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It is a recognized fact, as discussed by Zey Emir in the lead article of the October 1999 issue of the Revay Report (Volume 18, Number 3), that if crews or individuals produce more of the same product, their productivity improves. This improvement can be quite pronounced at the early stages of the project and it usually continues, albeit at a gradually reduced rate, as long as the flow and the character of the work remains unhindered by any extraneous impediments.

Notwithstanding this axiom, one is frequently exposed to cost records from construction projects which show the opposite, namely the best productivity may have been recorded during the first third of the project but rapidly deteriorated thereafter.

I have often been called upon to analyze projects where the contractor has reported profit until sixty or seventy percent completion, but sustained significant losses thereafter for no apparent reason. Do these projects put the learning curve theory in question or is this phenomenon the result of faulty progress reporting practice?

There are those who will argue that the final ten to fifteen percent of any task always takes longer than the average time required until then. On the surface this is a valid observation, particularly in times of high unemployment. A more in-depth analysis may, however, reveal that the slowdown resulted from some extraneous influence or simply from a change in the character of the work, such as final tie-ins or perhaps from correcting deficiencies, and not from automatic reduction in productivity being the natural consequence of approaching the end of a task. In either case, these anomalies can be an insurmountable handicap both in respect of proper job management and, if necessary, in the quantification of a claim.

The lead article of this issue, by Brian Foster of our Toronto office, describes a practical method of monitoring progress in a meaningful way on construction projects.

Finally, let me welcome Tom Martin back into our fold. Some of you may remember that Tom joined us in January 1994 as the president of our US operation. Unfortunately, he left us in January 1996 as the result of RAL losing its independence. Recently I was able to convince him to assume his earlier position and under his leadership we have opened an office in Gaithersburg, MD.

MONITORING JOB-SITE PRODUCTIVITY

by **Brian Foster**, Consultant
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It has been said that if you are not planning, organizing, coordinating, motivating and controlling, then you are not managing. During recent years, the construction industry has received considerable criticism from buyers of construction services for a perceived lack of management skills. The analysis of twenty-five projects executed over the past decade, and more specifically a close look at the 2.2 million manhours expended on these projects has provided support for such an allegation. Considering that, based on the competitive lump sum bidding process, the required manhours to perform these projects were estimated to be 1.1 million, the allegation deserves serious consideration.

The reasons for this overrun in manhours are numerous and varied but can be summarized as scope changes, project compression, bid errors, design errors, substandard materials, poor workmanship, changed conditions and interference by either client or other contractors.

A project cost overrun rarely flows from one source or responsibility, nevertheless contractors and buyers of construction services invariably take the stance — “it was all your fault” — which is why the involvement of an independent third party may be necessary. For such an intervention to be successful, the third party must be provided with some basic necessities. When planning and control have been effectively in place on a construction project, the incidence of residual dispute at project completion is greatly minimized. When planning and control are deficient, the chances of a clear determination, after the fact, are severely reduced.

For the purposes of this article the following definitions are offered:

Planning — involves the making of budgets, setting of objectives, formulation of policies, preparation of schedules and the making of forecasts.

Control — involves implementation of policies, enforcement of procedures, the establishment of accountability, work breakdown structures, codes of account, measurement of work-in-progress, cost and manhour collection, progress and productivity monitoring, analysis, interpretation of results and corrective action.

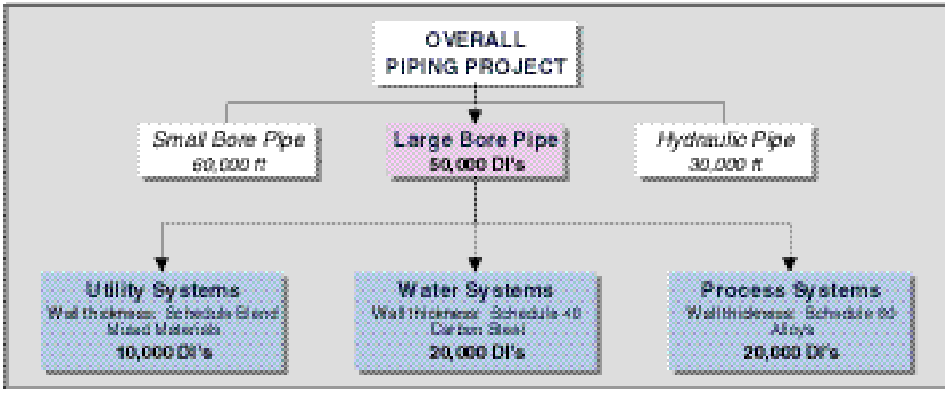
Over the past few years with the evolution of comprehensive scheduling software, there has been a marked improvement in detailed scheduling. Unfortunately, scheduling alone does not provide construction managers with sufficient data to forecast where the project is headed. The modern software is capable of creating ’monster’ schedules very quickly. All too often, managers are swamped with reams of never-to-be-used information. The firm price contractor faced with make-or-break decisions needs reliable forecasting and profitability data. The completion schedule must be adequately resource-loaded and strategies implemented for the recovery of extraneous costs.

This article is intended to stress that scheduling alone very rarely saves the day.

Construction Productivity in the Ideal Project

The October 1999 issue of the Revay Report dealt with the “Learning Curve” in construction and explored the theory that the speed or efficiency with which a task is performed increases as the number of units of work increases. This

Figure 1. Typical Work Breakdown for Pipe Installation



present article recognizes the learning curve phenomenon and is offered as an illustration of the ways, means and benefits of measuring and monitoring progress and productivity in the field, with a view to minimizing the impact of the unanticipated and the unforeseen.

What is Productivity Anyway?

There remains a certain amount of misunderstanding and misuse of the term, for it is used in many different contexts and means different things to different people. In its simplest form, productivity is an expression of what is being accomplished (in terms such as diameter-feet of pipe, diameter-inches of buttwelds) versus what is being expended (crew manhours).

Some take it a step further, comparing the planned one manhour per unit with the actual, say 1.3 manhours per unit and state that the productivity is (1:1.3) or 77 percent. This relationship is of course essential when considering profitability. However, in the first instance, it is imperative to establish the actual trend — at 30 percent completion the productivity was 1.3 manhours per widget and now at 50 percent completion it is 1.6 manhours per widget. What is going wrong? By now, the planned one manhour per widget is probably unachievable, nevertheless, there remains 50 percent of the work to be tightly controlled.

If it is found that the productivity deterioration between 30 percent and 50 percent of project completion coincides with the sudden realization that widgets were not fitting on the first visitation, or that the client was introducing excessive changes, or that excessive overtime was being worked, then one is well on the way to demonstrating cause and effect.

Why Monitor Productivity?

There are several important reasons why a contractor should monitor productivity in a reasonably sophisticated manner. Apart from providing valuable information for future bids, it also provides a yardstick by which to measure the competition. Furthermore, when productivity monitoring is in place, reliable forecasting is possible, meaning that completion schedules can be realistically resource-loaded.

Equally important is the notice provision of the contract. When a project manager is aware of the productivity trend, cause and effect are more readily established, thereby facilitating mitigation. Credible calculations of additional cost can be recorded and, if warranted, submitted to the client as a request for additional compensation. This style of project management invariably diminishes the need for claims submissions long after completion of the work, when much of the fact has faded into history.

How to Monitor Productivity

An uncomplicated and usable Work Breakdown Structure (WBS) is an essential first step. This is where an independent consultant can become invaluable. The in-house project management is quite naturally drawn to the bid estimate as a basis for designing the control system. An independent consultant may advise that although the estimate was instrumental in getting the project, accurate schedules and budgets prepared subsequent to the award of the contract and preferably by others than the estimators, would be necessary to control it. If small-bore hydraulic piping has been overlooked in the estimate, it certainly will not be overlooked in the WBS. Nor will the fact that the hydraulic support/anchoring system must be in accordance with the power piping code. Attempting to build the job with less manhours than are practical is courting disaster.

Figure 1 illustrates a typical WBS for pipe systems installation.

The diameter-inches (DIs) may not have been calculated at the time of bidding, but were established during the initial planning and kick-off of the project. This valuable exercise should probably involve the piping foremen. In any case, because the scope of prefabrication has to be determined as soon as possible, this exercise is a must. Welding procedures must be established and x-ray scopes developed. Crew sizes must be calculated and the welder/pipefitter relationship set. The requirements for construction equipment, tooling and consumables must be established. Thus, the WBS effort is not really adding more to the overhead cost. Rather, it can be considered an investment, essential to receiving timely, informative reports that will be available to operations and project management on Monday afternoon, following the Friday afternoon close-out.

Having established the most suitable WBS, the next step is to break down its key segments which will best represent the critical path of the project. Figure 1 shows that large bore piping should be further broken down. Small bore and hydraulic piping are allocated their respective weightings and can then be monitored simply but reasonably accurately in terms of footage installed.

Figure 2 is an illustration of how best to break down the large bore piping.

Figure 2.
Breakdown of Large Bore Piping

Pipe diameter	Utility systems	Water systems	Process systems	Total DIs
3	5 000			5 000
4	3 000	4 000	1 000	8 000
6	1 000	8 000	3 000	12 000
8	500	4 000	4 000	8 500
10	500	2 000	3 000	5 500
12		1 000	4 000	5 000
18		500	3 000	3 500
24		500	2 000	2 500
Total	10 000	20 000	20 000	50 000

This is a summary of individual WBS layout sheets, which have been filled in by counting the field welds shown on the drawings. This is a useful orientation exercise for the foremen. An independent consultant could provide reality checks.

Figure 3. Progress/Productivity Record

Location (bay)	Level	Line ref.	Pipe diameter	Total no. of welds to do	Equivalent total Dis of welds to do	Total no. of welds completed to date	Equivalent Dis completed to date
1	3	W1	4	3	12	1	4
4	8	W2	8	5	40	4	32
15	1	G1	16	4	64	2	32
etc...							
Total					50,000		24,470

Figure 3 illustrates how the base data (the field weld count) is set up as a spreadsheet, to facilitate the necessary sorting.

The WBS coding illustrated in Figure 3 provides the capability to sort by location, level, system/line reference as well as line diameter. Each foreman should be given responsibility for a precise portion of the WBS. The eventual task of transferring responsibility from erection crew to testing crew is also made easier. 'Sorts to manage by' should be firmly established prior to commencing the work take-off.

Figure 4a. Progress Sort (by System)

Systems	Dis of welds to do	Completed to date	% Complete
Utility			
Air	*6,000*	*3,240*	*54%*
Lube	*4,000*	*2,215*	*55%*
Water			
Plant Water	*7,000*	*6,750*	*96%*
Cooling Water	*8,000*	*5,395*	*67%*
De-scale Water	*5,000*	*1,165*	*23%*
Process			
Process A	*4,000*	*595*	*15%*
Process B	*7,000*	*3,510*	*50%*
Process C	*9,000*	*1,600*	*18%*
Total	50,000	24,470	49%

Figures 4a, 4b and 4c illustrate the readily available management information derived from the monitoring system. This information is essential for modifying the completion schedules.

As seen, 24,470 diameter inches of welding have been completed to date. The project progress stands at 49 percent.

The final step is to determine the performance and profitability of the project.

Figure 4b. Progress Sort (by Location)

Location (bay)	Dis of welds to do	Completed to date	% Complete
Bay 1	5,000	3,400	68%
Bay 2	4,500	2,600	58%
Bay 3	6,200	3,100	50%
Bay 4	7,800	4,200	54%
..	26,500	11,170	42%
Total	50,000	24,470	49%

Figure 5. Calculation of the Productivity Index

Prime WBS	Quantity	Measure	Completed to date	% Complete	Share	Earned value
Small Bore Pipe	60,000	ft	20,000	33%	20	6.67
Large Bore Pipe	50,000	di	24,470	49%	60	29.36
Hydraulics Pipe	30,000	ft	5,000	17%	20	3.33
Overall Pipe Progress (%)						**39.36**
Overall piping manhours worked						103,565
Actual manhours per 1% of job progress						2,631
Bid manhours per 1% of job progress						2,450
Productivity Index (PI)						**93%**

Figure 5 is an illustration of the final piece of information required to manage the job.

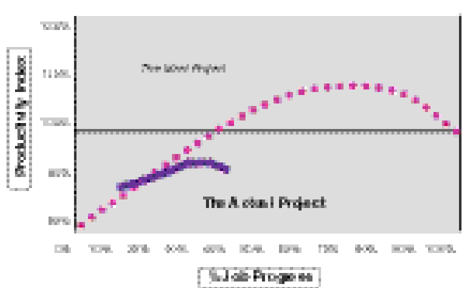
As seen, the overall pipe progress has been accurately determined to be 39.36 percent. The actual productivity is calculated as 2,631 manhours per 1 percent of progress. It should be noted that, in arriving at this figure the bid estimate was not consulted.

The comparison of the actual versus bid productivity indicates that things are not going well — the Productivity Index (PI) is tracking well below the traditional level. Why? Answering this question is the true role of the independent consultant. There can be many reasons ranging from low estimate to far too many changes.

Figure 4c.
Progress Sort (by Pipe Diameter)

Pipe Diameter	Dis of welds to do	Completed to date	% Complete
3"	5,000	3,200	64%
4"	8,000	1,800	23%
6"	12,000	7,500	63%
8"	8,500	3,500	41%
10"	5,500	1,200	22%
12"	5,000	4,800	96%
18"	3,500	2,000	57%
24"	2,500	470	19%
Total	50,000	24,470	49%

Figure 6.
Actual Productivity vs. Bid Productivity



Graphing the PI as in Figure 6 assists the consultant in several ways. The point of the off-trends, in progress and time, can be readily pinpointed. Differential cost calculations, based on productivity attained when the work was least disrupted, delayed or interfered with, may be demonstrated. Cause can be linked to effect.

The above curve represents a cumulative track, therefore it is more difficult to alter its direction as the progress is heading toward one point only — 100 percent complete. If it is found that the dramatic recent shift in the trend is the result of an abnormal amount of design changes, the impact cost can be credibly calculated.

Benefits of the Early Introduction of an Independent Consultant

The consultant could be visiting the job-site with the project superintendent on a regular basis to guide the foremen and superintendent through the spreadsheets in order to establish the percent complete of each activity on the WBS. At any given time no more than 20 percent of the activities will have been in progress during the period just ending, therefore it will never be a daunting or impossible task. The basic questions to be considered are

a) has the activity been started?

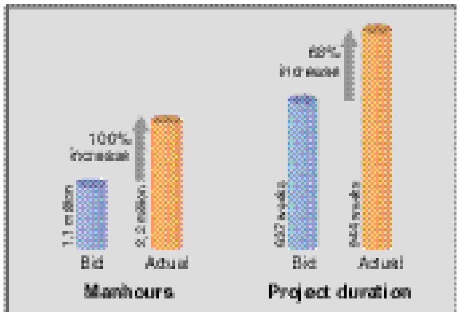
b) how far has it progressed to the nearest 10 percent?

c) has the activity been completed?

The results can be immediately discussed with the responsible personnel. Soon, all the reasons for the calculated result are established and rolled into an effective management report.

Not surprisingly, working in this manner, management and supervision develop good relationships and together become schedule- and cost-conscious. As a result, meaningful resource loaded completion schedules are produced with little effort. In short, they

Figure 7. Overview of Contractors' Performance on Twenty-five Mandates



become better supervisors and managers. The company thrives.

The Relationship Between Project Duration and Manhours Expended

As a byproduct of these progress / productivity-monitoring services, the contractor is in a position to step back every now and then and compare the performance achieved on different projects. Figure 7 provides an overview of twenty-five mandates carried out over the past few years during which over 2 million manhours were actually expended. Mechanical projects account for 35 percent of the expended manhours, and electrical projects account for 55 percent. The remaining 10 percent consists of supporting work such as fabrication and coverings.

In Figure 7, the x- and y-axis represent actual duration and actual manhours from the above referenced twenty-five projects. It was interesting to discover that, whereas the bid hours were 1.1 million and the actual hours were 2.2 million (100 percent overrun), the combined planned duration of the work was 637 weeks versus 944 actual weeks (48 percent overrun).

The work was seldom completed within the allotted time and in most of these projects such a breach of contract occured.

It has been found that in instances where the first 40 percent of the required construction duration was not wholly available for cost effective construction activities (through lack of design, materials, access etc.), there was a manhour overrun which was not fully accounted for by traditional contract change orders. The owner, often relying on a contract clause that states "changes in the work may be made, without invalidating the contract", overlooks the fact that too-frequent changes and changes in fact resulting from design errors or substandard owner-supplied materials, cannot be performed without altering the contract schedule.

It is worth noting that approved change orders account for only approximately 30 percent of the manhour overrun in the twenty-five projects studied. Almost 20 percent of the overrun is attributable to estimating errors or ambiguous specifications.

Accordingly, some 50 percent of the manhour overrun is caused by impact, which still remains an unspoken (or at least a misunderstood) word amongst many owners. The planned flow of work is denied to the contractor who, in an effort to mitigate delays, incurs the natural losses associated with stop-and-go work, relocation of crews, multi-shifts and extended workweeks, crew sizes above optimum, to name just a few impacting factors.

For example, sub-trade contract with 30,000 manhours and a nine-month schedule, is showing all the danger signs after just two months. In this case, it is worth considering that an impact loss of 15,000 manhours (possibly valued at $800,000) might be gathering momentum. It will be much easier and more prudent to demonstrate and evaluate cause and effect from week to week.

Planning and Control can help to manage and minimize construction claims. An independent consultant can objectively appraise the situation and offer advice on claim strategy.

One final note. Of these twenty-five projects, six proceeded to litigation, and none were put before a judge.

The Revay Report is published by Revay and Associates Limited, a national firm of Construction Consultants and Claims Specialists, assisting owners and contractors in achieving profitable and trouble-free construction projects.

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