

A Project Progress Measurement and Management System

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Abstract: A progress management in construction projects plays an important role in providing as-built information for project planning, control, cost engineering, and many others. However, progress information has not been collected through objective methods or criteria but mainly based on an individual's own experience or subjective judgment, which results in the limits of consistency, objectiveness, and accuracy in the progress management. This research aims at proposing a progress measurement framework that allows managing and applying various measurement methods dependent on work items to overcome the problems and limits of the current progress management. The framework was developed with a focus on integration of work breakdown structure, cost breakdown structure, and progress measurement methods, and it consists of three main objects: work, activity, and progress measurement unit. Base on the framework, an information system named PROSYS (project PROgress management SYStem) was developed to generate activities and progress measurement units depending on the characteristics of projects and work items, and to keep track of project progress more efficiently and effectively.

Keywords: Progress management, Progress measurement, Information system

1. INTRODUCTION

Project management information systems are increasingly applied at construction projects for more efficient management by collecting as-built information and supporting decision-making. Among the various types of as-built information, the project progress rate is one of the critical indices that represent the project performance and progress state, and it helps timely and accurate decision-makings by providing basic information that can be applied to project planning and control as well as cost engineering. However, the project progress management has not been quite effective, since it has not been based on objective data or criteria, but based on subjective judgments and different criteria dependent on an individual's experiences or preferences [1].

Regarding research on the progress management, Thomas and Mathews [2] classified the progress management into three categories by the progress measurement method, which are estimated percent complete, physical progress measurement, and earned value. CII [3] and Flemming and Koppleman [4] classified the measurement methods at more detailed level, and suggested the use of a different

method depending on the work item or project condition. However, there has been lack of a framework for applying various measurement methods with considering a work item and project characteristics based on objective and consistent criteria. In most construction projects, measurement methods are used inconsistently project by project without objective criteria, which make it more difficult to accumulate and reuse invaluable as-built information.

The objective of this research is to develop a progress measurement framework, which supports to apply various methods with considering a work item and project characteristics based on objective and consistent criteria. To do so, it was analyzed what kind of measurement methods exist, and how they could be applied differently depending on the characteristics of a work item and a project. Based on the methods, a progress measurement framework was developed to provide various measurement methods, depending on work items and project characteristics. Finally, based on the proposed framework, an information system called PROSYS (project PROgress management SYStem) was developed.

2. PROGRESS MANAGEMENT IN CONSTRUCTION PROJECTS

The definition of the progress management, measurement methods, and their targets were studied through literature review. And they are discussed in the following sections.

2.1 Definition of Progress Management

Generally, the progress management is defined differently depending on the aspects of cost engineering and scheduling, respectively [5]. However, in overall view, the progress management can be considered as the integration of cost and schedule [1]. Base on this definition, the progress management in this paper is the measurement and analysis of degree of progress based on measurement quantity as well as its budget, which is the same as budgeted cost work performed (BCWP) of Cost/Schedule Control Systems (C/SCS) [6].

2.2 Progress Measurement Methods and Targets

Existing research on progress management, listed in Table 1, suggested various measurement methods and targets in progress management. Measurement methods can be categorized into measuring, estimating, and checking, while targets can be classified into work quantity, milestone, process, and time.

Besides Eldin [7] developed a computer application for the measurement of work progress based on weighted milestones and earned value, and Choi [8] insisted that the effectiveness and efficiency of measuring progress can be maximized through specifying major items that can represent the real work progress.

Although the existing research suggested various measurement methods for work progress, the progress management has not been based on objective criteria but based on the manager's judgments and conveniences. In addition, the consistency and accuracy of work progress can be improved through application of various measurement methods and breakdown of measurement targets at more detailed level, however, this would require tremendous time and efforts to build criteria and to collect data in each project. To the contrary, estimating work progress would reduce the accuracy and consistency, although it does not need time and efforts that much. Therefore, there is a tradeoff relationship between accuracy/consistency and efficiency in progress management [1].

Accordingly, it would be very efficient to build a computerized system that allows various choices for progress measurement dependent on the degree of

impact of a work for better accuracy and timeliness in progress management. To do so, a framework needs to be developed to suggest and manage criteria, such as measuring methods, targets, and rules, and to apply them flexibly by work items and project characteristics in a consistent and timely manner.

Table 1 Measurement Methods and Targets

Research	Measurement Method	Measurement Target
Thomas & Mathews [2]	Estimated percent complete	Progress state (Individual evaluation)
	Physical progress measurement	Installed quantity
	Earned value	Measurable level of work progress
CII [3]	Unit completed	Installed quantity
	Incremental milestone,	Milestone
	Start/finish, supervisor	Start /finish point of work
	Opinion	Progress state
	Cost ratio	None
	Weighted or equivalent units	Finish point or progress state of work
Fleming & Koppleman [4]	Weighted milestones	Finish point of weighted milestone
	Fixed formula by task	Finish point of work (0-100) or Start /finish point of work (50-50)
	Percent complete & milestones gates	Progress state based on milestone
	Earned standards	None
	Apportioned relationships to discrete work	None
	Level of effort	Time of work

3. PROGRESS MEASUREMENT METHODS

Based the measurement methods listed in Table 1, only the methods that have measurement targets were selected and reagranged by excluding redundancy and ambiguity in its contents. The reagranged methods were reviewed through the analysis on existing office construction projects and workshops with construction practitioners in Samsung Corporation. Finally, possible methods in each work item were derived for a typical office project.

3.1 Derivation of Progress Measurement Methods

The progress measurement methods by work items were derived in the following manner. First, based on the existing research and paradigm at practice, 3 measurement methods and 6 measurement targets were derived. 3 measurement methods are physical measurement, milestone measurement, and estimated percent completed, and 6 measurement targets are quantities of a single major work item, multiple major work items and all work items, milestone, start/finish point, and percent completed. Secondly, 18 types of measurement methods were generated by

simply combining 3 methods and 6 targets, and they were narrowed down into 6 measurement methods through brainstorming with construction practitioners with considering applicability and redundancy of the candidate methods. The final 6 measurement methods are listed along with examples in Table 2.

3.2 Criteria for Applying Measurement Methods

For more accurate progress management, it is necessary to apply various measurement methods with considering the characteristics of a work item

and a project, and objective criteria are essential in this process. Therefore, this research adopted three factors affecting progress measurement accuracy proposed by Jung et al. [9] as criteria to choose an appropriate measurement method for a work item. Those factors are budget weight of a work item, typical durations of activities for a work item and the degree of ease in determining accurate progress rate in each activity. Based on these factors, criteria for applying measurement methods are developed on the assumption that the project progress is measured at the activity level every week.

Table 2. Measurement Methods & Examples

Measurement			Examples							
Measurement Methods	Criteria	Target	Work	Budget items					Checkpoint	
				No.	Description	Standard	Unit	Budget rate (%)		
1	Measure installed quantity of a single major item	Activities of this work item take more than a week, and budget rate is relatively high. A single major budget item can represent the work progress.	Single major budget item	Form	1	Wood form	3 Times	m ²	4.0555	Installed quantity of No. 1 item
					2	Wood form	4 Times	m ²	0.1104	
					3	Wood form	Round shape	m ²	0.0424	
2	Measure installed quantities of multiple major items	Activities of this work item take more than a week, and budget rate is relatively high. Multiple major budget items can represent the work progress.	Multiple major budget items	Interior decoration tile	1	Ceramic tile for wall	200mm*200mm	m ²	0.0241	Installed quantity of No. 5&6 items
					
					5	Tile for wall	150 mm*150 mm	m ²	0.1010	
					6	Tile for floor	150 mm*150 mm	m ²	0.0554	
3	Measure installed quantities of all items	Activities of this work item require intensive monitoring or large influence over a project. A few budget items are assigned.	All budget items	Gutter & downspouts	1	Steel downspouts	D100	m	0.0077	Installed quantity of all items
					2	Steel downspouts	D150	m	0.0002	
					3	Floor drain	D100	EA	0.0027	
					4	Floor drain	D150, ME Room	EA	0.0010	
					5	Roof drain	D150	EA	0.0018	
4	Check start/finish of works	Activities of this work item take less than a week, and budget rate is relatively low. Activities progress can be measured by 0/100 % basis, which means that progress rate is 0% until the activity is finished.	Finish of work	Handrail	1	STL Handrail	D=50 H=900	m	0.0021	Start [0%]
					2	Heliport Handrail	D=50.8*4 H=1000	m	0.0401	
					3	Cooling-Tower Handrail	D=100*3 H=900	m	0.0270	Finish [100%]
					4	Rooftop Handrail	D=50.8 H=800	m	0.0784	
5	Check milestones	Activities of this work take more than a week, and milestones can be assigned in each activity. And different weights can be assigned in each milestone.	Milestones	Aluminum door/window installation	1	FSD01	750*2100	EA	0.0052	Finish frame installation [30%]
					
					4	FSD47	1900*2100	EA	0.0011	Finish door installation [70%]
					8	SD51	1000*2100	EA	0.0003	
6	Estimate percent complete	Activities have very long durations and its influence is very small. Activities do not have clear targets to measure for work progress. The progress can be determined by time or progress rate(s) of other works.	None	Usually indirect cost item is included in this category. However, this method is not recommended for measuring work progress.						

4. A PROGRESS MEASUREMENT FRAMEWORK

This research propose a progress measurement framework (PMF) based on measurement methods and criteria described in the previous section. PMF has a three-dimensional structure that integrates work breakdown structure (WBS), cost break down structure (CBS), and measurement, and makes three main objects for progress measurement: work, activity, and progress measurement unit (PMU) as shown in Figure 1.

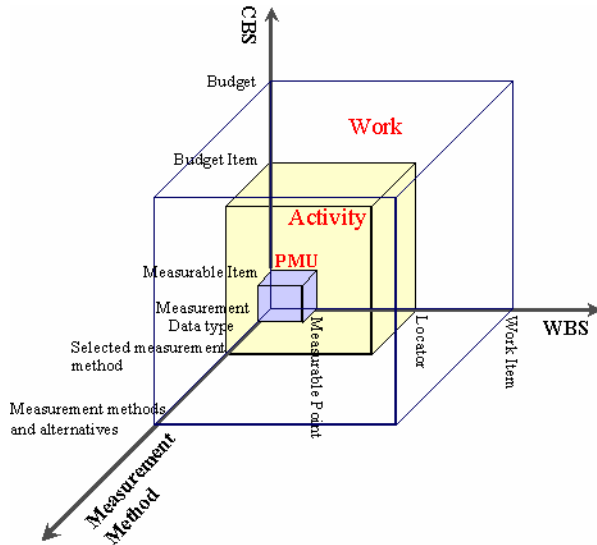


Figure 1. Progress Measurement Framework

WBS defines the structure for activities based on work item, locator, and measurement point. That is, each work item is divided into activities by locations where the work occurs, and activities have one or more measurement points for work progress.

CBS, which is for cost engineering, consists of three factors of budget, budget items, and measurable items. The structure of CBS can be almost identical to WBS at the high level, but CBS usually has the different level of detail from that of WBS. Therefore, in many cases, budget items of a cost account need to be reassigned into activities, and measurable items should be designated among the assigned budget items.

Measurement consists of alternative measurement methods, selected measurement method, and measurement data type. For a given work item, alternative measurement methods are available for progress management; an appropriate measurement method is selected for the work item based on the project characteristics; and progress data is collected in the specified data type to determine the progress at the activity level.

Although WBS is defined as an integrated structure for schedule and cost control systems [10], WBS and CBS are usually managed separately in reality [11,

12], which requires reassignments of budget items in CBS into the corresponding activities in WBS. Therefore, PMF defines a work as an integrated object of cost and schedule. Each work has assigned budget items and many alternatives for progress measurement of the work item, while a work progress is determined in each activity by measuring PMUs through the selected measurement method.

Activity is a unit where a progress rate is determined. It is generated through flexible combination of a work item and locators, such as site, building, story, space, and element, depending on the characteristics of a project.

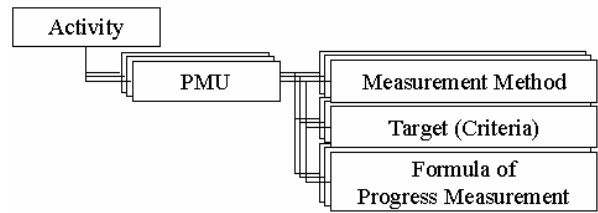


Figure 2. PMU's Structure

PMU, which is a unit to measure a work progress, tells what and how to measure progress for a specific work item, and it consists of measurement method, measurable item(s), and measurement point(s) as shown in Figure 2. An activity has one or more PMUs to measure targets, while a progress rate is determined in each activity through applying PMU values into the formula specified for the selected measurement method. Table 3 shows an example on how work, activity, and PMU are related and a work progress is determined. In addition, the overall project progress rate is determined by:

$$\text{Proj. Progress} = \frac{\sum (\text{Activity progress} \times \text{budget})}{\text{Project budget}} \times 100 \quad (1)$$

5. SYSTEM IMPLEMENTATION

An information system named PROSYS (project PROgress management SYStem) has been developed based on the progress measurement framework (PMF) described above. The objective of PROSYS is to support generation of activities and PMUs, integration of cost and activity by reassigning budget items into activities, measurement of work progress by utilizing PDAs, and analysis of work progress, etc. The system architecture and some of main features of PROSYS are presented in the following sections.

5.1 System Architecture & Information Flow

The system architecture of PROSYS is shown in Figure 3. PROSYS has two databases. One is a standard database that contains standard information, such as work items, measurement method and

Table 3. Examples of Work, Activity, and PMU

Work	Activity		PMU			Measurement		Activity progress rate	Project progress rate	
	Name	Budget (won)	Msrmt. Method	Target (unit)	Formula for work progress	Total quantity of target	Installed quantity			
Formwork	1F-formwork	47,000,000	[1]	Single major budget item (m ²)	$\frac{\text{Installed quantity}}{\text{Total quantity}} \times 100$	2690 (m ²)	1750 (m ²)	65.06 (%)	0.08 (%)	
	2F-formwork	47,000,000	[1]	Single major budget item (m ²)	$\frac{\text{Installed quantity}}{\text{Total quantity}} \times 100$	2690 (m ²)	-	0(%)	0(%)	
Door/window installation	1F-door/window installation	111,644,500	[5]	Finish frame installation	30 (%)	Σ Weight of milestone	Finish frame installation	completed	100(%)	0.3 (%)
				Finish door/window installation	70 (%)		Finish door/window installation	completed		
	2F-door/window installation	111,644,500	[5]	Finish frame installation	30 (%)	Σ Weight of milestone	Finish frame installation	completed	30(%)	0.09 (%)
				Finish door/window installation	70 (%)		Finish door/window installation	-		

alternatives and typical budget items for each work item and it is managed by standard manager. The other database is a project database managed by customization manager, and it manages project-specific information, such as the project schedule, activities, cost account and budget items, PMUs, etc. The progress measurement manager enables to measure progress based on generated PMUs, and it supports data collection through PDAs for more efficient progress measurement. Accordingly, the information in PROSYS flows from standard manager to customization manager, and to progress measurement manager.

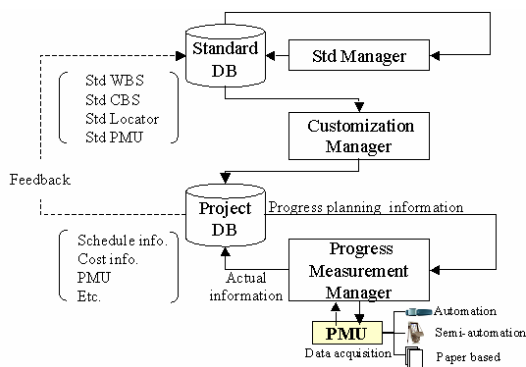


Figure 3. System Architecture

5.2 PROSYS

Some of main functions in PROSYS are presented in this section. Figure 4 shows the function to generate activities for a selected work item. A user selects locators, such as floor, space, and element, for the selected work item in the treeview of the left side of the window. And clicking generation button, in turn, generates activities shown at the bottom of the window in Figure 4.

Figure 5 shows the PMU generation. For the selected work item in the left side of the window, a standard measurement method and alternatives are shown, and the default value can be changed to fit to the project. A measurement method is determined at the work item level, since the system assumes the same measurement method is applied through the all

activities that belong to the same work item. This is because of the management convenience. If different methods need to be applied, the work item can be divided into as many items as the number of measurement methods required.

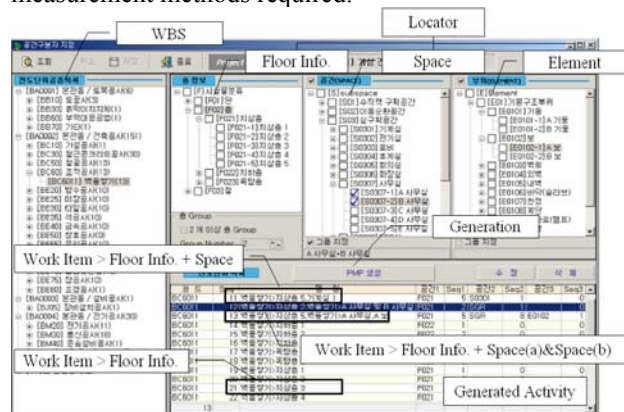


Figure 4. Activity Generation

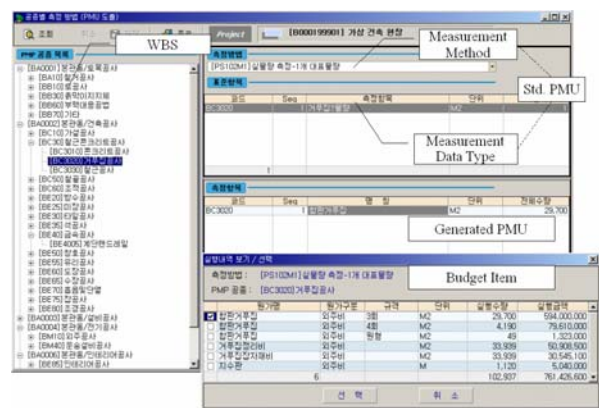


Figure 5. PMU Generation

Figure 6 shows the PDA module of PROSYS. After generating activities and PMUs, a work progress is measured through PMUs by using PDA. The left part of Figure 6 shows the initial page of PDA module, while the right part of Figure 6 shows the measurement window for a specific activity. A user measures progress according to the method specified at PMUs, and then the collected progress data is

summed and analyzed for project progress analysis as shown in Figure 7.



Figure 6. PDA Main & PMU measurement

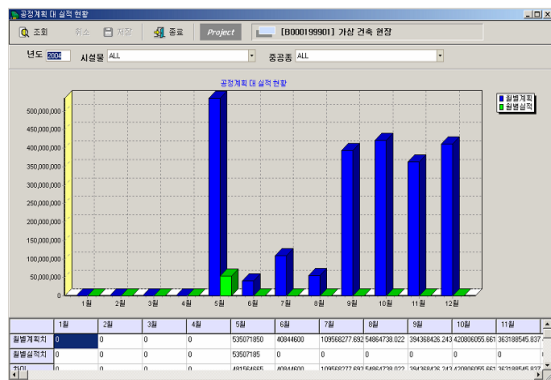


Figure 7. Monthly Progress Rate

6. CONCLUSIONS

This research proposed a progress measurement framework and developed an information system for more efficient and effective progress management based on the following outcomes:

- 1) six measurement methods were derived from the existing research [2, 3, 4, 7, 8],
- 2) the three-dimensional progress measurement framework were proposed on a basis of integrating WBS, CBS, and measurement methods,
- 3) the concept of progress measurement unit was proposed to measure a progress of an activity in a more consistent and objective manner,
- 4) an information system named PROSYS was developed to support the progress management based on the progress measurement framework.

The proposed progress measurement framework has been partially tested and validated by applying it to construction projects that had already been completed. In the near future, PROSYS will be fully tested for verification and validation of the progress measurement framework through an on-going construction project. Lessons-learned and experience will be shared through further publications.

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