COST VARIANCES OF CONSTRUCTION ACTIVITIES WITH MULTIPLE TASKS

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ABSTRACT

In project control, cost variance of a work item is the difference between the budgeted cost of work performed (*BCWP*) and actual cost of work performed (*ACWP*). *BCWP* can be calculated as the percent complete multiplied by the total budgeted cost of a work item, and the actual cost is the cost incurred to date. The percent complete of a work item is generally the finished output units divided by the total units to be performed. Where an activity consists of multiple tasks or processes that must be performed sequentially, the overall percent complete of an activity based on the finished units tends to be underestimated.

This paper presents the calculation of cost variances at a task level through an example of a concrete pavement, which is an activity of an airport taxiway project. In this example, the concrete pavement work item is composed of two tasks: installing reinforcement and placing concrete. Two approaches of cost variance calculations are illustrated: an inaccurate method in which *BCWP* is based on the quantity of concrete placed and a more accurate method where concrete pavement *BCWP* is the sum of steel reinforcement *BCWP* and concrete placement *BCWP*. The results demonstrate the differences in accuracy of the two methods.

Keywords: Cost Variance, Project Control, Tasks.

INTRODUCTION

In project control, the progress of a work item, which can be an entire project, an activity of a project, or a task of an activity, is measured by its actual percent complete = P_a,

$$P_a = \frac{U_a}{U_p} \quad (1)$$

where,

U_a = actual number of units of output that have been completed
U_p = projected number of output units required to complete the work item

The budgeted cost of work performed to date = *BCWP*, and the actual cost of work performed to date = *ACWP* = C_a, with

$$BCWP = P_a C_b \quad (2)$$

where,
C_b = total budgeted cost of a work item.

The cost variance of a work item measures the deviation of construction cost from its budget. At any time during construction, cost variance of a work item is the difference between the total budgeted value of work actually performed and the actual cost incurred or

$$V_c = BCWP - ACWP = P_a C_b - C_a \quad (3)$$

The budgeted cost of a work item = C_b is determined at the outset of the project, in the process of estimating its cost. Percent complete, on the other hand, indicates the progress of a work item at any point in time during construction. There are alternative methods of estimating percent complete, based on measuring progress by either the quantity of output units produced or the quantity of input resource units expended. In using output units as a progress measurement, the percent complete of a single task activity is simply the quantity of finished output units divided by the total projected final output quantity. For example, the percent complete of concrete pavement may be based on the length of finished concrete pavement or the square yards of concrete placed. A variety of resource input units can be used to measure progress, which includes cost incurred, labor cost or labor hours incurred, or equipment cost or hours incurred. For example, percent complete of concrete pavement can be based on labor hours incurred versus total estimated labor hours required.

In many cases, work items such as activities are composed of multiple tasks or processes. Percent complete of such a work item should be determined with caution, because the work items with different tasks may require different resources, budgets, and working durations that have different start and finish dates. In addition, the quantities of these tasks are measured in different units and cannot be combined. For example, a concrete pavement work item may be split into two tasks: steel and concrete. Each task requires different resources and has a separate construction process. The progress of the steel task may be measured by the square yards or the tons of steel put in place, and the progress of the concrete task may be measured by the cubic yards of concrete placed.

During construction of an activity having multiple tasks, some tasks may have been finished, some may be in-progress, and some may not have started. Thus, each task generally has a percent complete that differs from the percent complete of any other task. One way engineers may measure the overall construction progress of such an activity by quantity of the finished product. That is, the overall progress may be represented by the percent complete of the last task. For instance, one may calculate percent complete of concrete pavement as the square yards of finished pavement divided by the total estimated square yards of concrete pavement at completion.

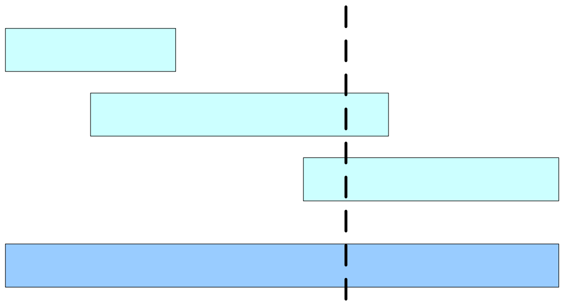

Fig. 1 – Percent complete of tasks

Fig. 1 shows work progress of A, B, and C, which are tasks of activity X. The vertical dashed line indicates the day on which progress of the three tasks is measured. On that day, task A has been completed, and P_a of task A = percent complete of task A = 100%. P_a of task B = 85%, and P_a of task C = 17%. As can be seen in

Fig. 1, C has the smallest percent complete of the tasks, because it is the final task. If P_a of the last task C is used to represent the overall progress of activity X, then P_a of X = P_a of task C = 17%. This significantly underestimates the percent complete and the *BCWP* of activity X. Note: The significance to percent complete of the overall project of this underestimation of activity X depends on the cost of X relative to the cost of the project. If the cost of X is small compared to the project, the error of underestimation is not significant in calculating the percent complete of the project; however, if the cost of X is a significant part of the project, the error of underestimation may also be significant.

ELEMENT COST VARIANCES

A different approach is required for multitask activities. This approach calculates progress of the activity as the combination of its tasks' progress. This combination of tasks' progress must recognize that different tasks of an activity typically have different resource requirements and their progress is measured in different units.

BCWP and *ACWP* of an activity are the sums of the *BCWP* and *ACWP* of its tasks,

$$BCWP = \sum_{\text{all } i} (BCWP)_i = \sum_{\text{all } i} (P_a C_b)_i = \sum_{\text{all } i} \left(P_{a_i} C_{b_i}\right) \tag{4}$$

$$ACWP = C_a = \sum_{\text{all } i} (ACWP)_i = \sum_{\text{all } i} C_{a_i}$$
(5)

where,
$(BCWP)_i$ = budgeted cost of work performed on task *i*
P_{ai} = percent complete of task *i*
C_{bi} = budgeted cost of task *i*
$(ACWP)_i = C_{ai}$ = actual cost of work performed on task *i*

And the cost variance of a work item with multiple tasks is

$$V_c = BCWP - ACWP = \sum_{\text{all } i} \left[(BCWP)_i - (ACWP)_i \right]$$

$$= \sum_{\text{all } i} \left(P_{a_i} C_{b_i} - C_{a_i} \right) = \sum_{\text{all } i} V_{c_i} = \sum_{\text{all } i} (P_a C_b)_i - C_a$$
(6)

PROJECT EXAMPLE

A recap sheet of an airport taxiway project with nine work items is shown in Table 1. As an example, the detailed calculations of cost variance of Work Item 4, Concrete Pavement are illustrated. In this example, construction cost of Concrete Pavement is the sum of costs of its two tasks, Steel and Concrete. Table 2 shows cost estimates for Steel and Concrete.

Table 1 Contractor's recap sheet

no.	Pay items	Unit	Quantity	Estimated cost ($)
1	Clearing and Demolition	each	1	18,550
2	Excavation	CY	100,500	138,120
3	Base Course	ton	78,400	868,610
4	Concrete Pavement	SY	160,000	3,552,000
5	Asphalt Surface	ton	140	3,300
6	Concrete Pipe	lf	1,100	36,400
7	Taxiway Lights	each	110	23,930
8	Taxiway Marking	each	1	6,570
9	Fence	lf	25,000	131,960

Table 2 Concrete pavement summary sheet

no.	Engineer's quantity (SY)	Sub-task	Contractor's quantity		Material unit cost ($)	Labor unit cost ($)	Equipment unit cost ($)	Unit cost ($)	Total cost ($)
4	160,000	Steel	176,000	SY	0.94	1.23	0	2.17	381,920
		Concrete	40,000	CY	55.99	20.74	2.52	79.25	3,170,080
					2,405,120	1,046,080	100,800		3,552,000

After 4 days of Concrete Pavement construction, 16,500 SY of Concrete has been placed. The site engineer now estimates that the total required quantity of Concrete Pavement has changed from budgeted quantity = C_b = 160,000 SY to projected quantity = C_p = 165,000 SY, and this causes the projected output quantities of its tasks Steel and Concrete to change. Table 3 shows the information of construction costs, new projected output quantities, quantities performed, and the costs incurred by the end of day 4.

Table 3 Work quantity and construction cost of Concrete Pavement and its sub-tasks on day 4

Job item/sub-task	Unit	Budgeted work quantity	Budgeted cost ($)	Projected quantity	Quantity performed	Cost incurred ($)	Percent complete
Concrete pavement	SY	160,000	3,552,000	165,000	16,500	381,705	10.00%
- Steel	SY	176,000	381,920	182,400	46,975	78,885	25.75%
- Concrete	CY	40,000	3,170,080	43,620	4,362	302,820	10.00%

Cost variances of Concrete Pavement at work item level

If the activity percent complete is incorrectly based on the last task = percent complete of Concrete, then

$$P_{a_{\text{pavement}}} = P_{a_{\text{concrete}}} = \frac{4{,}362}{43{,}620} = 10\% = \frac{16{,}500}{165{,}000}$$

This error would be continued through Eq. (3) to calculate an incorrect Concrete Pavement cost variance to date of

$$V_{c_{\text{pavement}}} = (10\%)(\$3{,}552{,}000) - \$381{,}705 = -\$26{,}505 \text{ (unfavorable)}$$

The correct approach is to recognize that activity progress and cost are the sum of the progress and cost of its tasks, Steel and Concrete in this instance. One can start by applying Eq. (3) to Steel and Concrete,

$$P_{a_{\text{steel}}} = \frac{46{,}975}{182{,}400} = 25.75\%$$

$$V_{c_{\text{steel}}} = (25.75\%)(\$381{,}920) - \$78{,}885 = \$19{,}459 \text{ (favorable)}$$

$$V_{c_{\text{concrete}}} = (10\%)(\$3{,}170{,}080) - \$302{,}820 = \$14{,}188 \text{ (favorable)}$$

Therefore, the actual cost variance of Concrete Pavement follows Eq. (6),

$$V_{c_{\text{pavement}}} = V_{c_{\text{steel}}} + V_{c_{\text{concrete}}} = 19,459 + 14,188$$

$$= \$33,647 \text{ (favorable)} \neq -\$26,505 \text{ (unfavorable)}$$

Eq. (2), (3), and (4) provide the basis for calculating the actual percent complete for the combination,

$$P_a = \frac{V_c + C_a}{C_b} = \frac{\sum_{\text{all } i} (P_a C_b)_i - C_a + C_a}{C_b}$$

$$= \frac{\sum_{\text{all } i} (P_a C_b)_i}{C_b} = \frac{\sum_{\text{all } i} (BCWP)_i}{C_b} = \frac{BCWP}{C_b} \quad (7)$$

Therefore, the *BCWP* for Concrete Pavement is

$$BCWP_{\text{pavement}} = (V_c + C_a)_{\text{pavement}} = 33,647 + 381,705 = \$415,352$$

And the actual Concrete Pavement percent complete = $P_{a_{\text{pavement}}}$ is

$$P_{a_{\text{pavement}}} = \left(\frac{V_c + C_a}{C_b} = \frac{BCWP}{C_b} \right)_{\text{pavement}} = \frac{\$415,352}{\$3,552,000} = 11.693\ \% \neq 10\ \%$$

This correct value of $P_{a_{\text{pavement}}}$ will calculate the correct value for Concrete Pavement variance when used in Eq. (3), which just reverses the calculations immediately above.

$$V_{c_{\text{pavement}}} = (11.693\%)(\$3,552,000) - \$381,705 = \$33,647 \text{ (favorable)}$$

Cost variance components based on progress of last task

Activity cost is the product of *U* = quantity of units and *C/U* = cost per unit,

$$C = \frac{C}{U} U \quad (8)$$

and the cost variance is the sum of $V_{c\ U}$ = cost quantity variance = variance due to U_p = projected number of units ≠ U_b = budgeted number of units and $V_{c\ C/U}$ = cost quantity variance = variance due to $(C/U)_a$ = actual cost per unit ≠ $(C/U)_b$ = budgeted cost per unit, where

$$V_{C\ C/U} = U_a\left[\left(\frac{C}{U}\right)_b - \left(\frac{C}{U}\right)_a\right] = U_a\left(\frac{C_b}{U_b} - \frac{C_a}{U_a}\right) = C_b\frac{U_a}{U_b} - C_a \tag{9}$$

$$V_{C\ U} = \frac{C_b}{U_b}\left[P_a U_b - U_a\right] = C_b\left(P_a - \frac{U_a}{U_b}\right) \tag{10}$$

and

$$V_C = V_{C\ C/U} + V_{C\ U} = \left(C_b\frac{U_a}{U_b} - C_a\right) + C_b\left(P_a - \frac{U_a}{U_b}\right) = P_a C_b - C_a \tag{11}$$

which agrees with Eq. (3).

If the activity percent complete is incorrectly based on the last task = percent complete of Concrete, then $P_{a_{\text{pavement}}} = P_{a_{\text{concrete}}} = 10\%$ as was shown above. Variance components based on this incorrect value of $P_{a_{\text{pavement}}}$ are

$$\left(V_{C\ C/U}\right)_{\text{pavement}} = \left(C_b\frac{U_a}{U_b} - C_a\right)_{\text{pavement}}$$

$$= \$3,552,000\left(\frac{16,500\ \text{SY}}{160,000\ \text{SY}}\right) - \$381,705$$

$$= \$3,552,000(0.103125) - \$381,705$$

$$= -\$15,405\ \text{(unfavorable)}$$

$$\left(V_{C\ U}\right)_{\text{pavement}} = \left[C_b\left(P_a - \frac{U_a}{U_b}\right)\right]_{\text{pavement}}$$

$$= \$3,552,000\left(10\% - \frac{16,500\ \text{SY}}{160,000\ \text{SY}}\right)$$

$$= \$3,552,000(-0.003125)$$

$$= -\$11,100\ \text{(unfavorable)}$$

and by Eq. (11),

$$V_C = V_{C\ C/U} + V_{C\ U} = -\$15,405 - \$11,100 = -\$26,505\ \text{(unfavorable)}$$

which agrees with the incorrect value calculated earlier. These results indicate that the difference between actual and budgeted cost per unit has increased the project cost to date by $15,405, and the difference between actual and budgeted total number of units has increased the project cost to date by $11,100, a total increase of $26,505.

Cost variance components based on activity = sum of tasks

The correct approach to calculating cost variance component values parallels earlier calculations that recognize that activity progress and cost are the sum of the progress and cost of its tasks, Steel and Concrete in the example.

Eq. (9) to (11) can be applied to Steel and Concrete,

$$(V_c\ C/U)_{\text{steel}} = \left(C_b \frac{U_a}{U_b} - C_a\right)_{\text{steel}}$$

$$= \$381,920\left(\frac{46,975\ \text{SY}}{176,000\ \text{SY}}\right) - \$78,885$$

$$= \$381,920(0.2669) - \$78,885$$

$$= \$23,049\ \text{(favorable)}$$

$$(V_c\ U)_{\text{steel}} = \left[C_b\left(P_a - \frac{U_a}{U_b}\right)\right]_{\text{steel}}$$

$$= \$381,920\left(25.75\% - \frac{46,975\ \text{SY}}{176,000\ \text{SY}}\right)$$

$$= \$381,920(-0.0094)$$

$$= -\$3,590\ \text{(unfavorable)}$$

$$V_{c_{\text{steel}}} = (V_c\ C/U + V_c\ U)_{\text{steel}} = \$23,049 - \$3,590 = \$19,459\ \text{(favorable)}$$

$$(V_c\ C/U)_{\text{concrete}} = \left(C_b \frac{U_a}{U_b} - C_a\right)_{\text{concrete}}$$

$$= \$3,170,080\left(\frac{4,362\ \text{CY}}{40,000\ \text{CY}}\right) - \$302,820$$

$$= \$3,170,080(0.10905) - \$302,820 = \$42,877\ \text{(favorable)}$$

$$\left(V_C\ U\right)_{\text{concrete}} = \left[C_b\left(P_a - \frac{U_a}{U_b}\right)\right]_{\text{concrete}}$$

$$= \$3{,}170{,}080\left(10.00\% - \frac{4{,}362 \text{ CY}}{40{,}000 \text{ CY}}\right)$$

$$= \$3{,}170{,}080(-0.00905)$$

$$= -\$28{,}689 \text{ (unfavorable)}$$

$$V_{C_{\text{concrete}}} = \left(V_C\ C/U + V_C\ U\right)_{\text{concrete}} = \$\$42{,}877 - \$28{,}689 = \$14{,}188 \text{ (favorable)}$$

Then, in parallel with Eq. (6), activity variance is the sum of task variances,

$$V_C\ C/U_{\text{pavement}} = V_C\ C/U_{\text{steel}} + V_C\ C/U_{\text{concrete}}$$

$$= 23{,}049 + 42{,}877$$

$$= \$65{,}926 \text{ (favorable)}$$

$$V_C\ U_{\text{pavement}} = V_C\ U_{\text{steel}} + V_C\ U_{\text{concrete}} = -3{,}590 - 28{,}689 = -\$32{,}279 \text{ (unfavorable)}$$

and by Eq. (11)

$$V_C = V_C\ C/U + V_C\ U = 65{,}926 - 32{,}279$$
$$= \$33{,}647 \text{ (favorable)} \neq -\$26{,}505 \text{ (unfavorable)}$$

CONCLUSION

The accuracy of cost variance calculations is dependent on the accuracy of the estimated percent complete. Estimating the percent complete of an activity with multiple tasks is somewhat complicated, because input and output of different tasks are measured in different units; hence, they cannot be combined. Therefore, the best approach is to report progress and variance in a common unit, their budgeted cost equivalents. Using percent complete of the final task to represent the overall progress of an activity leads to underestimated *BCWP* and unfavorably overestimated cost variances.

To avoid mistakes and troubles in finding the percent complete of multi-task activities, the activity *BCWP* can be calculated as the sum of the *BCWPs* of its tasks. Additionally, the cost variance of a multi-task activity is the sum of the cost variances of its tasks. Activity and task cost variances can also be decomposed into cost quantity variance and unit cost variance.

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NOMENCLATURE

U = Number of units of quantity, such as meters or cubic meters
$C = c$ = Cost in dollars
P = Percent complete = partial completion
V = variance = difference between budgeted value and actual value

Quantities of these variables are subscripts:
b = budgeted to be required at completion of the process,
a = actual to date,
p = projected at completion

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