterion to group activities varies. For instance, activities related to reinforced concrete work are managed floor by floor, but tile work is done in 10-floor intervals. However, the criterion to divide the work group at the intermediate level of work in the WBS in Table 1 is unclear. For instance, the plaster work group is divided according to types of elements (e.g., wall plaster and room plaster), while the masonry work group is divided by types of materials (e.g., blocks and bricks).

Table 1. Conventional WBS of an Apartment Building

<table>
<thead>
<tr>
<th>Work group</th>
<th>Intermediate level of work group</th>
<th>Activity</th>
<th>Controlling floor units (number of floors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete</td>
<td>Reinforced concrete</td>
<td>From work</td>
<td>1</td>
</tr>
<tr>
<td>Masonry</td>
<td>Blocks</td>
<td>Blocks</td>
<td>1</td>
</tr>
<tr>
<td>Bricks</td>
<td>Masonry</td>
<td>Masonry</td>
<td>5</td>
</tr>
<tr>
<td>Plaster</td>
<td>Cement paste</td>
<td>Cement paste</td>
<td>3–5</td>
</tr>
<tr>
<td>Wall plaster</td>
<td>Window and door mortar</td>
<td>Insulating mortar</td>
<td>5</td>
</tr>
<tr>
<td>Room plaster</td>
<td>Floor insulating mortar</td>
<td>Floor mortar</td>
<td>10</td>
</tr>
<tr>
<td>Concrete</td>
<td>Concrete</td>
<td>Concrete</td>
<td>1</td>
</tr>
<tr>
<td>Water</td>
<td>Liquid proof</td>
<td>Liquid proofing</td>
<td>3–5</td>
</tr>
<tr>
<td>proofing</td>
<td>Sheet proof</td>
<td>Sheet proofing</td>
<td>3–5</td>
</tr>
<tr>
<td>Calking</td>
<td>Waterproof calking</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Tile</td>
<td>Wall tile</td>
<td>Bathroom, kitchen tile</td>
<td>10</td>
</tr>
<tr>
<td>Floor tile</td>
<td>Bathroom, floor, balcony</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

The authors designed a work-packaging model by simplifying these criteria and introducing controlling floor units. The model is fundamentally based on the CBS. The lowest level of the CBS is the cost reported on the bill of quantity. There, the quantity of resources and their costs are presented at the tasks level of the WBS. A work group in the CBS is conducted by a specialized contract. A work group becomes a package for subcontracting. In general, these two are matched one-to-one.

However, scheduling at the tasks level is impractical. As a solution, the control attribute, which is the combination of work group and controlling floor unit, is defined for scheduling. The budget of the control attribute is the aggregated cost of tasks that fall under it. Fig. 3 is the work-packaging model designed by the writers.

Core Process

Based on the work-packaging model, the writers have developed a method to manage the daily progress and explain its rationale in the following subsections according to the process sequence as follows:

1. Scheduling control attributes;
2. Allocating the budget of control attributes into daily budgets according to daily weighted values;
3. Calculating the BCWS by accumulating the daily budget of a control attribute at a control point;
4. Measuring work progress in terms of earning percentage and input this estimate into the daily work report. The earning percentage at a control point (i.e., task) is defined from the bill of quantity, and BCWP is measured at this stage; and
5. Analyzing the variance between the BCWS and BCWP.
Table 2. Duration of Control Attributes in an Apartment Building

<table>
<thead>
<tr>
<th>Work group</th>
<th>Control attribute</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete</td>
<td>Foundation</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>1st floor</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>2nd floor</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>3rd floor</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>20th floor</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>PH2</td>
<td>13</td>
</tr>
<tr>
<td>Masonry</td>
<td>1–5F masonry</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>6–10F masonry</td>
<td>15</td>
</tr>
<tr>
<td>Plaster</td>
<td>1–5F inner wall</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>6–10F inner wall</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1–5F stairway room</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>6–10F stairway room</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2–10F floor plaster</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>11–20F, 1F plaster</td>
<td>7</td>
</tr>
<tr>
<td>Water proofing</td>
<td>2–5F water proofing</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>6–10F water proofing</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Roof water proofing</td>
<td>10</td>
</tr>
<tr>
<td>Tile</td>
<td>2–5F tile work</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>6–10F tile work</td>
<td>12</td>
</tr>
</tbody>
</table>

Scheduling

The duration of the control attribute is estimated by considering the sequential order of work activities, the quantity of work, experimental data, and the opinions of specialists. Table 2 shows an example of the control attribute’s duration.

Reinforced concrete work, the most essential part of construction, is generally processed in a 10-day cycle and consists of about 10 activities. Each activity takes 1 or 2 days. Once reinforced concrete work is finished in the upper floors, the masonry, plaster, Korean floor heating, windows, painting, wallpaper, and furnishing work in the lower floors succeed in order. For instance, the masonry work of the first floor starts after the reinforced concrete work of the seventh floor is finished. Once the relationship between tasks and the duration of each is determined, scheduling can be conducted using commercial project management applications like Primavera Project Planner or MS Project.

Allocating Budget to Control Attributes and Calculating BCWS

In South Korea, at the construction planning stage, the bill of quantity is prepared by the quantity surveying teams at a company’s headquarters. There is no mechanism for solidly integrated connection between the cost and schedule at this stage. The data-handling workload associated with integrating the cost- and schedule-control was mentioned as a main factor diminishing the practicability of the proposed method earlier in the paper. As a solution, the writers suggest a technique to allocate the budget to the control attributes according to weight values instead of allocating resources.

The resource allocation then can be performed in two steps. The first step is to allocate resources by controlling floor units. For example, the total amount of concrete is allocated to each floor because the controlling floor unit for reinforced concrete work is 1 floor. For masonry work, the total amount of blocks is allocated to each floor unit. The second step is to divide the resources allocated by controlling floor units into the activities. For example, the reinforced concrete works of the 1st floor include erecting and placing forms, rebar work, etc. However, in many cases, the duration of these activities is 1 or 2 days, and it seems less efficient to allocate resources for only 1 or 2 days of work.

Therefore, instead of allocating resources in the second step, the budget of the control attribute is distributed to activities according to their weighted value. The weight value of activities is produced from the ratio of the budget of an activity (e.g., $300 for Activity 1 in Table 3) to the budget of the control attribute (i.e., $1,000 in Table 3).

Currently, the weight values of activities are calculated from the bill of quantity and registered in the database management systems of the PMS developed by the authors. Its use will be explained in the next section of the paper. For multiple apartments’ construction, the weight value calculated for a representative apartment can be reused in other apartments that have similar floor plans and resources allocated.

The schedule chart is drawn based on the control attribute. The daily budget of the control attribute can be calculated from the distributed budget of the control attribute according to the daily weight value of activities. To calculate the daily weight value, an activity’s overall weight value is divided by the activity’s expected duration, if more than 1 day. In Fig. 4, the duration of Activity 1 is 2 days and its weight value is 0.3 from Table 3; thus, its daily weight value is 0.15 (i.e., 0.3/2). If the budget of the control attribute is $1,000, the daily budget of the first day is $150 (i.e., $1,000 × 0.15). By using the daily weight value, the budget of the control attribute can be divided at the level of activities while the budget of activities is not calculated individually. BCWS is the accumulated daily budget of all control attributes to a control point.

Measuring BCWP and Analyzing the Variances

The BCWP is measured at the level of individual tasks. The concept of the quantitative technique presented by Eldin (1989) is
used, but the control point in Eldin’s method is replaced by the task. Table 4 shows the relationships between the weight value of tasks and activities.

The information is derived from Table 3 and Fig. 4. The sum of earning percentages of tasks under an activity is 100%. The sum of weight values of the activities under a control attribute is 1. The weight value of a task is calculated by multiplying its earning percentage by the weight value of the activity.

If a task is finished, this means that the budget of a control attribute is spent according to the ratio of the weight value of its tasks to the budget of the control attribute. For example, in Table 4, if the budget of a control attribute is $1,000 and only Task 1 is finished, the earned value of the day is $150, i.e., $1,000 \times 0.15$.

In this case, the variance between BCWS and BCWP is nil, as the BCWS for day 1 is $150$ in Fig. 4.

Once the BCWP can be measured daily, the variance between the BCWS and BCWP can also be analyzed daily. Given that the daily work report is one of the essential documents for construction projects in South Korea, as it records daily progress, the daily earning percentage can be obtained to measure the BCWP. This relieves the burden of additional data handling workloads.

### Project Management Systems Currently in Use

The writers developed the PMS and applied this to a building project of 54 apartment buildings, 26 underground parking lots, and 4 commercial buildings. Apartment buildings comprised of 3,600 housing units of four types of floor plan. The project duration was 28 months. This is one of the largest multiple apartment construction projects in South Korea.

### Scheduling

Scheduling is done at the level of the control attribute as shown in Fig. 5. Types of control attributes in the schedule charts for each apartment building construction are similar. The number, name and starting date of attributes of a type vary according to the location of an apartment building, number of its floors, number of units in a floor and starting date of its construction. The number of activities for one apartment building is about 200. These activities are construction only and construction management activities are not included. A master schedule chart is drawn for 54 apartment buildings and necessary data are translated from the schedule charts of each apartment building. The schedule for other activities such as earthwork, civil work, parking lots, common facilities, and community spaces is added to it.

### Table 4. Weight Value of Tasks

<table>
<thead>
<tr>
<th>Activity number</th>
<th>Weight value of activity</th>
<th>Task number</th>
<th>Earning (%)</th>
<th>Weight value of tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
<td>1</td>
<td>50</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>30</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>20</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>4</td>
<td>40</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>60</td>
<td>0.12</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>6</td>
<td>100</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Fig. 5. Standard schedule chart of an apartment
A CPM network schedule chart presented in Fig. 5 of an individual apartment building is made using Microsoft (MS) Project. Given that commercial scheduling-oriented software makes scheduling and displaying schedules convenient, the scheduling is conducted using MS Project. To effectively deal with the numerous data on resources and costs, it is better to use the tailored PMS developed by the writers rather than commercial scheduling software programs (e.g., Primavera Project Planner or Microsoft Project). In order to implement the proposed method by the writers, the budget should be distributed according to weight values of all tasks or activities under a control attribute. However, commercial software programs provide a function to distribute no less than 10 weight values and there are control attributes with more than 10 tasks or activities. The proposed PMS enables to handle 250 weight values. These weight values need to be systematically managed in a database due to sizable numbers and these would be used for monitoring and reporting planned and actual cost. The authors implement it and the detail will be explained in the following subsections.

**Budgeting**

When scheduling and budgeting are conducted simultaneously, much effort is needed to integrate them. As a solution, the scheduling is done first and then the budget is distributed at the levels of control attributes, activities, and tasks. Budgeting based on the bill of quantity is conducted. A resource for the entire project is divided into sections of work (Sectors 1–6) and apartment buildings according to its weight value. To save time, an automatic function for the distribution of a resource into controlling units (e.g., a floor) is developed.

Fig. 6 is the screen that captures this function in the PMS. Fig. 6 shows the total quantities of certain types of deformed bars (e.g., 10 mm) are distributed to each floor of an apartment (i.e., No. 201 apartment in Sector 2 in Fig. 6).

**Connecting the Budget of Tasks and the Control Attribute in the Schedule by Grouping Tasks**

The items in the bill of quantity, compared to the control attribute of the schedule chart, have many more items and they do not correspond to each other one-to-one. For example, the detailed types of work for reinforced concrete consist of formwork, rebar work, and concrete pouring, but the schedule chart indicates it as a single structural work. Such a difference is solved by devising a function to group relevant tasks and elements. Fig. 7 is an example of this grouping.

In the PMS, if a column title (e.g., the third floor) is double clicked under the activity section (e.g., reinforced concrete work), an interface window pops up prompting the elements (e.g., wall, stairway rooms, slab etc.) as required. The aggregated budgets of these items (e.g., the third floor unit No. 303 reinforcing bar) then becomes the budget of the control attribute in the schedule chart of MS Project.

**Measuring BCWS and BCWP**

The files including schedule charts are loaded on the PMS and then the start dates, finish dates, and WBS code of each control attribute.
attribute is imported from the schedule file. In the PMS, the total budget is distributed to control attributes according to the daily weight values.

Fig. 8 shows the daily weight value distributed to each control attribute. The cumulative budget distributed among various control attributes is the daily BCWS at the project level. In order to manage the daily progress, the BCWP must be calculated daily. However, the process to acquire the relevant data must be simple and clear. Therefore, the daily work report is used in the PMS to obtain the earning percentage for measuring the BCWP. The contents of the daily work report include the name of the control attribute, its start and finish date, and its daily progress. The junior staff’s job is to select a task on the interface window and input the required information. For example, as shown in Fig. 9, after selecting a task (e.g., Apt. No. 202 1–5 Floor Brick Wall Erection), the staff input its progress percentage.

Currently, the earning percentages of an activity’s tasks are saved in the PMS database, to which the staff can refer before inputting new data. The start date is given and, if the progress rate is 100, the current data automatically becomes the finish date in the PMS. The PMS enables managers to copy the contents of tasks from other projects and to modify them.

When the progress is entered into daily work report windows, the PMS calculates the budget of the tasks performed. The budget of tasks performed is summed and the project-level BCWP is calculated. The payment of earned value is made to subcontractors according to the progress calculated on the daily work report.

Analyzing Variances at the Project Level

When the BCWS and the BCWP are measured, the plan-result comparison can be for a particular point in time. The site manager can check the progress in real time on the PMS. Fig. 10 shows the planned and actual progress in terms of overall progress status and the progress status of individual control attributes (i.e., the activity name in Fig. 10). The progress of each multiple apartment construction project is gathered and monitored on a single window of the PMS. The headquarter management team can monitor all projects which are currently underway.

Fig. 11 shows the BCWS and BCWP measured monthly. In the chart, the weight value of the work group (i.e., masonry) is distributed by month. The ACWP are recorded along with the BCWS and BCWP. The derived measures (i.e., SV, CV, SPI, and CPI) are
Fig. 10. Real-time progress status report

Fig. 11. Monthly BCWS and BCWP measurements
calculated from BCWS, BCWP, and ACWP. The derived measures are displayed in an integrative analysis window of the proposed PMS.

**Practicability and Accuracy of the Proposed System**

The proposed system provides a graphic user interface to group tasks and activities as a work group. This function enhances the flexibility for defining work package comparing to commercial scheduling software programs. Another practical function of the system proposed by the authors is to distribute the budget into the level of tasks according to the weight values. The BCWS can be calculated from the budget of control attributes by allocating it at the level of activities or tasks according to the daily weight values. This technique can reduce the data handling workloads as compared to the method which calculate the budget of the control attribute from the costs of tasks and activities. Measuring the BCWP in real time just by inputting the progress (%) of tasks obtained from the daily work report, without additional data handling workloads, is the other function enhancing the practicability. Using this method, the manager is able to check on the progress of a project in real time and to analyze any problems. The practicability of this method and the PMS has been proven from the real case described.

The accuracy of the proposed system is closely tied to the accuracy of the weight values used in calculating the BCWS and to that of the earning percentages used in measuring BCWP. Theoretically, the technique of allocating the budget of the control attribute to activities and tasks yields the same results as the technique which calculates the resources and costs of activities and tasks and sums-these costs to obtain the control attribute budget. The accuracy of the earning percentage should be further validated. The earning percentage at the task level is calculated from the bill of quantity for a representative apartment and used for other apartments with similar floor plans. Currently, the earning percentages of tasks under an activity are saved in the database and used. In future research, any difference between the earning percentage calculated directly from the bill of quantity and that from a representative apartment will be measured.

Compared to the previous method in which the BCWS and BCWP are measured monthly, the new method can present daily progress data. It can be assumed that daily progress control would provide notice of problematic situations more efficiently than monthly progress control. As a result, the schedule and cost would remain on the track, as planned. The contribution of this new method for progress control can be validated by measuring the variances in cost and schedule of projects using the previous and the new method. Such analysis will be addressed in future research.

**Conclusion**

This paper has proposed a method to manage the progress of multiple apartment construction while maximizing the practicability and not diminishing the theoretical rationale. Examples of implemented PMS follow to support the method.

The challenge in the field of progress management is the increase in data handling workloads when the progress is controlled at the lowest level of work to enhance accuracy. An investigation into the current practices of progress control for multiple apartment construction projects in South Korea addresses the same dilemma. In practice, work activities are grouped into controlling floor units and work groups are the main attribute used for scheduling and control. Due to data handling workloads, the variance between plans and actual performance has been measured only monthly. In order to reduce data handling workloads, the budget has been allocated to sublevels of detail according to predefined weight values. Daily progress is recorded in the daily work report.

Key aspects of the method presented by the writers are a work-packaging model designed to provide a flexible level for calculating and measuring basic measures. According to the level of detail in the model, daily weight values are defined bottom-up and the budget is allocated top-down. By doing this the BCWS can be calculated. The method then uses the earning percentage of daily work to measure the BCWP.

The writers developed a PMS and implemented the method for its use by applying it to a real multiple apartment construction project. The system was able to integrate many schedule charts and bills of quantity one to one, and was able to calculate the BCWS with minimum data handling by introducing the budget distribution technique based on the daily weight value. To effectively calculate and input the BCWP, a progress updating method based on the daily work report has been developed. Simply by including the percent of progress in the daily work report, the BCWP can be calculated on a daily basis. The case study shows the practicability of the PMS.

Many features of the method and the PMS are derived from characteristics of multiple apartment construction projects in which similar floor plans are repeated, producing unique patterns of the work process and types of resources. The practicability of the method and the PMS in other types of projects needs to be validated further. In addition, to enhance the practicability of the PMS, a simple standard that defines the level of tasks should be provided. The accuracy of earned values will be further validated by real data from completed projects in future research.

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