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Effective Use of Earned Value for Controlling Construction Projects

Laurie Bowman, CCP DRMP EVP PSP
and Mina Sabouri, PSP

Abstract— the effective management and control of construction performance is a key determinant in overall project success. It is in the interests of both the contractor and the owner to plan, measure, monitor and control construction progress so that:

1. Project managers are well informed of problems and opportunities early and are better informed to make decisions that have a positive impact on project and;
2. It is easier to identify delay, disruption and productivity problems and their root causes so they can be resolved quickly so that stakeholders' goals are satisfied and the risks associated with dispute and litigation reduced.

Key aspects of construction performance management include setting a valid performance measurement baseline, systematic performance updates, controlling scope change and regularly working closely with the project team to optimize forecasts to complete the remaining scope of work. By setting up the project well and systematically employing effective processes for measuring progress, assessing risks, controlling scope changes and forecasting you can reduce cost risks and increase the likelihood of project success.

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List of Abbreviations

Abbreviation	Expansion
AC	Actual Costs
Av	Average
CBS	Cost Breakdown Structure
CPI	Cost Performance Index
EAC	Estimate at Completion
EOT	Extension of Time
ETC	Estimate to Complete
EV	Earned Value
EVM	Earned Value Management
FTE	Full Time Equivalent
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
hrs	hours
IBR	Integrated Baseline Review
LDs	Liquidated Damages
NCR	Non-Conformance Report
OBS	Organizational Breakdown Structure
PMB	Performance Measurement Baseline
PV	Planned Value
RAM	Responsibility Assignment Matrix
S Curve	Chart of planned, earned value and actual costs versus time
SPI	Schedule Performance Index
WBS	Work Breakdown Structure

Introduction

There are great benefits to be gained by effectively managing construction performance on a project. This paper describes the application of earned value performance measures as applied on the construction phase of a multidiscipline construction project. By utilizing Earned Value Management (EVM) principles and establishing effective project control processes both owner and contractor can effectively identify and respond to cost and schedule risks such as resource availability, performance problems and scope changes. This paper outlines some key concepts on establishing effective EVM systems and processes, and outlines many of the benefits of using earned value on construction projects. It also provides practical examples of these benefits from a case study. The benefits of applying earned value management apply for both owners and contractors and, contrary to popular belief, there are risk reduction benefits to an owner even if the construction contract is fixed price

Setting up a Construction Project for EVM

Performance Measurement Baseline

All EVM performance measures are made against the Performance Measurement Baseline (PMB). The purpose of this baseline is to establish a benchmark against which cost and schedule variances can be measured, quantities tracked, progress claims validated and performance metrics calculated. It is vital that a credible baseline be established at the start of the project so that variances and performance measures are valid. The baseline is essentially a resource loaded schedule containing the authorized scope of work and the overall budget for the work. Cost Engineers can then work with Contract Administrators to use the schedule as the basis to verify progress claims for the value of work accomplished as a contractor, or for claim verification as an owner. By aligning the schedule progress with progress claims it also helps ensure the validity of forecasts for remaining work are accurate.

The steps involved in creating the baseline can be summarized as follows:

1) Organize the Work
   This involves defining the scope of work, Work Breakdown Structure (WBS), identifying control accounts (the points in the WBS at which actual costs and schedule progress can be compared), identifying key stakeholders, defining the Organizational Breakdown Structure (OBS), defining the Responsibility Assignment Matrix (RAM), determining the cost estimate, determining the execution and contracting strategy, and defining the reporting requirements.
2) Create the Schedule
   This involves defining activities, determining durations, relationships, constraints, calendars, loading resources and costs to activities, identifying key interfaces and milestones, analyzing the schedule health, applying coding and modeling project risk (ideally using quantitative

cost and schedule risk analysis). The quantities, resources and budgets in the schedule control accounts are aligned with those in the control accounts of the cost control system. The schedule is aligned with the assumptions of the project risk register and risks are cross referenced in the schedule.

3) Set the baseline
   This step involves refining and optimizing the schedule, analyzing and validating the critical path, gaining buy-in from key stakeholders, documenting the basis for the schedule and creating the baseline in the project controls system. The results of the quantitative cost and schedule risk analysis will be considered and costs and schedule contingency applied to an extent that depends on the risk appetite of the Project Manager and organization.

Integrated Baseline Review

Prior to accepting the PMB it is beneficial to conduct a review. The purpose of this review is threefold; firstly to establish whether the project has a realistic plan to completion, secondly to verify commitment to the plan from key stakeholders and thirdly to establish a baseline that can be used to measure performance.

The IBR Process verifies that project managers will be able to effectively utilize the project PMB to assess performance, and to better understand the project's inherent risks.

The IBR helps ensure the project has an achievable plan and, once approved, change control should be instigated to manage change to the baseline scope, cost and schedule.

The benefits of an IBR include:

- Clarifies the objectives for the project
- To verify that all parties are reviewing the same scope of work including Engineering (Design Packages), Procurement (Contracts and Procurement Packages), Construction (Work Packages), Commissioning (Work Packages) and Project Controls (Work Breakdown Structure, Budgets, Quantities, Resources)
- Provides an opportunity for key stakeholders to align their expectations
- Promotes Project Management Team member knowledge of the project plans and risks and opportunities
- Determines whether the baseline covers the entire scope of work, is realistic and satisfies the project objectives
- Increases confidence in the project PMB, which enables timely and reliable cost and schedule projections
- Clarifies the expected methods of measuring quantities installed and progress for the different activities being undertaken e.g. Earthworks, Civil and Structural, Mechanical Installation and Electrical
- Clarifies the expected reporting requirements for the project

- Ensures there is alignment between quantities, resources and dollars the schedule and in the cost control system
- Ensures there is alignment between the quantities and costs in an owners team schedule and the quantities and prices in a contractors Bill of Quantities

Depending on the size and risk of the project the IBR can be either highly structured and formal or less rigorous and informal.

Progress Updates

Systematic Updating and Forecasting - Drum Beat

Performance reporting becomes more effective if the reporting process is designed to be systematic in nature rather than an ad-hoc compilation of progress information. The reporting process is an integration of a variety of time dependent inputs so the entire project control system needs to be synchronized well. This requires that the project team be committed to process. For example weekly reporting provides project managers with frequent feedback on project performance so that “surprises” are minimized and corrective actions can be taken quickly. For weekly reporting the project team needs to commit to providing status updates, timesheet submissions and other data on the day required (e.g. every Friday). The project controls team then commit to the project manager to process the progress, cost and forecast information, analyze and deliver reports like clockwork every week (e.g. every Monday). By maintaining discipline in these areas it greatly improves the quality of status updates and the value of information that is provided to the project manager and other stakeholders. The chain is as valuable as the weakest link and if full team commitment to the process is achieved then the data flowing in will be timely and hygienic and the information provided to the Project Manager will be valuable. Team progress meetings can be synchronized to occur every Tuesday thereby having a fresh set of weekly earned value reports for each meeting. Cost Engineers and planners can use the mid week period to implement approved changes and baseline updates so that the schedule and costs structures are stable for the weekly update due on the Friday. Once these weekly Plan-Do-Check-Act performance habits are established they are easy to maintain. Some organizations may require significant culture change in order to achieve weekly EVM reporting in which case monthly reporting might be appropriate to begin with. A typical weekly reporting cycle or “drum beat” is shown in figure 1.

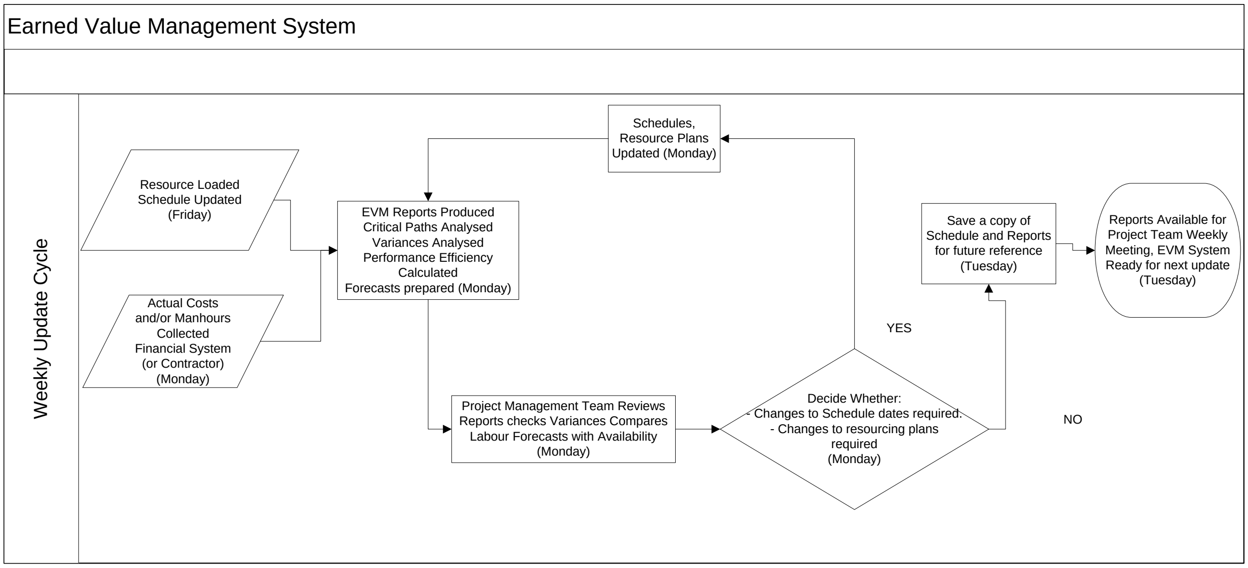

Figure 1 – Typical Project Weekly Reporting Cycle

Reporting and Communication

The earned value management system is a valuable communication tool on a project. If set up well it can inform a variety of stakeholders at different levels and can provide information in different formats to suit the needs of different stakeholders. It is essential that lower level schedules and reporting tools (Level 4 and 5) are vertically aligned with the level 3 schedule so that progress rolls up seamlessly. The detailed level 3 schedules also needs to be vertically aligned with the level 2 schedule and level 1 milestone schedules so that the data can roll-up seamlessly and to ensure consistency in schedule reporting at different levels. Different levels of stakeholders have different information needs to enable them to plan and make decisions for future. High level management may be interested in high level cost performance summaries expressed in dollars and level 1 Milestone dates, whilst project team leaders may be interested in cost and schedule performance and productivity reports and resource histograms expressed in Full Time Equivalent (FTE) which help them plan for future manpower requirements, whereas frontline construction supervisors are likely to be more interested in quantity tracking curves. At the start of the project it's beneficial for Cost Engineers to be aware of the various reporting needs and set up the project control system to enable reporting to a range of stakeholders without creating excess administration. This will increase the value of the project control system by enhancing each key stakeholders' visibility of their area of influence on the project and best enabling them to identify trends and risks and apply timely mitigation. Although the capacity to establish effective project controls is somewhat constrained by an organization's project management maturity, in most cases it should still be possible to establish a simple Earned Value management EVM system that at least describes performance and progress for high level stakeholders.

Frequency of Updates and Record Keeping

By performing regular updates of the project schedule and EV system the project managers receives regular feedback regarding project progress that enables them to respond quickly to risks and opportunities as they arise. The other advantage of regular updates and Earned Value reporting is that it creates an excellent contemporaneous historical record of the project. By maintaining weekly records of the project schedule and earned value reports an entire performance history can be retained including the projects critical path, productivity levels, records of the issues causing productivity problems and their impacts for any given week of the project. Earned Value reports can be supplemented by verification of progress including site photographs and reports from quantity surveyors. This weekly history is like a time lapse camera recording of project performance and is invaluable for creating a lessons learned for future projects and becomes excellent evidence for avoiding or resolving disputes regarding delays, back-charges, disruptions and EOTs. If contractor and owner exercise effective earned value management practice by setting up a logically linked network of resource loaded activities, and agreed methods of measurement, and regularly monitor progress, incorporate agreed changes and revise forecasts against this network then they will always know where their critical path is, will be in position to assess and measure how and why they are being delayed and will have the records to demonstrate these causes and impacts. The contemporaneous records from weekly updating and reporting help avoid disputes and the need for retrospective analysis. During the set-up of the project PMB and project control processes the Cost Engineer has a great opportunity to set the project up for success by defining, and gaining project team commitment to, a reporting calendar that incorporates the weekly “drum beat” for status updates, performance reports (weekly and monthly) and team progress meetings.

Change Management Process

Every scope change or variation that occurs on a project has the potential undermine or disrupt the validity of the earned value performance metrics if these changes are not tracked and controlled well. A disciplined change control process is absolutely essential in order for EVM performance metrics to remain reliable when scope change occurs. The project team needs to be proactive in:

1) Identifying potential changes to the project scope, schedule or cost
2) Assessing and documenting the cost and schedule impact of each potential change and,
3) Ensuring that management are aware of the risks associated with potential changes and expedite for timely decisions so that change management cycle times are kept as low as possible.

Approved scope changes should be included in the schedule forecast and added to the performance measurement baseline as soon as possible after approval. Lack of clarity and slow decision making regarding potential changes can result in distorted performance metrics, increased rework and high levels of uncertainty and inefficiency for owner's and contractor's project teams. If a project is subject to frequent change proposals it is beneficial to have regular change management workshops to encourage open discussion and effective, timely decision making regarding all potential changes that are proposed. There are many factors that can have a large influence magnitude and frequency of changes and it is beneficial for a cost engineer to have an awareness of them so that effective communication processes and controls can be established. Some of the larger sources of project change have been summarized in the following sections.

Risk Management

Project risk reviews and workshops tend to involve a lot of decision making regarding project priorities and risk mitigation activities. It is very beneficial for the cost engineer to be involved in these meetings to provide information to assist the decision making processes and to ensure that all decisions made, changes and risk mitigation work is captured in the project forecast. The project budget should include contingency that allows for the project's identified risks ("known unknowns") and well as an allowance for unidentified risk ("unknown unknowns"). By allocating budget to contingency in this manner it ensures that project progress is weighted appropriately overall progress allows for contingency as part of the uncompleted scope. The contingency can be drawn down upon via the change control process as risks and their associated treatments are identified during the project.

Design Package Risks

Another significant risk occurs if the construction contract is awarded prior to the design being completely mature. If design packages are evolving and being issued for construction while the construction phase is in progress it can cause changes in execution strategy, disruptions to progress and cause significant project changes or variations.

It is beneficial for the cost engineer to expedite the completion of design as much as possible prior to awarding a fixed price construction contract to mitigate the inefficiencies caused to a project by late project changes and the negotiation processes involved for fixed price contracts. The cost engineer should work with design teams to identify and expedite all constraints to releasing holds from design packages, such as vendor data, so that the construction team can proceed with certainty and without disruption.

Constructability Risk

Different contracting models tend to yield differing levels of scope change during the construction phase. It is very beneficial to involve construction expertise as an integral part of the project team from the beginning of the project with participation throughout the design phase. This collaboration will help ensure that construction phase safety and cost effectiveness is considered in the project design. The constructability review should include safety management planning such as HAZID (Hazard Identification) and HAZOP (Hazard and Operability Study) and Planning for Traffic Management if applicable.

Conducting regular constructability reviews during design phase with Construction experts and, where possible, the construction contractor help reduce the risk of constructability problems especially when the design and construction contractors are different entities. This would enable value adding input from the construction contractor and mitigate the risk of changes late in the project.

There are significant advantages when the Design and Construction Contractor are the same entity thereby performing under a 'Design and Construct' contract. This ensures that there is early input into the design from the Construction Contractor thus enhancing constructability, improving value engineering and reducing the risk of variations during the construction phase of the project.

Weather Risks

Cost Engineers need to understand the impact that weather has on the productivity of different work fronts, the historical weather patterns at the location of the construction project and be able to convey the weather risk to the project manager. They also need to be aware of the contractual terms that are applicable on the project. Weather has the potential to have a large impact on project plans and the eventual success of projects. If a project is exposed to adverse weather it is important that the project team proactively mitigates the impact before its impact. Cost engineers are well placed to investigate weather risks, and include appropriate cost and schedule contingency, identify mitigation actions and include them in the project plans. Both owners and contractors should take into account the number of typical days of weather impact to be expected throughout the project as they develop their plans and forecast their productivity rates. Both the owner and contractor should have an understanding of the expected number of lost workdays (including site clean-up) the contractor has allowed for due to inclement weather and or the impact that weather is anticipated to have on productivity. The planning for these weather impacts should include the cost and time required for mitigating weather impacts including activities such as access road upgrades, laying gravel so that access isn't as sensitive to weather, procuring pumps, ensuring appropriate contouring for water run-off from key areas, having sumps to remove water from a site should a rain event occur and identify suitable dams or collection points to pump the water into.

By defining responsibilities for the risk mitigation measures and gaining agreement between the owner and contractor both owner and contractor understand their responsibilities early and weather impacts can be mitigated effectively. If commitments and obligations are unclear it can lead to problems during a weather event, for example pumps not being available and or disputes between contractor and owner regarding what mitigation efforts should have been planned for and undertaken. By working together and having a clear understanding of risk allocation and responsibility the owner and contractor have aligned goals of mitigating weather impacts when they occur resulting in teamwork and co-operation rather than disputes when the weather events occurred.

There should also be a common understanding of a delay causing event (for exceptional weather events), or force majeure, so that responsibilities and risk allocations are understood under all circumstances.

Aligning Owners Team Baseline with Contractors Baseline

Often an owner will develop a PMB prior to having selected a construction contractor. In most cases the baseline for the construction work will be based on the original estimate. The value and structure of this estimate may be different to work breakdown structure and pricing that applies to the construction contractor once selected. Using an owner's estimate for measuring a contractor's performance would be time-consuming and would result in a large number of performance variances that aren't meaningful. An effective way to manage this problem is to have an internal change process that enables an owner's team to update the PMB to align with the contractor's baseline, in terms of work breakdown structure, bill of quantities, resources and price once the contractor has been selected and their baseline approved. Any difference between the owner's original estimate and the contractor's price can be transferred to or from contingency as part of the change control process. This enables the owners PMB to align with the contractors PMB and effectively measure contractor performance. In situations where the construction contractor has not yet been selected, it is beneficial for the cost engineer to plan construction packages at a high level, based on the owners estimate, and perform detail planning when the detailed plans of the successful contractor are known. This detail planning step provides the opportunity to align the owner's team plan, coding, work breakdown structure and resource weightings with that of the construction contractor. This type of "rolling phase planning" will ensure that meaningful performance information is obtained from the EVM system for the contractor and the owner.

Site Instructions

On occasion there may be a need to issue instructions either requiring a variation or instructions regarding discrepancies between Contract Documents. For transparency all instructions should be in writing and be given to the contractor, or the contractor's agent on site. There is no specific format required for instructions, but it is good practice to have a system of numbered instructions in a standard format or template. These templates can have fields included to ensure that key stakeholders such as project managers, planners and cost engineers have their information needs satisfied (e.g. agreed cost, quantities, man-hours and schedule impact) and still provide provides construction managers and contract administrators with enough flexibility to enact necessary changes quickly and provide clarity to construction teams.

The contracts administrator can easily record the signed forms photographed with a smart phone or iPad for immediate distribution to key people through document control. This process ensure that on-site variations and directions are controlled and recorded well and that key stakeholders such as project managers, planners and cost engineers are well informed.

Results

The projects studied as part of this case study were multidiscipline construction projects with a large proportion of Earthworks and Civil construction. The EV system was quite simple with capacity for reporting to be rolled up to project level. Each contractor had a project manager who was accountable for the performance reporting of all scope within their contract. This EVM reporting enabled the project managers to identify trends and provided the owner's team project manager summary reporting per contractor so that underperforming or under resourced construction teams could be quickly identified and supported.

Cost Performance Analysis

EV performance management enables trends to be identified, corrective actions taken and improved resource and cash-flow forecasts. S-Curves and cost performance metrics based on quantities, dollars and man-hours were produced to provide management with visibility of cost performance. The S-curve in Figure 2 provides an example of the S-Curve expressed in dollars for senior management.

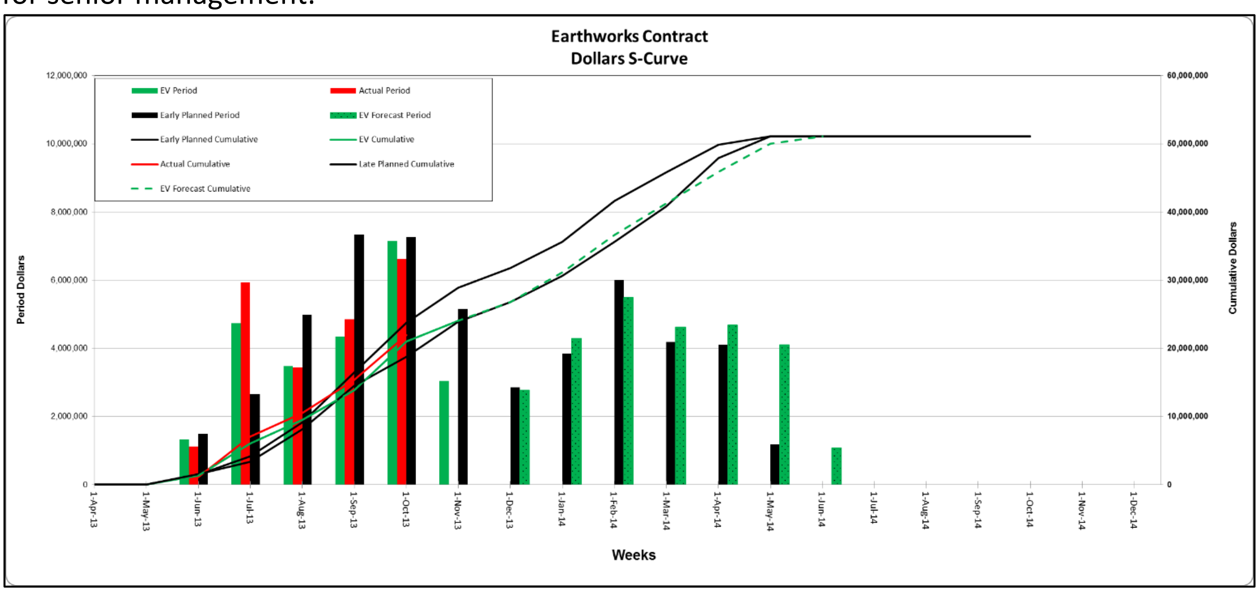

Figure 2 - S Curve (Dollars)

The cost performance index is calculated as the earned value divided by actual cost (for an owner's team engaging contractors this would be the contractor's price). Another useful measure is the CPI in units of hours. This is calculated as earned hours / actual hours to provide a measure of the labor efficiency of each contractor. The efficiency can be measured for the current reporting period to provide a temporary performance measure as well as the cumulative to date for longer term performance measures.

Period and cumulative performance were tracked each week and all significant causes of productivity loss were documented. As a result an informative contemporaneous performance history of the project was recorded, monitored and controlled.

For example Figure 3 shows an extract from a cost performance report that provides a history of the project performance against a timeline that can be interpreted in conjunction with disruptive events that were occurring along the same timeline.

1- The project was constrained by a lack of accommodation in the first 10 weeks of the project. This meant that contractors had to stay in a nearby by town and travel 2 hours per day to site, making their productive hours per day 8 rather than 10
2- There was a temporary problem in the provision of construction water that was needed for treating soil during the bulk earthworks phase of the project
3- Another temporary problem was the contractor having discovered a slightly greater than expected volume of unsuitable material during excavation in the bulk earthworks phase of the project, this unsuitable material caused additional time to be taken in removing and disposal and could not be used for fill showing a temporary reduction in productivity throughout September.

Refer to Figure 3 below:
CPI (hours) = EV (hours)/ AC (hours) **Equation 1**
EV (hours) =Earned Value (hours)
AC (hours) = Actual Cost (hours)

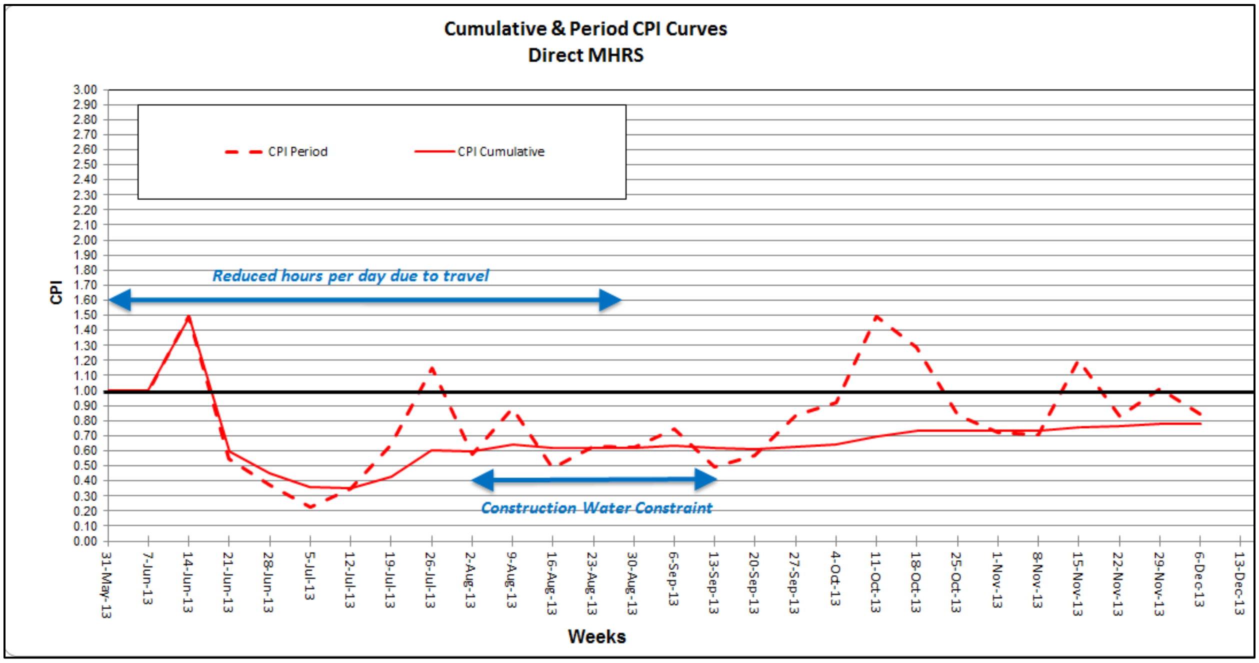

Figure 3 – Period and Cumulative CPI (hrs)

In a cost reimbursable contract the benefits are more significant given that owners own the cost risk associated with productivity problems, hence it's very beneficial to measure and control contractor cost performance using earned value. Earned Value measurement and monitoring of the cost performance index provide valuable information for the owner to help ensure that the contractors cost and schedule performance is under control from the outset and with the contractor being accountable to explain the root cause of variances on a weekly basis. Once the contractor's cost performance is well understood future cost forecasts and cash flows can be predicted better by dividing the remaining work (in either cost or man-hours format) by the cost performance index. There are many who argue that there is little benefit to an owner's team in applying EVM for a fixed price contract as the contractor owns the risk of cost overrun however in these case studies the contracts were fixed price the cost performance metrics provided very helpful information for risk reduction including labor productivity analysis, resource forecasting and cash-flow forecasts. EVM provides an additional tool to help drive the contractor's performance which is in everyone's interest particularly if LD's apply. Accommodation was scarce for these projects and by having a strong command of labour productivity and forecasting the owner's team was able to reduce project risk by planning for accommodation demand more effectively.

There are some cases where the cost performance factor may not be a good indicator of future performance, for example there may have been a temporary issue or disruption that has had a distorting impact on performance such as delayed access, restricted availability of construction water, over-allocation of resources or excessive overtime. The validity of resource forecasts can be improved if the cost engineer is proactively analyzing unencumbered contractor performance of direct labor by filtering out the masking effects of indirect labor, and filtering out temporary causes of disruption or performance issues that are not likely to exist in the future. By understanding this unimpeded performance level forecasts for future manpower requirements can be easily made.

In the case studies this was achieved by tracking and measuring both the period CPI and the cumulative CPI. The period CPI indicated the performance in the current period and was sensitive to any short term/temporary issues occurring in that period. All temporary and long term performance trends were measured and root causes recorded through the weekly reporting process. This type of analysis was performed at project level and at a lower level for each contractor.

Refer to Figure 4 which provides a visual depiction of the breakdown of temporary factors (extra travel time, construction water constraints) and long term factors (underestimating) impacting the contractor's direct labour cost performance during one week of the project (Extra travel time, construction water constraints, versus typical unimpeded performance level).

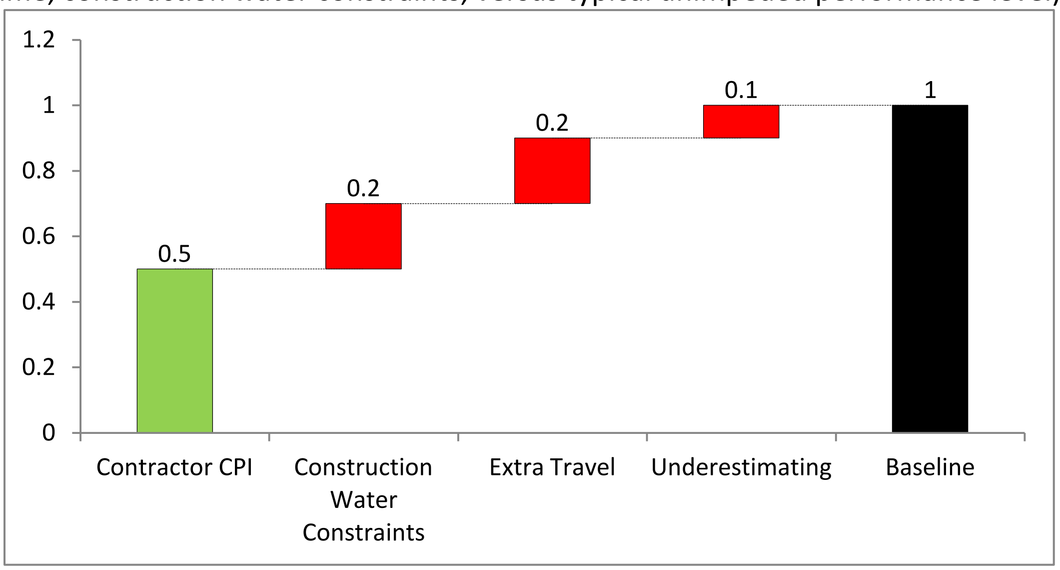

Figure 4 – CPI (hrs) Analysis for Week ending 16th August

By filtering out any short term disruptions to productivity, a benchmark of contractor productivity can be determined and applied to the remaining budget (unearned budget) for each contractor to provide a more realistic forecast of future resource requirements.

Schedule Performance Analysis

EVM S-Curves based on dollars, man-hours and quantities can be produced to provide management with visibility of schedule performance. The schedule performance index can be measured in dollars, man-hours and quantities.

SPI = EV/PV **Equation 2**
EV = Earned Value
PV = Planned Value,

Earned Value and Planned Value can be expressed in units of dollars, hours, m^3, m^2, tonnes, units installed or any other appropriate unit of measure for quantities.

When analyzing schedule performance it is beneficial to analyze direct work alone as it better represents the discrete work that is being achieved. The SPI of each contractor's direct labor is calculated as earned hours/planned hours to provide a measure of the schedule performance of each contractor. The SPI is measured for the current reporting period (week) as well as the cumulative to date. Refer to Figure 5 below.

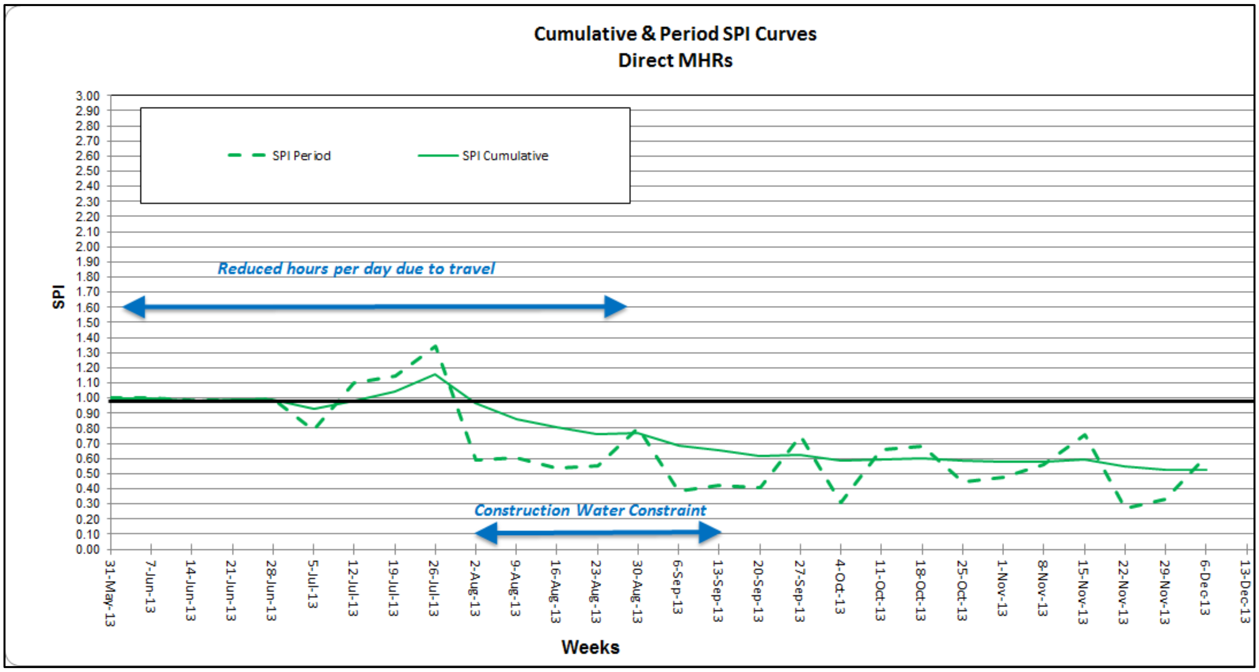

Figure 5 – Period and Cumulative SPI

When analyzing the schedule performance it is advantageous to monitor activity schedule variances to enable schedule problems to be quickly identified, root cause investigations to be made and corrective actions taken. When considering schedule variances it is important to consider the Total Float available for activities that have slipped. Cost Engineers should monitor closely activities with little or no total float where slippages or poor schedule performance in activities with significant float may be tolerable. It is helpful to provide the project manager with feedback regarding the schedule performance on near critical activities versus the schedule performance of activities that are non-critical. Ideally the project will be prioritizing and performing most strongly on near critical activities.

For the construction projects analyzed for this study the most common causes of schedule variance was delays in construction water availability. This problem was well highlighted by the SPI analysis shown in Figure 5.

Cost and Schedule Performance Analysis Combined

It is beneficial for project teams to consider cost and schedule performance indicators simultaneously as this provides greater insights into the performance of the project than looking at either index in isolation.

This was exemplified in the case study where the project started off with over-resourcing in order to overcome the reduced productive hours per day per person due to travel. This meant that the CPI (hrs) was poor at the start of the project while the SPI was close to one. Following this initial phase the project encountered problems in the availability of construction water which caused a constraint on earthworks and reduction in the SPI. The project then went through a phase of being under-resourced which can be seen as a period of improving CPI and a decreasing SPI. Overall the project was underestimated by approximately 10% which resulted in the CPI struggling to get higher than 0.9 even when all constraints and disruptions were removed from the contractor. Refer to Figure 6 which demonstrates how EV performance information can be used to communicate the performance history of a project.

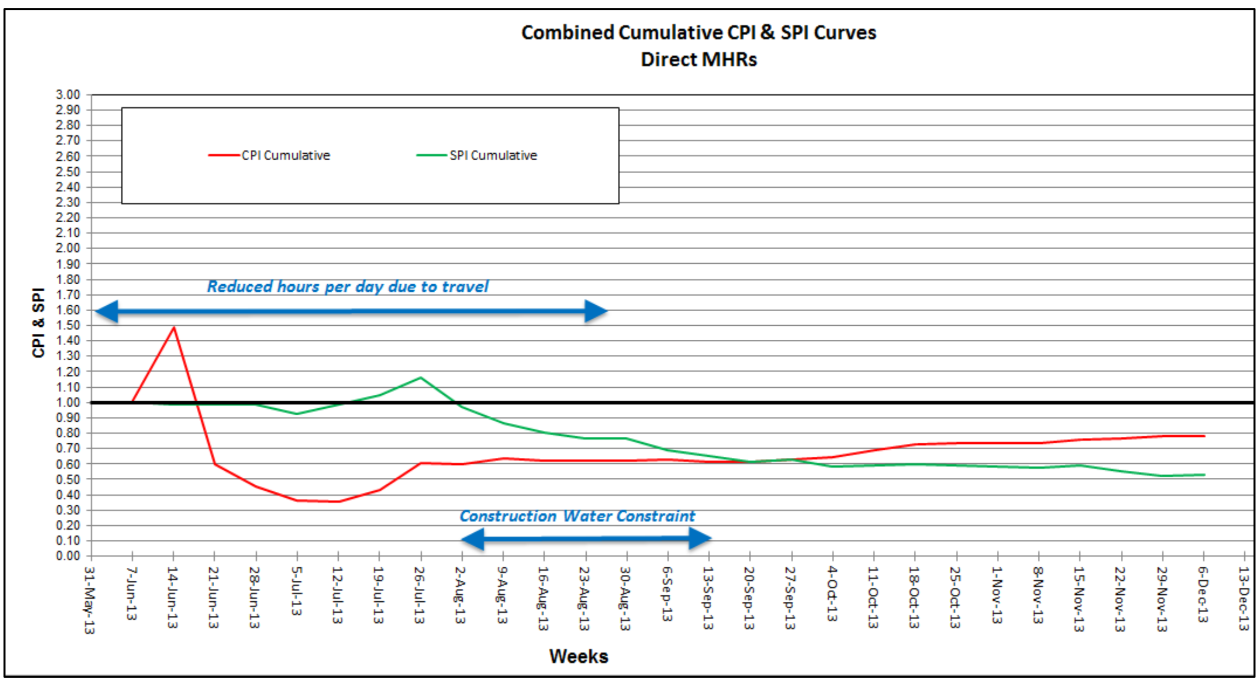

Figure 6 – Cumulative SPI & CPI (hrs)

Improved Resource Forecast

CPI (hrs) can be used to provide a better indication of the forecast workload required in order to complete the project on time. As mentioned previously the supply of accommodation for these remote projects was key constraint on these projects. By taking labour productivity into account when forecasting future manpower required at site it enabled the owner's team to improve their accommodation planning. The time phased earned value and forecast data were be used to present resource forecasts for comparison with resource and accommodation availability. Presenting forecasts in this manner helps managers identify resourcing risks quickly and take action as necessary.

The forecast man-hours per period was divided by standard working hours per period to provide a forecast of the number of full time equivalent (FTE) resources forecast for each resource type. By continually re-assessing remaining work the contractor was able to plan well for their future resource needs. The same information for each contractor was used by the owner's team project manager to review resourcing from a project wide perspective and, where necessary, take action such as accommodation planning, traffic management and supervision. This cumulative CPI (hrs) was applied to the remaining work (unearned budget) for each contractor to provide a more realistic forecast of future resource requirements. In addition, analysis of contractor performance showed that the estimate was optimistic because when all disruptions were removed the contractor tended to perform at a CPI (hrs) of 0.9. Therefore, the remaining manpower requirements were then divided by 0.9 to yield a better estimate of remaining resource requirements.

ETC Forecast = Remaining Budget/CPI (excluding temporary disruptions) **Equation 3**

This analysis also enabled the owner's team to have better visibility of where the contractor may be bow-waving work and / or they need to increase manpower in order to meet contractual delivery dates. An example of possible bow waving is seen in the Figure 7 below where the contractors forecasts suggests that in order to complete the project on time there seems to be a large increase in forecast man-hours period compared to the actual resources per period on the project to date.

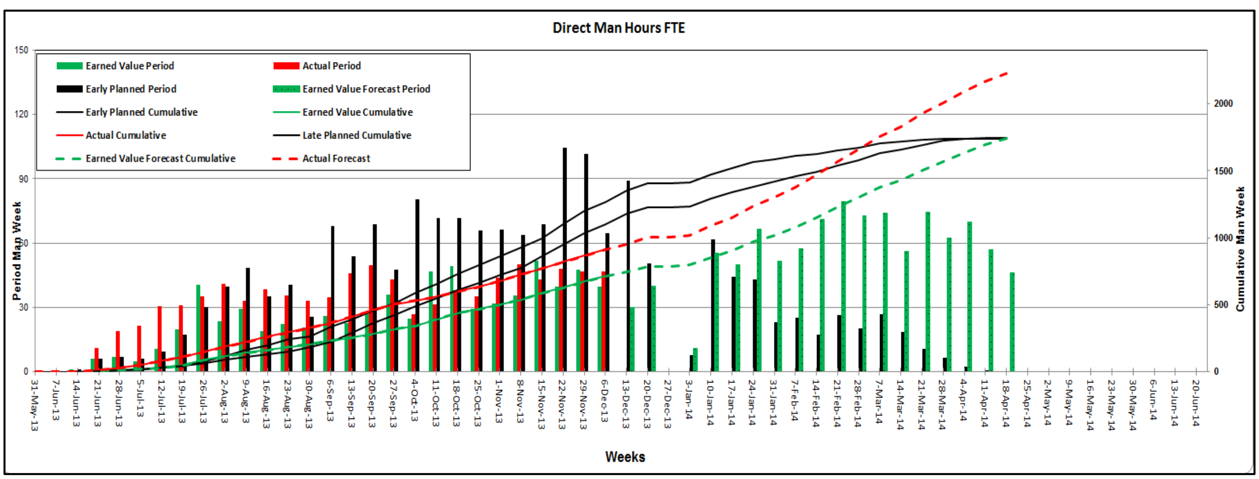

Figure 7 – Resource Histogram and Forecast Considering Productivity

External Interfaces

Another cause of performance problems is the dependency of construction on external factors such as client decisions and interfaces which may not be well measured by EV. In the case study client interfaces and milestones which had the potential to significantly influence progress such as site access, traffic management on access roads, interfaces with existing operations, arrival of free-issue materials and equipment on site, construction water availability and commissioning water availability were tracked and monitored for schedule slippages. The most significant of these dependencies in the project studied was construction water. The bulk earthworks and soil treatment for these projects was heavily dependent on the availability of construction water and, in projects where the client is responsible for the provision of this water, it is important for contractors to monitor and manage the risk of delays. The provision of construction water did not carry earned value weighting hence these activities did not directly exhibit earned value schedule variances when they were late. However, when these activities exhibited schedule slippages, they caused a large delay in construction activity, and these activities did show large schedule variances due to their resource loading. These schedule slippages were tracked separately as leading indicators and expediting teams were established to mitigate the risk to construction.

Analysis and Mitigation of Weather Impacts

It is important for both owner and contractor to have a good appreciation of the local weather patterns so that work can be sequenced to minimize negative impacts to the project due to weather and so that appropriate mitigation can be well planned. For example in the project studied the wet weather patterns over the previous 12 years were examined. Refer to Figure 8 below:

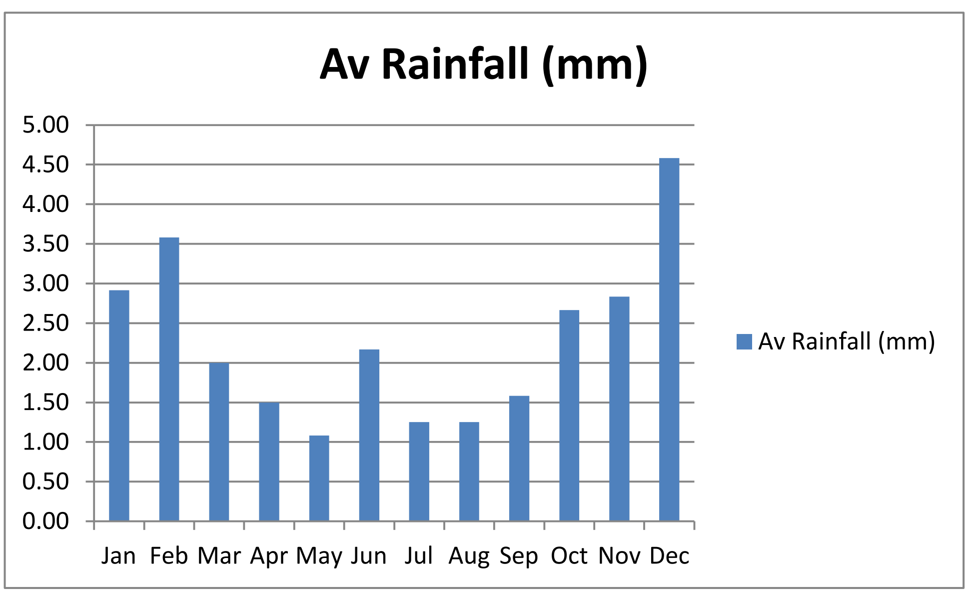

Figure 8 – Average Rainfall

The figure shows that rainfall is seasonal with higher volumes of rain expected to occur during the months October to February.

Different types of work have differing levels of sensitivity to inclement weather. The work involved in the Dam construction project was largely civil work making it very sensitive to wet weather. The civil work itself had a number of phases each of which had differing levels of sensitivity to wet weather as well. The scatter plots of rainfall versus work days lost for different construction phases shown in Figure 9 provide an indication of the differences in weather sensitivity encountered in the case study.

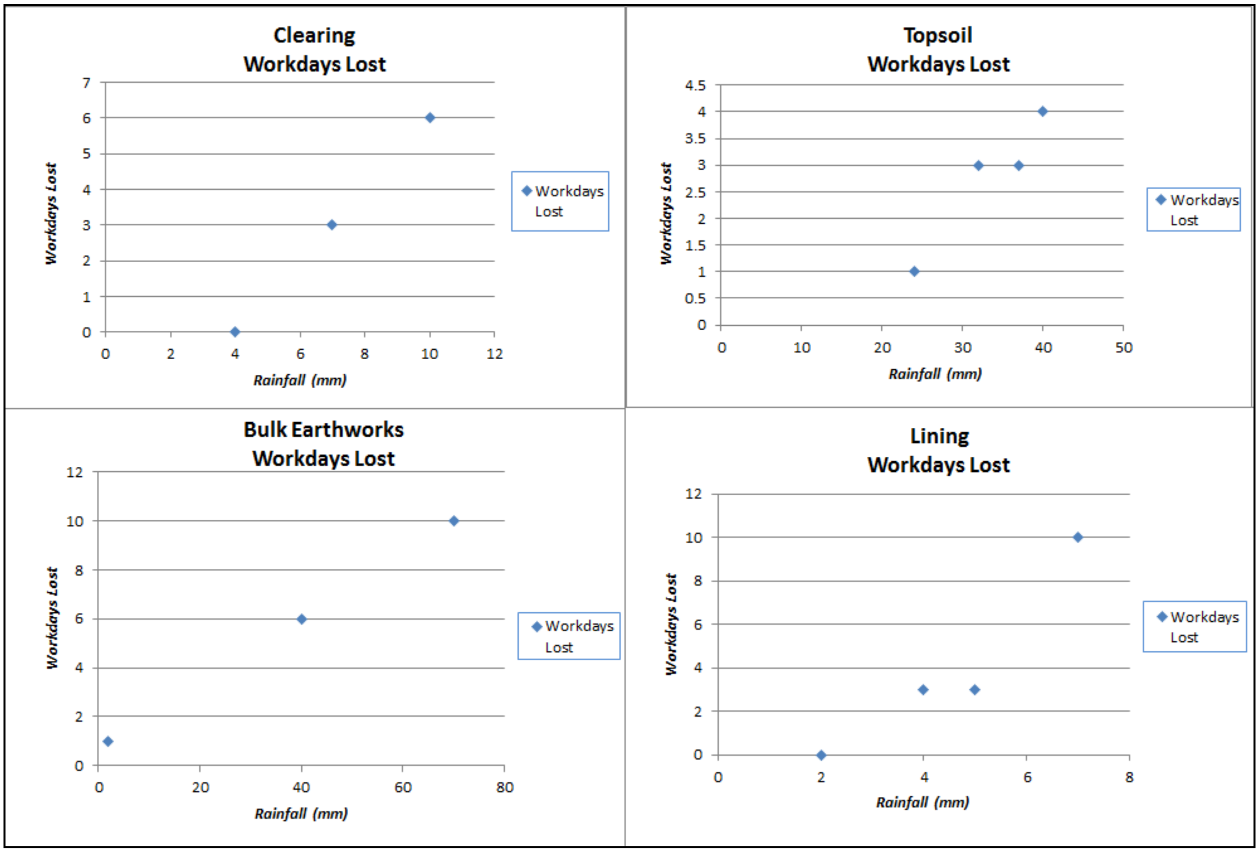

Figure 9 – Civil Works Sensitivity to Rainfall

These phases included initial clearing, topsoil stripping, bulk earthworks and lining. The Lining involved applying 2 layers of an impermeable HDPE membrane to a newly constructed Dam surface. This phase was particularly sensitive to weather with long delays encountered for any rain events that occurred after the first layer had been applied. During the planning of the work considerable effort was made to schedule the work so that the work that was highly sensitive to wet weather, such as applying HDPE liners to the dam, occurred during the drier months. Another consideration was excessively high temperatures. The process of applying the liners was sensitive to heat due to the reflective heat from the liner surface. Once again the contractor and owners team worked together to schedule the lining to occur away from the summer months (which coincided with the wet season) and staggered the shift for liner installation so that they started earlier in the morning 2am to 12 noon when heat was as extreme.

Delay and Disruption Analysis

In analyzing delay and disruption claims it is important to be able to demonstrate the cause and impact to critical path of delays and disruptions. In the case study this was achieved by recording weekly schedule updates and earned value performance reports. These reports become historical evidence for project progress and forecasts for remaining work. The project also measured both the period CPI (hrs) and the cumulative CPI (hrs) for each contractor on a weekly basis. All temporary and long term performance trends were measured and root causes recorded through the weekly reporting process. By documenting the causes and impacts well it enabled the effect of a number of concurrent sources of inefficiency relative to the baseline plan to be measured and understood. The project studied had a baseline that was underestimated. Analysis determined that when the contractor was working efficiently and was unimpeded by temporary factors their CPI (hrs) was 0.9 relative to the baseline/estimate. In addition the project also had some temporary disruptions caused by the owners that impacted contractor performance. The impacts of these disruptions were easily identified by monitoring the period CPI and cumulative CPI. This information recorded became invaluable for simplifying and quickly resolving a number of concurrent disruption and EOT claims on the project. Weekly performance data was recorded along with narrative explaining the cause of productivity problems. These records became excellent contemporaneous evidence for reviewing and assessing claims and mitigated the risk of disagreements and disputes. Refer Figure 4 for an example of cost performance during one of the periods experiencing a number of factors simultaneously impacting labour efficiency. Performing this analysis on a weekly basis enabled very quick proactive resolution of claims for delay associated with disruption.

The impact of disruptions to productivity can also be demonstrated effectively on quantity S-Curves. For example Figure 10 shows a model of the effect of low productivity caused by additional travel time required for the contractor to get to site each day as a result of the site accommodation was not being available until the end of August. Additional early and late curves were superimposed on the original early and late curves to provide a model of the impact caused by reduced productive hours that were available to the contractor up to the end of August (due to additional travel time). This figure simplifies and shows visually how much delay was excusable due to travel and clearly indicates that other factors are involved in the low performance.

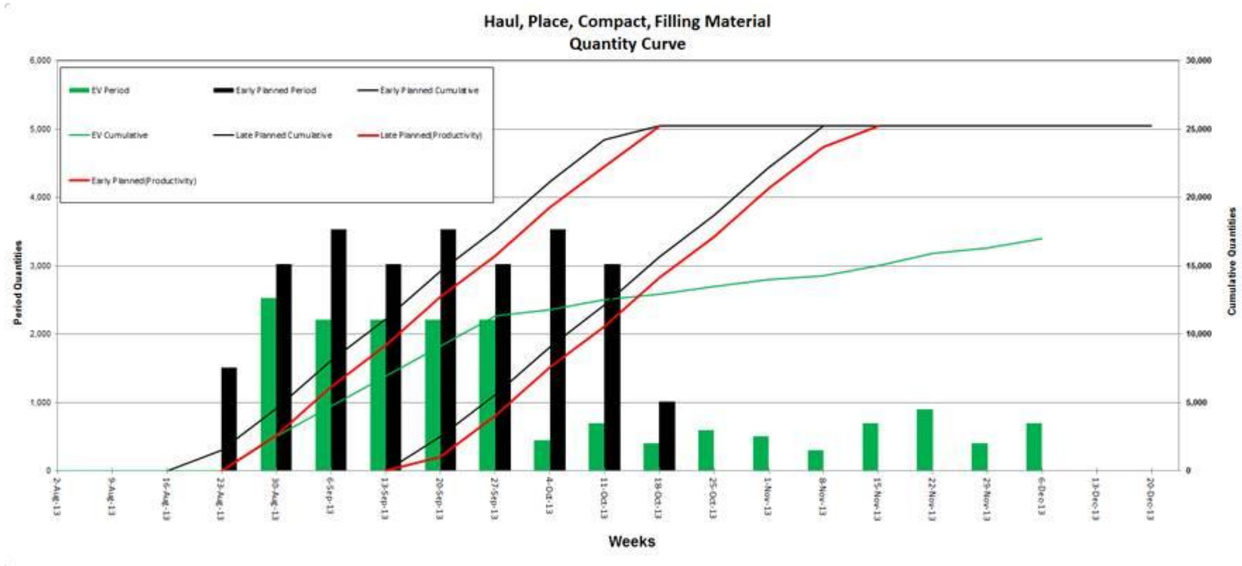

Figure 10 - Quantity Curve Including Productivity Impacts

Discussion

Structure

The WBS and control accounts should be developed thoughtfully as they determine the level of detail at which performance reporting can be performed. As the WBS is developed the scope should be broken down progressively into mutually exclusive packages of work. Each work package had its own scope definition and this helped ensure there are no inefficiencies in work plans and inconsistencies in reporting. In designing a WBS it is important to ensure each element so that there are no gaps and no overlaps in scope. One of the great lessons learned from the case studies was the benefits of creating project control structures for cost and schedule that were aligned. Performance reports from these structures were then rolled up to for higher level reporting levels as required for different stakeholders. Another learning was the great benefit of the aligning the owners and contractors work breakdown structures for the contractors scope of work. This meant that both parties were speaking the same language and comparing apples with apples when analyzing performance.

The Drum Beat

The case study provided verification of the benefits of collaboration at the start of the project and to establish effective flow of information between stakeholders during execution. The integrated baseline review was very successful in creating value and trust through collaboration, optimizing plans and gaining a shared view of project requirements. It was at the IBR that reporting requirements were agreed which paved the way for open, transparent and weekly performance reporting and meetings between the owner and contractor. The schedule and earned value management system provide excellent communication tools for identifying trends and the managing projects. The contractors were very effective in synchronizing their EVM reporting process with the drum beat. Field planners, contract administrators and cost engineers carried iPads and were able to seamlessly supplement progress reports with a suite of photographic records of site progress in addition to being able to record and distribute site variations and instructions in real time.

Perhaps one aspect of the project that struggled to maintain the "drum beat" of weekly EVM reporting was the owner's team. There were some who struggled to see the importance of timely status updates and timesheet entries indicating that better communication and training could have been employed to establish the performance culture at the start of the project. Fortunately the majority of the work being performed by the owner's team was indirect meaning that the consequences to performance reporting were not significant.

Communication and Control

Different stakeholder groups see the project through different lenses and it was useful to be able to tailor the communication and earned value reports to suits the perspectives of different stakeholders. For example Senior Program Management with limited time received one page dashboards, Financial Management received Cost Performance reports and cash-flow forecasts described in dollars, construction supervisors preferred to see earned value and forecasts described in terms of quantities where as human resources department and accommodation planning teams appreciated earned value reports and forecasting described in terms of direct and indirect man-hours per period and forecasts full time equivalent (FTE) manpower forecasts. The project manager received reports in all three formats enabling the project to be viewed through a variety of perspectives. By tailoring the communication in this way it saved people time, made interpretation easier and increased the effectiveness of earned value as a project performance management tool. The weekly earned value reporting Project Manager was able to detect problems early. The greatest benefit was realized by measuring production efficiencies and using this information to produce better forecasts of the future manpower requirements and accommodation needs.

Mitigation of Disputes

The transparency created via the weekly EVM performance reports, corresponding meetings and site reports and photographic records enabled the project team to quickly identify and resolve problems and gain clarity on disagreements so that disputes were avoided. This was a great achievement considering the number of complex factors that were impacting project performance. Perhaps one lesson learned would have been that could have been improved if the owner's team had engaged improved tracking processes for back-charges. When the contractor had significant NCRs (non-conformance reports) raised on them it would have been beneficial for the owner to have created codes for tracking and recording costs associated with these non-conformances for improved clarity and to avoid disagreements.

Training

Another observation from these projects was that project team members had a wide range of knowledge and experience in earned value concepts and their practical application. Some people understood the concepts and immediately saw the benefits whilst others resisted the planning work involved and struggled to see the benefits early in the project. This resulted in some confusion and delays in gaining commitment from some stakeholders. For future projects it would be beneficial to have increased focus on basic training and familiarization with earned value concepts and application to help gain understanding and commitment from those people either providing input or receiving reports from the EVM systems.

Conclusion

This paper has described how the application of EVM and productivity measures can be applied to the construction phase of multidiscipline construction projects to reduce risk, enhance forecasting and improve project decision making. By utilizing EV principles and establishing effective project controls both the owner and the contractor can effectively identify and respond to cost and schedule risks such as resource availability, scope changes and performance problems. This case study verified that performance can be managed well and disputes avoided by the owners and contractors setting up cyclic EVM process to monitor and control construction performance.

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Laurie Scott Bowman, CCP DRMP EVP PSP
Synchrony
laurie@synchrony.net.au

Mina Sabouri, PSP
Synchrony
mina@synchrony.net.au