ABSTRACT— Cost and resource loaded CPM network schedules provide detailed planning information to the owner’s project management team. Cost curve projections from the baseline schedule graphically depict the planned rate of project expenditures. Resource loading provides evidence that the contractor has planned thoroughly, identifying all resources and equipment required to complete the project. There is no downside to a cost and resource loaded baseline schedule, which is why many owners require them for projects above a certain size.

But network schedules are designed to measure and manage time, not dollars. During the course of construction, resource or cost drivers can make CPM schedule calculations invalid. Unpaid remnants of activities in progress (paid to 97% and holding) can distort the schedule by increasing “out-of-sequence” reporting. Schedule updates must provide valid projections of completion in order to support the management team.

This paper will evaluate the problems inherent in using cost-loaded schedule updates as the basis for progress payments. The author recommends steps toward a “divorce” of the cost tracking from the schedule tracking during the course of construction.
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Introduction

Cost and resource loaded CPM network schedules provide the owner’s project management team with a basis to measure and manage any or all of the following:

- Time
- Cost
- Earned Value
- Resources
- Risk
- Information and Communication
- Coordination
- Work Organization
- Forecasting
- Financial Planning
- Record Keeping
- Dispute Resolution

The cost and resource loading process requires the preparation of the Work Breakdown Structure (WBS) which allows the owner to analyze the work organization. Schedule and cost output reports can be used for performance measurement, forecasting and financial planning. The record-keeping qualities of the schedule updating process result in an as-built schedule, essential to support or defend claims for delay, disruption, lost productivity and other problems that can lead to dispute resolution.

Murray B. Woolf addresses the competing purposes of various project management support technologies, and he expresses concern that the value of the Project Execution Schedule as a time management tool can be greatly diminished by the well-intended, yet competing requirements that each technique or methodology places on a schedule [7]. The schedule database is now able and expected to contain significant amounts of information not directly related to time management. Primavera Project Planner (P3®) scheduling software is now sold as Primavera P6 Project Management/Methodology Management® with scheduling functions being only a portion of the portfolio analysis, resource management, timekeeping, communication, collaboration and methodology/process improvement package.

This paper addresses the problems inherent in using cost-loaded schedules and the resulting distortions that can occur during the course of construction. It provides guidance for the owner’s project management team, recommending a “divorce” of the schedule tracking from the cost tracking functions during the update cycles.

Purposes for the Project Execution Schedule

The primary purpose of a CPM network project execution schedule is to plan and schedule the project work sequence to support management during the construction phase. Logical planning factors are laid out in network form and sequence to form a “road map” to project completion. The *raison d’etre* is to enable the project management team to look ahead and plan/procure instead of walking out of the
trailer each morning, looking around the jobsite and saying, “What can we work on today?” Adding long-lead procurement activities to the schedule is an essential aspect of this planning, as delivery dates directly affect installation. Adding resources to the network schedule allows the tallying and advance ordering of materials and the optimization of their use and installation. Major equipment resources (cranes, hoists) can be planned and scheduled based on the needs of the schedule activities they support. Efficient staging of subcontractors becomes possible when the project team has accurate information about when work areas will become available for each trade. All these purposes have been realized through the use of CPM network scheduling, whose float calculations show how early or late a procurement item, resource, trade or crew can be scheduled while still maintaining overall project completion on schedule.

Cost loading a schedule adds value to the project management information system by incorporating the contract cost into the schedule database (some contractors look at this in reverse) and projecting the expenditures over the course of the project. Project financing, particularly useful for timing when bonds need to be sold, is possible given an accurate baseline cost projection curve. Project owners have found it efficient and equitable to base progress payments on the cost-loaded schedule monthly update. For most federal projects, the monthly application for payment is based on progress of cost-loaded work activities in the project execution schedule [2].

Resource loading (beyond the scheduling of major equipment) allows tracking, optimization and leveling of project resources which can include workers, equipment, trades, and even individual persons. This permits the reporting (and leveling) of resource curves, the identification of driving resources, the tracking of resource usage, and the handling of “resource conflicts” when two or more schedule activities require the same (limited) resource. Resource loading can provide a projection of resource peak requirements (how many electricians will we need on site at the same time?) and allows the project management team to identify key or limited resources and plan accordingly.

**Schedule Projections Adjusted by Resource Leveling**

None of the valuable reporting abilities listed above will be useful to the project management team unless the network schedule is accurate, and remains so over the course of the project. While resource drivers and leveling calculations can adjust schedule projection dates, there is usually a simple solution to confirm and maintain schedule accuracy (do not use the resource leveling function!). The addition of resource loading to the schedule database does not inherently distort projections of completion for schedule activities either at the baseline or during the course of construction/updating.

The example in figure 1 shows a sample baseline schedule loaded with a single resource (workers) and a maximum limit established (20) [3]. The resource profile histogram printed below the bar chart section shows the peak number of workers on site (on a weekly basis), and the display highlights the (five) weeks where multiple schedule activities running concurrently would require more workers than the maximum limit allows.
Primavera software will “level” resources on command. Forward leveling determines the earliest possible dates for scheduling without exceeding the maximum limit of resource availability. The “leveled dates” will replace (shift) the early dates [4] in the schedule, resulting in a new schedule calculation which may affect the highlighted project completion date. In our example schedule, there is no imposed project finish date, so leveling is permitted to shift the projected completion date. The result of resource leveling may be seen in figure 2.
The schedule calculation which results from resource leveling is shown in figure 2. The project completion date has shifted from 28Feb2011 to 09Mar2011, a slippage of 9 calendar days. Resource leveling calculates that if there are no more than 20 workers available for this project (the maximum limit setting), the project will take 9 additional calendar days to complete. Resource loading of the activities in the schedule database does not automatically change the schedule projections unless the leveling function is used. If specific resources are limited and cannot exceed specified maximums, the schedule dates should be adjusted accordingly, both at the baseline and during the course of construction. This is not a distortion to the calculated schedule projections; it is simply a different calculation method designed for resource management and performed for the benefit of the project management team. The “resource leveling” calculation method must be specifically selected; if the “schedule” calculation is performed, the activity dates will shift back to their original baseline dates. There is no inherent danger of distorted schedule projections with resource loading; the scheduler has control over the calculation method.

Cost Loading as the Basis for Progress Payments

Owners and contractors have found it reasonable, efficient, and equitable to quantify and justify progress payments based on the individual cost-loaded network schedule activities. A generic request

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for a 40% payment to the electrical subcontractor is far more difficult to justify (and negotiate) than taking the individual cost-loaded electrical activities, measuring progress on each independently, and paying the overall percentage generated by this calculation summary. The project management team sends inspectors to the field to verify progress and estimate the completion percentages, then loads the data thus generated, and the software performs the calculations. What could be more effective?

The project execution schedule has now acquired another purpose during the construction period; not only to maintain and report the current status of schedule progress, but to justify progress payments developed from its cost loading. The project management team must keep in mind that the schedule database is primarily to measure time, not dollars. If updating focuses on the dollars alone, the data input may distort the time aspects of the schedule. This is the basis for recommending a “great divorce” between the schedule tracking and cost tracking aspects of updating.

The first step toward the divorce between schedule and cost progress is to separate the remaining schedule duration from the cost percent complete. Software will usually accommodate a difference between schedule percentage and cost percentage completion; these percentages may be “unlinked.” If an activity that was scheduled for 10 days (original) duration is reported as 90% complete, and the inspector agrees to pay 90% as the progress payment, a linked calculation would result in a one-day remaining duration on the schedule. However if the project management team is aware that it will actually take longer than one day to complete the remaining ten percent of this activity, they should immediately unlink the cost percentage from the schedule percentage. They may pay 90% for progress, but should assign an accurate remaining duration to the activity. This difference is permitted by the software and is essential to keep the schedule’s projected completion dates accurate for future activities. Remaining durations may even be assigned that are greater than the original duration (for example, a missing part that will need additional time to be ordered and delivered.)

An inherent and frequent problem in updating cost-loaded schedules is the decision to withhold payment just below 100%. The scope of a specific activity may be complete and all of its successor activities in the schedule may proceed, but the owner’s representative, typically the inspector, decides to hold payment below 100% because of needed corrective work or missing accessory work. For example, if the contractor has requested 100% payment for a piping activity, the inspector may pay less than 100% if a section of pipe was damaged during installation, or if a pipe hanger is missing (or a temporary or non-compliant hanger has been used.) There is unwillingness on the owner’s project team to “sign-off” for 100% payment on this activity; keeping a percentage unpaid prevents the defective or missing or temporary accessory work from being forgotten, and it maintains an incentive for the contractor to complete the work to the full satisfaction of the owner.

The result is that schedule activities can report a 95% to 97% completion (for both progress and cost) and then report no further progress over a period of time, sometimes for several update cycles, until the necessary correction is made or the temporary accessory is replaced with a permanent (compliant) part. For an activity which is complete to the point where it has no further impact on its network successor activities, this activity is 100% complete (on a schedule basis) and should have a zero remaining duration. In the piping example given above, if the temporary (non-compliant) hanger may be replaced at any time, and its replacement does not disrupt successor activities (the pipe is not obstructed by a closed ceiling), the activity should be scheduled as 100% complete. Maintaining less than 100% progress for completed activities will distort schedule projections for the successor activities.
activities. In many instances, the successors have started and are in progress; there is a calculated remaining duration and shift in the projected completion date resulting from the uncompleted predecessors. The result is “out-of-sequence” reporting by the software (the successor has started before the predecessor has finished) and the projected finish dates of the successors are no longer accurate.

Another negative result of payments withheld below 100% is the affect on the record-keeping purpose of the schedule, particularly important in a time impact delay evaluation or dispute resolution. A schedule activity cannot have an actual finish date assigned until it has been statused as 100% complete (schedule, not necessarily cost.) An as-built schedule file with large numbers of activities that were progressed to 97% with then no further progress for several update cycles before reaching 100%, indicates that work was continuing throughout and that comparison between original durations and actual durations will be invalid. The AACE International Recommended Practice for Forensic Schedule Analysis [RP29R-03] acknowledges this problem and states that the analyst must identify the “true finish” of an activity in a progressed as-built schedule. It instructs the analyst to assume that “when the period of concentrated work is completed on an activity, the activity is complete [1].” This distinction between the reported actual finish dates in an as-built schedule and their “true finish” dates frequently results from the project management team using the progress schedule primarily as a payment mechanism.

The Situation: Distorted Schedule Projections

Out-of-Sequence reporting can be an indication that the CPM schedule calculations of project completion may no longer be accurate. Primavera software allows three different calculation methods in an attempt to account and adjust for this, retained logic, progress override and actual dates (version P6 only). [6] All three methods produce the same CPM calculations except when out-of-sequence progress occurs. With the most commonly used Retained Logic calculation method, the progress on a successor activity is allowed and reported, but the uncompleted portion of the work is assumed to “wait” until all predecessor work has been completed.

Figure 3, shows an excerpted page from an actual schedule update where, using the “retained logic” CPM calculation method, successor activities currently in progress had their completion dates shifted by as much as several months even though they were underway and some were even nearing completion. Uncompleted predecessor activities (not shown) created an inaccurate delay in the completion dates of the clouded activities. Primavera software graphically depicts this by “necking” (narrowing) the bars indicating non-work periods (while waiting for the predecessors to be completed) before displaying the remaining duration. An analysis of this schedule update confirmed that these activities were not actually being restrained by their uncompleted predecessors; the work was already in progress and reported as 70% to 90% complete. The schedule activity finish projections had been distorted by uncompleted predecessor durations and were no longer accurate.
During the course of this particular project, the two-week look-ahead reports (presented at the weekly progress meetings) were clearly inaccurate; they were therefore disregarded by the superintendents and subcontractors as unreliable and useless as a planning tool.

This distortion can be corrected by using the "progress override" or "actual dates" setting in the CPM calculation method, but these solutions present difficulties. Some contracts expressly forbid using the "progress override" setting on the grounds that it automatically disconnects the original schedule logic for all out-of-sequence work without regard to whether the original logic was valid and should continue to impact the CPM calculations. This position requires the scheduler to evaluate the situation and to revise the logic, a burdensome task if logic changes also require review and approval by the owner. Another reason for disallowing "progress override" is that it effectively disconnects the uncompleted predecessors from the schedule; they can finish any time prior to project completion if they no longer affect their (started) successors.

Wickwire, Driscoll, et al. firmly recommend that the scheduler not rely on changes to the calculation method and "correct the network logic to properly reflect current planning for completing the activities in progress [5]." But for cases described herein where out-of-sequence reporting is the result of a focus on the cost/retainage held below 100% for payment purposes, the network logic is valid and correction is not necessary. In these cases, the schedule logic should remain, the activity schedule

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**Figure 3 – Out-of-Sequence/Uncompleted Predecessors**

This figure shows the out-of-sequence and uncompleted predecessors in the project schedule. The diagram highlights how the scheduler should not rely on changes to the calculation method and recommends keeping the original network logic for cases where out-of-sequence reporting is for payment purposes. The activities involving cost/retainage below 100% for payment purposes should maintain their original schedule logic.
Case Study – Shift between Retained Logic and Progress Override

The contractor for a high-finish building project submitted a schedule with 3,400 activities, and an overabundance of logic ties. In addition to network logic based on physical restraints, there was crew logic (the contractor did not resource-load the schedule) reflecting schedule limitations based on the number of crews planned.

As the project progressed through the update cycle, the out-of-sequence report generated by the Primavera software increased greatly, reaching over 16 pages for several updates. The contractor did not address the logic reflected in the out-of-sequence work but did make substantial numbers of logic changes (often called “schedule embezzlement” by the project manager) thus increasing concurrent work at the latter stages of the project. He also switched from “retained logic” to “progress override” as the project passed the mid-point of the contract duration period. Both actions were viewed with suspicion by the owner.

The owner began to run a “shadow schedule” each month using an earlier version of the network schedule (without the contractor’s logic changes or the progress override calculation). The owner updated the progress percentages in-house each month which resulted in two different schedule completion projections each update which varied by as much as three or four months.

The actual completion of the project fell between the contractor’s revised schedule (progress override calculation) and the owner’s shadow schedule (using retained logic.) The contractor’s schedule logic changes had put too much concurrency on finish activities; he did not have sufficient crews to complete the work at that rate. But the owner’s shadow schedule had pessimistic projections because of the out-of-sequence updating, much of which was based on cost withholding for nearly completed (95% to 97% progress reported) work which had been “riding the data date” each month. Neither approach provided an accurate projection of project completion.

Recommendation: Divorce the Cost Factor

Divorce: to disassociate, part, cease or break association with [wordnetweb.princeton.edu definition]

When the cost-loaded schedule update is used to generate the progress payments, the attention of the project team is unavoidably directed toward its purpose as a cost reporting tool. If the project management team focuses too much attention to cost progress, the update inputs can distort the schedule’s accuracy. We have seen how a desire to withhold payment quantities and not permit activities to reach 100% can distort, sometimes seriously, the completion projections of the schedule network. The situation described in our case study, above, had a disruptive influence on the projected completion dates. The out-of-sequence report showed a large number of uncompleted predecessors with a high completion percentage (95% to 97% complete as reported) with no current work being performed. The successor activities had started, but their finish dates were being extended by the
remaining duration of the predecessors.

Our first recommendation to the project team is to unlink the remaining duration from the schedule percent complete to allow accurate determinations of remaining durations to be entered each month without regard to the cost progress payment update percentage. This requires the project management team to maintain their focus on schedule completion, remembering that the project execution schedule’s primary purpose is to measure the time aspect of the project. If the schedule becomes distorted in its time projections, all other reporting (earned value, cash flow projections, etc.) becomes invalid.

Our second recommendation is to treat an activity as complete (100% schedule completion and an accurate Actual Finish date) when it has reached the point where all its successors can begin. Activities listed in the out-of-sequence report (“Activity started, predecessor has not finished”) should be a signal to the project management team to evaluate the uncompleted predecessors. If the network logic is still valid (recognizing that some logic links are resource/crew related) then the scheduler must determine whether the predecessor is being withheld below 100% for cost reasons alone. If so, schedule progress should be updated to 100% and an Actual Finish assigned, but the cost should be unlinked and updated to less than 100%. For reference, the remedial work can be tracked using a “running punchlist” activity.

In these situations, the scheduler must do the following:
1. Determine whether the remaining work of the predecessor does still affect the completion of the successor. This can occur when the network logic is resource/crew related. Frequently a work crew will “skip ahead” to a successor activity for various reasons. In this instance (and when there is no second crew available) the crew will have to return to complete the predecessor work and the extended finish calculation is valid.
2. If the predecessor work is actually complete, but payment is being withheld for correction or replacement of temporary accessories as in our examples above, the scheduler must determine that no successors are affected by this correction/remediation and take steps to divorce the cost from the schedule update.

Figure 4, shows our sample schedule updated to progress through 04Feb2011 with all activities working on schedule. However, the inspector made two withholds, for spalled concrete at the water tank foundations and for uncompacted backfill over the sewer line, which has reduced these progress percentages. Uncompleted predecessor activities are impacting the finish dates of two activities in progress, and the project substantial completion date is projected one day late.
Figure 4 – Update With Linked Schedule/Cost Percentages

Figure 5 shows the same status but with the cost and schedule percentages divorced. The actual finish dates for the two activities with payment withheld are accurate; the repair work has been highlighted on the new “running punchlist” activity concurrent with the consolidated punchlist. The references to the activity ID numbers for payments withheld and repairs needed are listed as log records below the bar:
The projected date for substantial completion is on schedule, as it should be. This divorce of cost and schedule progress percentages preserves the schedule integrity and accuracy. The earned value report for this update information (shown on the following page) highlights the withheld payments as cost variances and can be used to track their resolution in future updates. Although up to 99 log records may be assigned to the “running punchlist” activity, updating that many manually each month may become burdensome. Primavera version P6 has a new function called “activity steps” which makes the running punchlist activity easier to track and status.
The two payment withholds are shown as cost variances in the earned value report in figure 6. The schedule percentages (PCT CMP column) and cumulative actual cost to date figures are unlinked. The Total (65%) shown in the schedule completion column is based on the cumulative earned value ($1,300), not on the actual cost ($1,260) which would be 63% as a cost basis.

Conclusion

The increased functionality of modern schedule database software provides management information far beyond that contemplated by the original proponents of CPM network scheduling for use in construction. These useful yet competing purposes can diminish the value of the schedule as a time management tool if the distinct purposes and functions are not understood and the status update information is not segregated accordingly. We have observed that the addition of cost-loading and contractual requirements to base progress payments on the monthly schedule update can create inherent problems if the project management team focuses on the cost tracking purpose to the exclusion of the time management purpose. Schedule update percentage information may be added which distorts schedule projections if they are not based on time but instead linked to dollars/payment. Progress payment withholds that are linked to both cost and schedule status percentages will result in a schedule with many “out-of-sequence” activities. The fully progressed as-built schedule will therefore have actual finish dates assigned that reflect completion of remedial or punchlist-type work, rather than the actual completion date of the original scope of the activity. This invalidates comparisons between the as-planned and as-built schedules.

The project management team must divorce the schedule progress update information from the cost percentage update for payment. Remaining durations must be assigned on the basis of accurate information and expected completion dates, not merely calculated from the percentage remaining
after the cost/payment is approved. When out-of-sequence activities are reported, the scheduler must first verify that the logical network link to the successor is not a resource/crew restriction (the work crew “skipping ahead”). If the out-of-sequence report results from payments withheld from predecessor activities which are substantially complete but short-paid for necessary remedial work, the scheduler must determine the actual finish date of the predecessor and update its schedule percentage to 100%, leaving the cost percentage as a variance until the remediation is completed. If the project management team desires additional tracking (beyond the earned value cost variance report) a running punchlist activity can be created to track remedial or missing work in detail.

At the risk of over-generalization, there are only two times a schedule progress percentage update must match the cost update: at the baseline (zero progress) and at the as-built (100% progress.) During the course of construction, schedule progress has no need to match cost percentage completion and should be treated as unlinked/divorced by the project management team. The danger of allowing cost reporting to overshadow and to distort accurate schedule reporting is that the myriad functionality of and purposes for the schedule database are invalidated by distorted and inaccurate schedule information.

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John P. Orr, PSP
URS Corporation
john_orr@urscorp.com

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