Measurement of Work Progress: Quantitative Technique

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Abstract: In this paper a procedure is presented which provides a method to quantify work progress on construction projects. The procedure employs two management concepts, the work breakdown structure and the earned value. Although the theoretical basis for the proposed procedure is not new to the industry, it provides professional construction managers and project managers with a practical implementation of these concepts. The procedure is also an excellent computer application in construction management that requires only minimum programming skills. Examples of the input data file and output reports from an actual project are provided for numerical illustration.

Introduction

A successful project is one that is completed on time, that is within budget, and that satisfies the appropriate technical and safety standards. Although several systems and techniques are available to support project management efforts, the task of tracking costs and durations of a project is still difficult and challenging. This difficulty is perhaps due to the fact that the three basic categories of project data (i.e., cost, scheduling, and progress) are intimately interrelated, and they are also time dependent. This makes independent tracking of any one category of little or no value unless it is integrated with the other two. The writer agrees with other researchers (Stevens 1986; Bromberg 1984) regarding the need for a practical quantitative method for measuring work progress, which would eliminate a major cause for this difficulty.

The objective of this paper is to present an outline for a comprehensive and practical system to measure work progress on a construction project objectively. The proposed system employs two principles. The work breakdown structure (WBS) technique is used to integrate cost and scheduling data, and the earned value concept is used to serve as the yardstick for measuring progress.

Basic Requirements

Two basic requirements need to be established at the start of a construction project to enable the quantitative measurement of work progress. These are: (1) Definition of the level of detail at which progress will be measured; and (2) selection of the basis for progress evaluation. A brief discussion of these two requirements is provided next.

Definition of Level of Detail

The work breakdown structure (WBS) is the current management tool for defining the lowest level of detail at which progress will be measured on a

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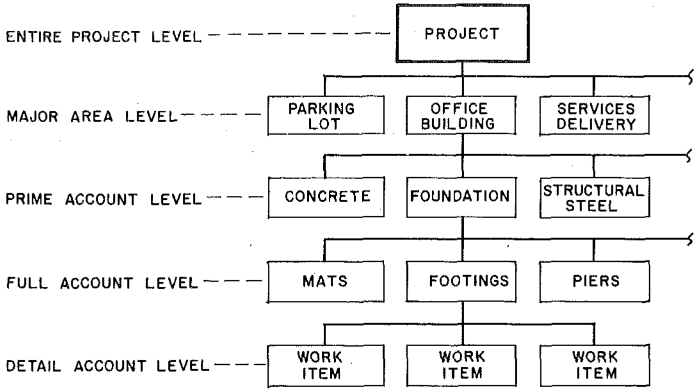


FIG. 1. Work Breakdown Structure

construction project. It is a concept by which work items are grouped to establish meaningful relationships among the different levels of control on the project hierarchy, such as is shown in Fig. 1. The WBS is also considered the key to integration of cost and scheduling data ("Cost" 1981; Barrie and Paulson 1984; Meredith 1985). This integration can be achieved by developing a WBS in which the work items represent scheduling activities, and by assigning a unique cost code to each level of control on the WBS. By doing so, costs of each scheduling activity can be tracked for control purposes and integration of cost and scheduling can be achieved.

Selection of Basis for Progress Evaluation

Review of the attempts to quantify work progress to date reveals that three bases for progress measurement have been used. These are: (1) Project's expenditures; (2) installed quantities; and (3) earned value. The principal assumption in using project's expenditures as a progress measurement tool is that the ratio of the project's cost-to-date to its total estimated cost is indicative of the project's progress (percentage of completion). In other words, a project is considered 50% complete when one-half of the budget has been spent. It is quite apparent that a substantial amount of the project's funds can be expended without any significant progress being realized. This shortcoming directed attention to the fact that assessment of work progress should be based on the actual quantities installed rather than merely actual expenditures.

This principle of measuring progress based on quantities installed appeared promising at first. However, the use of different units of measurement (i.e., pounds, cubic yards, tons, feet, etc.) was a major obstacle in the application of this method. The different units prevented the summation of the progress achieved on subcomponents to determine the progress of a work item. Also, the summation of progress achieved on different work items, to determine the overall project's progress, was not possible without assigning weight factors to each item and computing what became known as the weighted percent complete (WPC) method (Clark and Lorenzoni 1979). The WPC approach entails lengthy and cumbersome calculations, as will be discussed later in this paper.

It was also realized that the progress of work items having the same units of measurement was affected by other qualifications that were not merely based on installed quantities. For example, although the quantity of concrete placed on the first floor of a skyscraper is equal to that placed on the top floor of the same building, the cost of and time for placing each of these two work items are significantly different. Similarly, although all piping work is measured in units of linear feet, the cost and time required for installing a certain length of a 60-in. diameter pipe are several times as much as that required for installing the same length of a 2.5-in. diameter pipe. Measurable differences in cost and duration can be a result of differences in the size, thickness, metallurgy, complexity, and location of similar work items.

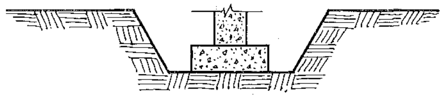
All these difficulties in measuring work progress, whether based on either project's expenditures or installed quantities, led to the development of the earned value concept. The earned value is the amount budgeted or planned to reach a specific goal regardless of the actual expenditures incurred in reaching that goal. This concept was first implemented by the Energy Research and Development Agency (ERDA) on government projects, and its use has been continued by the Department of Energy and several other government agencies (Rogers 1979). These applications, however, were performed at a summary level and no detailed and specific procedures have been published to date to assist contractors in implementing the earned value concept on construction projects.

Proposed System

It may not be obvious from the definition presented how the earned value concept is applied. The writer has successfully implemented this concept by identifying distinguishable events (control points) throughout the life cycle of the work items and by developing earning rules for reaching these events. The control points for a work item, such as placement of a footing foundation, may include excavation, forming, steel reinforcement, concrete placement, and backfilling. The earning rules assign a value to each control point. The earning values can be expressed as percentages of the item's budget, duration, or an arbitrary work unit. The control points and earning rules for this example are illustrated in Fig. 2.

Different control points and earning rules need to be developed for each type of work. Typical sets of control points and earning percentages will soon develop once a contractor adopts this technique and obtains feedback from computed projects. Standardized control points and earning percentages may become available when this technique receives wide application in the industry.

In the proposed system, measuring work progress only requires compilation of basic project data and simple mathematical operations. Fig. 3 depicts the four categories of data (account numbers, budget data, control points percentages, and status of control points) required to establish the system's data file. Account numbers should be designed to describe uniquely each work item that exists at the lowest level of detail on the project's WBS. As shown in the figure, each digit or group of digits address a certain level on the WBS hierarchy. A full description of each account can also be provided to facilitate the input and retrieval of project data. The second category of data contains the budget for each work item. Budgets can be expressed in



CONTROL POINTS			EARNINGS PERCENTAGES
CP_1	=	EXCAVATION	5 %
CP_2	=	FORM	10 %
CP_3	=	REINFORCEMENT	35 %
CP_4	=	CONCRETE	50 %
			100 %

FIG. 2. Example of Control Points and Earning Percentages

terms of dollars, man-hours, or work units, depending on the contractor's setup and preference. The third category consists of the earning rules expressed in terms of percentages assigned to each control point as previously explained. The fourth category involves the actual status of each control point.

The status of each control point is determined by examining whether the control point was accomplished. The work item earns fully the percentage assigned to a control point only when that point is completed. Partial credit may also be allowed if appropriate. The work progress (percentage of completion) and the earned value for a work item are determined by the following equations:

$$\text{Percent Complete } (PC) = \Sigma(CP_i) \cdot (A_i) \quad (1)$$

$$\text{Earned value} = \text{Current Budget of Subject Work Item} \times PC \quad (2)$$

where (PC) = the percentage complete for the work item under considera-

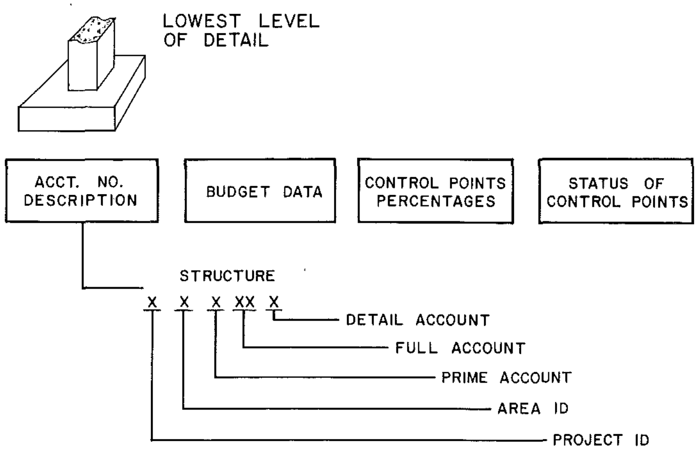


FIG. 3. Schematic View of Proposed Data File

COL#1	COL#2	COL#3	COL#4	COL#5	COL#6	COL#7
DATA INPUT				COMPUTED		
Item No.	Contr.Points % #1 #2 #3 #4 #5	Contr.Point Status% #1 #2 #3 #4 #5	Item's Budget	Item's % Comp	Earned Value	Progress %
1-1-21-1	5 15 10 40 20	100 100 100 100 100	400	100	400	
1-1-21-2	5 15 10 40 20	100 100 100 100 100	800	100	800	
1-1-21-3	5 15 10 40 20	100 100 100 100 100	50	100	50	
1-1-21	Progress of Major Acct		1250		1250	100 %
1-1-22-1	5 15 10 40 20	100 100 100 100 100	1000	25	250	
1-1-22-7	50 10 40 - -	100 100 50 - -	70	80	56	
1-1-22-9	20 5 10 10 55	50 50 0 0 0	500	12.5	63	
1-1-22	Progress of Major Acct		1570		369	24%
1-1-23-1	10 10 50 10 20	100 100 100 0 0	900	70	630	
1-1-23-2	25 25 25 25 -	100 50 50 0 -	1000	50	500	
1-1-23-3	50 10 40 - -	0 0 0 - -	200	0	0	
1-1-23	Progress of Major Acct		2100		1130	53%
1-1	Work Progress for Area 1		4920		2749	55%
1-2-21-1	5 15 10 40 20	100 100 100 100 100	300	100	300	
1-2-21-2	5 15 10 40 20	100 100 100 100 100	720	100	720	
1-2-21-5	5 15 10 40 20	100 50 0 0 0	680	12.5	85	
1-2-21	Progress of Major Acct		1700		1105	65%
1-2-22-8	10 10 10 50 20	100 0 0 0 0	90	10	9	
1-2-22-9	5 15 10 40 20	100 100 100 100 100	825	100	289	
1-2-22	Progress of Major Acct		915		298	33%
1-2	Work Progress for Area 2		2615		1403	54%
1-3-75-1	50 10 10 30 -	100 100 50 0 -	3781	65	2458	
1-3-75-2	50 10 10 30 -	100 100 100 100 -	2109	100	2109	
1-3-75-4	50 10 10 30 -	100 100 100 100 -	1097	100	1097	
1-3-75	Progress of Major Acct		6987		5664	81%
1-3	Work Progress for Area 3		6987		5664	81%
1	Work Progress for the Project		14522		10015	68%

FIG. 4. Illustration of Proposed Method

tion; (CP_i) = the earning percentage associated with control point number i; and (A_i) = the actual progress accomplished on control point number i expressed in percent.

The use of this procedure is appreciated once an attempt is made to determine work progress at higher levels on the project hierarchy. For instance, if one attempts to determine the progress of the entire foundation as one work package, one adds the earned value of all footings and divides that total by the total budget for the entire foundation. This computation is expressed by the following equation:

$$\text{Percent Complete } (PC) = \frac{\text{Total Earned Value for all Footings}}{\text{Total Budget for all Footings}} \qquad (3)$$

It should be noted that Eq. 3, which is another form of Eq. 2, is applicable at all levels of control on the WBS. Eq. 3 simplifies the computations of the PC at any level, and makes the use of this procedure advantageous compared to other available methods requiring more involved computations.

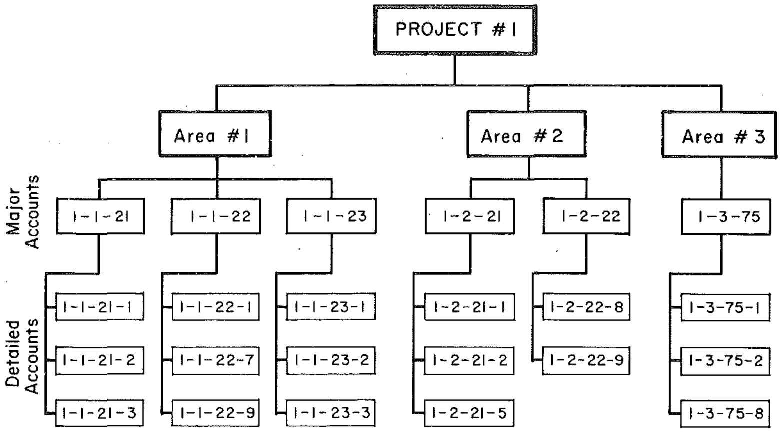


FIG. 5. Work Breakdown Structure for Numerical Example

Computations and Computer Application

Fig. 4 provides a numerical example for the proposed procedure. Fig. 4 shows the data file and the work progress (percentage of completion) computed at the various levels of the WBS for a hypothetical project, shown in Fig. 5.

The first four columns in Fig. 4 represent the data input and the last three columns represent the computed information. Column 1 contains the account number assigned to each detail account. Column 2 provides the number of the control points used for each account and their earning percentages. Column 3 shows the actual status of each control point. Column 4 lists the budget for each item. Column 5 provides the percent complete of each item determined by Eq. 1 at the detailed level. Column 6 is the earned value determined by Eq. 2 at the detailed level. Column 7 shows the percentage complete determined by Eq. 3 at the summary levels.

In reference to Fig. 4, the computation procedure is as follows:

1. Multiply the contents of column 2 and column 3, satisfying the expression: $\Sigma(CP_i)(A_i)$. The result is the progress measured on each work item, which is placed in column 5.

2. Multiply the contents of column 4 and column 5. The product is the earned value on each work item, which is placed in column 6.

3. Subtotal the earned value (column 6) and the budgeted amounts (column 4) for the various levels of summary at which progress is to be measured. Divide the subtotals (column 6/column 4) to determine the work progress achieved at that level of summary, which is placed in column 7.

Advantages of Proposed Procedure

The simplicity of the aforementioned computations prove the practicality of the system in which one small file contains all input data and computed information. The system makes use of the advantages of the spreadsheet layout, where the user sees and easily accesses all data and information.

There are no hidden or transparent files. Computations proceed in a one-way flow, avoiding back looping, eliminating the need for more advanced programming skills, and reducing processing time.

The use of this system may resolve a vast number of contractual legal disputes between owners and contractors. Disputes have arisen due to subjective assessment of work progress and disagreement on the associated compensation, which may involve large sums of money. In 1982, the writer was involved in the settlement of a $60,000,000 claim based on differences concerning the value and timing of work progress reported, the associated compensation, and the earned interest on delayed payments for some offshore installations. In the proposed procedure, the rules of measuring progress are clearly set before work starts. This is the most opportune time for reaching agreements and commitments based on good faith and healthy relationships before the parties are affected by the heat of the work pressure.

Use of the proposed system can also relieve senior project staff from routine tasks such as assessing work progress, and thus allows devotion of additional time to the more significant management activities. With this procedure, determination of work progress and assessment of project status can be delegated to a junior field engineer. It should be noted that devotion of considerable time to routine tasks by senior project personnel is a recognized current problem (Russell 1982). Employing a junior individual to assume effectively the responsibilities of a senior staff obviously enhances cost effectiveness and resource use.

Similar Evaluation Techniques

The weighted percent complete (WPC) is a widely used method for determining work progress on construction projects. Although the proposed method appears somewhat similar to the WPC, the proposed method is more advantageous. Its advantages stem from its objectivity, accuracy, and practicality compared to the WPC method. The proposed method eliminates the need for the subjective judgment of the assessor and simplifies the calculations involved in computing work progress. For the same WBS shown in Fig. 5, Fig. 6 provides a numerical example for computing the work progress with the WPC method. To facilitate the comparison between the two methods, a summary of the computation steps of the WPC method, shown in Fig. 6, is provided here.

1. Assess the progress (percent of completion) of each work item shown in column 4. Multiply the percent complete (column 4) by the *WF* (column 3) to determine the weighted percentage complete (*WPC*) (column 5) for each account.

2. The weight factor (*WF*) is computed as the ratio of the budget of a work item to the total budget of the work category to which the item belongs. For example, the *WF* (0.32) for item 1-1-21-1 is computed by dividing its budget ($400) by the total budget ($1,250) of its group (i.e., 1-1-21).

3. To determine the percent complete at the next higher level on the project hierarchy (e.g., 1-1-21) add the *WPC* (column 5) calculated at the immediate lower level (i.e., 1-1-21-1, 2, and 3).

4. To determine the *WPC* at a higher level on the project hierarchy (e.g., area 1-1), a new *WF* at the higher level has to be generated. This is done by dividing the budget of the immediate lower level account (i.e., 1-1-21) by the total budget

DATA INPUT		COMPUTED INFORMATION			
COL#1	COL#2	COL#3	COL#4	COL#5	COL#6
Acc. No.	Item's Budget	Weight Factor	Work Item % Compl	WPC	Group Budget
1-1-21-1	400	0.32	100	32	
1-1-21-2	800	0.64	100	64	
1-1-21-3	50	0.04	100	4	
1-1-21	1250			100	1250
1-1-22-1	1000	0.57	25	14.25	
1-1-22-7	700	0.04	80	3.2	
1-1-22-9	5	0.29	12.5	3.6	
1-1-22	1750			21.1	1750
1-1-23-1	900	0.43	70	30.1	
1-1-23-2	1000	0.48	50	24	
1-1-23-3	200	0.09	0		
1-1-23	2100			54.1	2100
1-2-21-1	300	0.18	100	18	
1-2-21-2	720	0.42	100	42	
1-2-21-5	680	0.40	12.5	5	
1-2-21	1700			65	1700
1-2-22-8	90	0.10	10	1	
1-2-22-9	825	0.90	35	31.5	
1-2-22	915			32.5	915
1-3-75-1	3781	0.54	65	35.1	
1-3-75-2	2109	0.30	100	30	
1-3-75-4	1097	0.16	100	16	
1-3-75	6987			81.1	6987
1-1-21	1250	0.25	100	25	
1-1-22	1750	0.34	21.1	7.17	
1-1-23	2100	0.41	54.1	22.18	
1-1	5100	Progress Status of Area 1		54.35	
1-2-21	1700	0.65	65	42.25	
1-2-22	915	0.35	32.5	11.38	
1-2	2615	Progress Status of Area 2		53.63	
1-3	6987	Progress Status of Area 3		81.1	
1-1	5100	.35	54.35	19	
1-2	261	.17	53.63	9	
1-3	6987	.48	81.1	39	
1	14702	Progress Status for Project		67%	

FIG. 6. Illustration of WPC Method

of the major category to which it belongs (i.e., the total of 1-1-21, 22, and 23). A *WPC* at the higher level (area 1-1) is then computed by multiplying the new *WF* by the percent complete computed in step 3.

5. Steps 3 and 4 have to be repeated for each level on the project hierarchy to compute the overall progress on the project.

Comparison of Two Methods

The WPC method requires subjective assessment of the work progress of a work item as the first step in the computation procedure. The method does not explicitly address the breakdown of a work item (e.g., a footing) into its subcomponents (i.e., excavation, forming, rebar, and concrete). Neither does it clearly establish assessment rules to evaluate such a breakdown objectively. This subjective assessment of the work progress defeats the purpose for developing an objective quantitative method for measuring work progress. If subjective assessments were acceptable in the first place, a need for the method would have not existed. Although there is no replacement for solid experience and educated intuition at times, the personal interest of an individual may distort his or her judgment. In many instances the assessment of work progress is also an evaluation of self performance for the individual in charge of such assessments.

The computation and maintenance requirements for the WPC are lengthy and cumbersome. Additions, deletions, or modifications even on a minor work item create changes that propagate through the entire procedure and require recomputing of every line item. This limits the frequency at which a cost engineer can practically perform the project's updates. Thus, the cumbersome computation of the WPC adversely affects the availability of current information. Automation of the WPC procedure also requires a higher level of programming skills. It requires keeping and retrieving subtotals at various levels on the project hierarchy and back-looping procedures.

Perhaps even more importantly, the progress of a work item in the WPC method appears to have no absolute value, since the WF of an item depends on the ratio of its budget to the budget of the other work items. In the WPC method the weight and performance of a work item is, in a way, judged only relative to the other work items. The WPC method does not penalize overspending situations and may even overshadow them by basing the WF on the item's budget.

Implementation of Proposed System

Identification of representative control points and assignment of adequate earning percentages to each point are the key to successful implementation of the earned value concept and the system described. It is advisable, therefore, that such points (events) and their earning rules be determined by senior level project management experts. It is also essential that those who are assigned to implement and maintain the system endorse the CPs to warrant common understanding and full commitment. An agreement between the project's owner and the contractor is also a must to ensure full realization of the system's benefits.

The procedure proposed was recently implemented on a $70 million construction project built for a major oil producing company. The project included three major physical areas, a refinery and two gas oil separation plants (GOSPs). A WBS similar to that shown in Fig. 7 was developed to map the project's work items and to define the level of detail at which progress was to be measured. A six-digit cost code was developed for the project. The cost code used: (1) The first 2 digits to describe the major areas of the project (Abqaq plant, GOSP5, and GOSP6); (2) the next digit to describe the primary account level (foundation, steel work, piping, instrumentation, painting); (3) the next 2 digits to describe the full account level, which is the breakdown of the primary accounts (e.g., foundation: mats, sleepers, footings, etc.); and (4) the last digit to describe the details of the full account level (e.g., Footing for: piperack, FIN-Fan, etc.).

From the WBS, the estimate, and the developed earning rules, the data base shown in Fig. 8 was created. As discussed before, only four categories

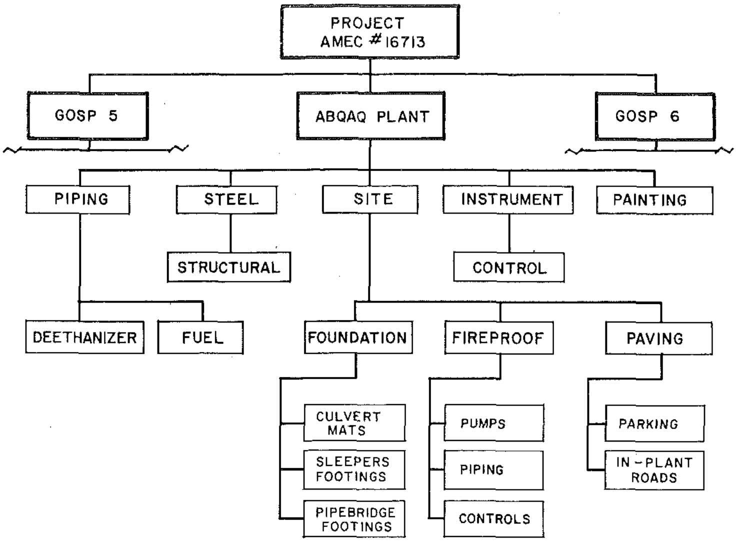
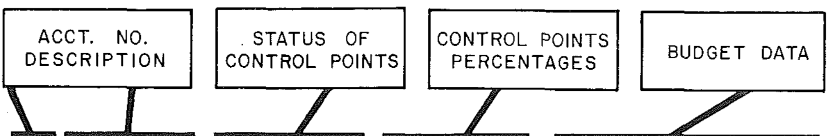


FIG. 7. Work Breakdown Structure for Example Project

of data were required for the proposed system. A simple program was written in MarkIV to perform the computations and generate management reports. Samples of the output reports are provided in Figs. 9–13.

Fig. 9, the detail account report, lists all the work items for each major area. The reports includes information on budget, earned amounts, and the work progress (percent complete) measured for each work item that exists on the lowest level of detail on the project's WBS. Fig. 10, the full account report, focuses on one major area at a time, the Abqaq Plant in this example,



ACC. NO.	DESCRIPTION	A1	A2	A3	A4	A5	A6	M1	M2	M3	M4	M5	M6	CUR.EST WORKUNIT	CUR.E. QNTY	QNTY UNIT	ORG.E. QNTY	ORIG.EST WORK UNT
G5260A	K.O. DRUM FDN							10	45	10	5	15	15	285	11.41	CYD	11.41	285
G5260B	PIPERACK FTGS							10	45	10	5	15	15	583	16.65	CYD	16.65	583
G5260C	FIN-FAN FTGS	100	100	100	100	100	100	10	45	10	5	15	15	349	11.64	CYD	11.64	349
G5260D	C.I. TANK FDN	100	100	76	78	67		10	45	10	5	15	15	500	16.68	CYD	16.68	500
G5260E	C.I. SKID FDN	100	100	76	78	67		10	45	10	5	15	15	337	11.24	CYD	11.24	337
G5260F	SWITCHRACK FDN	100						10	45	10	5	15	15	199	3.29	CYD	3.29	199
G5260G	MISC. FDN	51	18	57	66	18		10	45	10	5	15	15	854	16.16	CYD	16.16	854
G6260A	K.O. DRUM FDN	100						10	45	10	5	15	15	227	9.09	CYD	9.09	227
G6260B	PIPERACK FTGS							10	45	10	5	15	15	461	13.17	CYD	13.17	461
G6260C	FIN-FAN FTGS	100						10	45	10	5	15	15	265	8.82	CYD	8.82	265
G6260D	C.I. TANK FDN							10	45	10	5	15	15	500	16.68	CYD	16.68	500
G6260E	C.I. SKID FDN							10	45	10	5	15	15	337	11.24	CYD	11.24	337
G6260F	I.A. COMP/REC FDN							10	45	10	5	15	15	719	23.95	CYD	23.95	719
G6260G	SWITCHRACK FDN							10	45	10	5	15	15	199	4.70	CYD	4.70	199
G6260H	MISC. FDN	20						10	45	10	5	15	15	1500	28.45	CYD	28.45	1500
GA260A	PIPEBRIDGE 1/2 FTGS							10	45	10	5	15	15			CYD	22.25	779
GA260B	PIPEBRIDGE 3 FTGS							10	45	10	5	15	15	630	18.00	CYD	18.00	630
GA260C	PS-1 TO 12 FTGS	84	24	33	41	24		10	45	10	5	15	15	1364	38.87	CYD	38.87	1354
GA260H	SLEEPERS 1/2/3/4/5FTG	62	49	52	42	49		10	45	10	5	15	15	5779	165.11	CYD	165.11	5779
GA260L	PR-1/2/4 FTGS	55	12	9				10	45	10	5	15	15	2152	60.62	CYD	60.62	2152
GA260O	CULVERTS 1/2							10	45	10	5	15	15	939	26.83	CYD	26.83	939
GA260P	PA-1/2/3/4	54						10	45	10	5	15	15	315	18.12	CYD	18.12	315
GA260Q	DL-1 FTG										5	15	15	.50	1.08	CYD	1.08	.50
[illegible]	[illegible]									[illegible]	5	15	15	.20	.37	CYD	[illegible]	[illegible]

FIG. 8. Data File Used in Example Project

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AMEC CONTRACT-16713
PROGRESS ANALYSIS REPORT
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DETAIL ACCOUNT REPORT ABQAIQ PLANT

ACCOUNT NO.	DESCRIPTION	CUR.EST. QUANTITY	UNIT QNTY	CUR.EST. WORK UNIT	EARNED WORK UNIT	PHY. % COMPLETE	ORIG.EST QUANTITY	ORIG.EST WORK UNIT
GA260A	PIPEBRIDGE 1/2 FTGS		CYD			.00	22.25	779
GA260B	PIPEBRIDGE 3 FTGS	18.00	CYD	630		.00	18.00	630
								1364
								5779
								2152
								939
								315
								.50
								.20
								486
								800
								2465
								2291
								3126
								912
								136
								.60
								.300
								120
								.40
								16640
								2308
								239
								307
								1550
								43638

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DETAIL ACCOUNT REPORT GOSP 5

ACCOUNT NO.	DESCRIPTION	CUR.EST. QUANTITY	UNIT QNTY	CUR.EST. WORK UNIT	EARNED WORK UNIT	PHY. % COMPLETE	ORIG.EST QUANTITY	ORIG.EST WORK UNIT
G5260A	K.O. DRUM FDN	11.41	CYD	285		.00	11.41	285
G5260B	PIPERACK FTGS	16.65	CYD	583		.00	16.65	583
								349
								500
								337
								199
								854
								221
								600
								4256
								1064
								439
								600
								300
								200
								250
								6360
								225
								1477
								529
								602
								1331
								552
								2215
								1218
								668
								1282
								27496

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DETAIL ACCOUNT REPORT GOSP 6

ACCOUNT NO.	DESCRIPTION	CUR.EST. QUANTITY	UNIT QNTY	CUR.EST. WORK UNIT	EARNED WORK UNIT	PHY. % COMPLETE	ORIG.EST QUANTITY	ORIG.EST WORK UNIT
G6260A	K.O. DRUM FDN	9.09	CYD	227	22	10.00	9.09	227
G6260B	PIPERACK FTGS	13.17	CYD	461		.00	13.17	461
G6260C	FIN-FAN FTGS	8.82	CYD	265	26	10.00	8.82	265
G6260D	C.I. TANK FDN	16.68	CYD	500		.00	16.68	500
G6260E	C.I. SKID FDN	11.24	CYD	337		.00	11.24	337
G6260F	I.A. COMP/REC FDN	23.95	CYD	719		.00	23.95	719
G6260G	SWITCHRACK FDN	4.70	CYD	199		.00	4.70	199
G6260H	MISC. FDN	26.45	CYD	1500	30	2.00	28.45	1500
G6261A	K.O. DRUM FIREPROOF	1.00	LS	220		.00	1.00	220
G6262A	PAVING	1.00	LS	600		.00	1.00	600
G6401A	COOLER STRUCTURE	32.00	TON	4256	153	3.60	32.00	4256
G6401B	PIPERACK	7.80	TON	1038	74	7.20	7.80	1038
G6501A	FIN-FAN COOLERS	1.00	EA	600		.00	1.00	600
G6502A	K.O. DRUM	1.00	EA	300		.00	1.00	300
G6503A	C.I. TANK	1.00	EA	200		.00	1.00	200
G6504A	C.I. SKID	1.00	EA	250		.00	1.00	[illegible]
G6505A	I.A. COMP/REC			321				

FIG. 9. Detailed Account Report for Each Major Area

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FULL ACCOUNT REPORT ABQAIQ PLANT

ACCOUNT NO.	DESCRIPTION	CUR.EST. WORK UNIT	EARNED WORK UNIT	PHY. % COMPLETE
GA260	FOUNDATIONS	11179	2,974	26.60
GA261	FIREPROOFING	486		0.00
GA262	PAVING	800		0.00
GA401	STEELWORK	9350	1,141	12.20
GA604	DEETHANIZER PIPING	16640	6,198	37.24
GA605	FUELGAS CONVERSION	2308		0.00
GA801	INSTRUMENTATION	546		0.00
GA901	PAINTING	1550		0.00
		42859	10,313	24.06

FIG. 10. Full Account Report for Abqaiq Plant

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PRIM ACCOUNT REPORT ABQAIQ PLANT

ACCOUNT NO.	DESCRIPTION	CUR.EST. WORK UNIT	EARNED WORK UNIT	PHY. % COMPLETE
GA2	FOUNDATIONS	12465	2,974	23.85
GA4	STEELWORK	9350	1,141	12.20
GA6	PIPING	18948	6,198	32.71
GA8	INSTRUMENTATION	546		0.00
GA9	PAINTING	1550		0.00
		42859	10,313	24.06

FIG. 11. Prime Account Report for Abqaiq Plant

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ACCOUNT SUMMARY REPORT

ACCOUNT NO.	DESCRIPTION	CUR.EST. WORK UNIT	EARNED WORK UNIT	PHY. % COMPLETE	ORIG.EST WORK UNIT
260	FOUNDATIONS	18494	4,218	22.80	19273
261	FIREPROOFING	927		0.00	927
262	PAVING	2000		0.00	2000
401	STEELWORK	20403	1,591	7.79	20403
501	FIN-FAN COOLERS	1200		0.00	1200
502	K.O. DRUMS	600		0.00	600
503	CORR. INHIB. TANKS	400		0.00	400
504	CORR. INHIB. SKIDS	500		0.00	500
505	INSTR. AIR COMPRESSOR	321		0.00	321
601	ABOVEGROUND PIPING	12217		0.00	12217
602	FIREPROTECTION	450		0.00	450
603	DRAINAGE SYSTEMS	2647		0.00	2647
604	DEETHANIZER PIPING	16640	6,198	37.24	16640
605	FUELGAS CONVERSION	2308		0.00	2308
701	SWITCHRACKS	1063		0.00	1063
702	PERMANENT LIGHTING	1254		0.00	1254
703	DUCTBANKS	3110		0.00	3110
704	GROUNDING	1204		0.00	1204
705	ELECTRICAL BULKS	5214		0.00	5214
706	PANEL BOARDS	667		0.00	667
801	INSTRUMENTATION	4345		0.00	4345
901	PAINTING	4117		0.00	4117
		100081	12,007	11.99	100860

FIG. 12. Account Summary Report

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AREA REPORT

ACCOUNT NO.	DESCRIPTION	CUR.EST. WORK UNIT	EARNED WORK UNIT	PHY. % COMPLETE	ORIG.EST WORK UNIT
GA	ABQAIQ PLANT	42859	10,313	24.06	43638
G5	GOSP 5	27496	1,389	5.05	27496
G6	GOSP 6	29726	305	1.02	29726
		100081	12,007	11.99	100860

FIG. 13. Area Summary Report

and displays the aforementioned information at the full account level. Fig. 11 summarizes the same information to the prime account level. Another level of summary at the full account level is given in Fig. 12. In this report, the information is summarized across the three major project areas, instead of one specific area. Fig. 13, the area summary report, furnishes a summary at the major physical area level and at the entire project level.

Conclusion

A practical procedure for evaluating work progress in a quantitative manner is presented in this paper. The procedure uses the WBS and the earned value. A comparison to the widely used WPC method was made and some advantages of the proposed procedure over the WPC have been highlighted.

The procedure was successfully implemented during the remolding of a large petrochemical project involving upgrading of three refinery facilities. Samples of the generated reports are provided. The use of this procedure can minimize expensive contractual and legal disputes between owners and contractors regarding project status and associated contractor's compensation. The procedure is also a means of reducing the involvement of senior management in time-consuming routine tasks which can be delegated to less senior personnel. This would result in improving resource use, cost effectiveness, and contract administration. In addition, the procedure is an ex-

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cellent project tracking tool for consultants and professional construction managers, since it only requires data which are available in the estimate (or control budget) and visual inspection of the project site. The procedure does not require any data which may be considered proprietary by contractors or additional information that has to be furnished by the contractor.

It is the writer's intention to include this procedure in a comprehensive expert system for managing construction projects. Formulation of such an expert system is currently underway.

APPENDIX. REFERENCES

Barrie, D. S., and Paulson, B. C. (1984). *Professional construction management.* McGraw-Hill Book Co., New York, N.Y., 252–274.

Bromberg, I. (1984). "Earned value back to basics." *AACE Transaction,* 28th Annual Meeting, A6, Montreal, Canada.

Clark, F. D., and Lorenzoni, A. B. (1979). *Applied cost engineering.* Marcel Dekker, Inc., New York, N.Y.

"Cost and scheduling control systems criteria for contract performance measurement—Work breakdown structure guide." U.S. Dept. of Energy, Oct., Washington, D.C.

Meredith, J. R., and Mantel, S. J. (1985). *Project management—A managerial approach.* John Wiley and Sons, New York, N.Y., 324–334.

Rogers, M. F. (1979). "Cost/performance measurements—A new concept for contractors." *Trans., 23rd Annual Meeting,* Amer. Assoc. of Cost Engrs., Cincinnati, Ohio, Jul., D.8.1–D.8.4.

Russell, A. D. (1982). "General contractor project control practices and MIS." ASCE, *J. Constr. Div.,* 108(3), 419–437.

Stevens, W. M. (1986). "Cost control: Integrated cost/schedule performance." *J. Mgmt. in Engrg.,* 2(2), 157–164.